



**Pedestrian Bridge in Institute Park using
Sandwich Structured Composite
Structural Design Major Qualifying Project**

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Civil Engineering Department

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Abstract

Currently, WPI community members who reside in Salisbury Estates have no constructed path to get through Institute Park, to and from the main part of campus. This capstone project works to design a bridge between Salisbury Estates and Goddard Hall, while also investigating an alternative to a reinforced concrete slab. Excel Sheets were created to size the members through a computer application rather than through hand calculations. The sandwich structure composite alternative slab proved to reduce column size and number of reinforcements needed to hold the same load. A cost estimate was done using RSMMeans and reduction in size also proved that the lightweight concrete alternative would reduce the cost of materials for the bridge.

Authorship

Within the paper, both members contributed equally to each section. Once one person completed a section, the other would proofread that section. This process was true for the entirety of the paper. The rest of the project pertaining to development of the bridge was split in terms of the traditional concrete slab and the alternative sandwich structure.

Alisa Da Silva

Alisa's main contributions to the project were the calculations of all of the reinforced concrete members and her knowledge of RISA. She created Excel Sheets to size the members once the moment, axial force, loads and unit weights were added. Alisa's research for the Background focused, mainly, on the reinforced concrete and which resources will be used for the calculations. Once the calculations were completed for the bridge completely made out of reinforced concrete, Alisa helped Zebadiah with finding the rigid plastic for the outer layer of the sandwich structure composite. She also had the most knowledge of RISA, so she took charge of all of the work on RISA.

Alisa was the main author of the Abstract, Executive Summary and Conclusion, with Zebadiah as editor for all of these sections.

Zebadiah Yap-Chung

Zebadiah was responsible for the development of the alternative slab. He designed the mold for the SSC (AutoCAD) and did research into the plastics material for the rigid outer plates. The research and development of the SSC was vital in Zebadiah's contributions to sections such as the Capstone Design Statement, Background, and Methodology. Zebadiah also contributed to Professional Licensure and Conclusion.

In order to size the members for the alternative bridge that utilized the Sandwich Structured Composite, Zebadiah made use of the Excel sheets created by Alisa for the traditional slab member sizing. All conceptual drawings and engineering sketches were done by Zebadiah. The cost estimate was also completed by Zebadiah.

Capstone Design Statement

Worcester Polytechnic Institute (WPI) project-based learning, specifically the Major Qualifying Project (MQP), provides a capstone design experience that is in line with that required by the Accreditation Board for Engineering and Technology (ABET). As an institution providing ABET-accredited degrees, WPI requires students to incorporate various engineering standards into their MQP's. It is expected that students will utilize the engineering experience from their 4 years of undergraduate studies and apply it to a real-world problem. This factor is important as it is a reflection of the work that graduating students will have to do in their profession as engineers. By addressing real-world issues, they will be exposed to real-life constraints and standards that are not discussed in the classroom. This project focused on the structural material and its applications to the WPI community. The structural design and analysis was the focus of the project.

Economics

When addressing the economics of a project, one must consider the various budgetary constraints that will affect the decisions made before and throughout its completion. These decisions pertain to things such as the design of the structure, the materials to be used, the methods that will be used to construct it as well as any possible changes that would require additional funding. For the purpose of this project, design, materials and construction methods were analyzed. After each feature was sized using the material that was being analyzed at that time, a cost estimate table was constructed. This cost estimate table includes how much it would cost to construct this feature; RSMeans (Plotner, S. C. , 2019) was used to estimate costs of construction for each material.

Environmental Impacts

Before construction can begin, the environmental impacts of the structure must be explored. Examination must be conducted in order to discover any constraints that already exist within the landscape. In the initial stages of the project, the bridge was proposed to run only through the park, and not disturb the pond. Because of the curvature and measuring tools used, the bridge was designed to go through Institute Pond. The pond will be affected by the installment of the columns because of the choice to put the columns in the pond.

Ethics

The American Society of Civil Engineers (ASCE) has a code of ethics that lists the 7 canons of professional practice for Civil Engineers. These canons will be followed, to the best of our ability, when designing the bridge and its features. The first canon of “Hold Safety Paramount” will be the main focus for this project. This canon focuses on the principle of sustainable development; referring to making the bridge safe for public use as well as sustainable for years to come. The other canons, while equally as important, focus on the professional practice and honor that comes with being a professional engineer. As for canon 7, “Continue Professional Development”, this project will prove to follow that canon as is the nature of this project. When sizing the features, a factor of safety that has been identified by AASHTO will be used (AASHTO, 2018). The method that will be used to size each reinforced concrete feature will be the LRFD method. The ASD Method will be used for determining required thickness for the sandwich structure composite slab.

Constructability

The constructability of a project addresses how it will be built with decisions based on analysis of the constraints of the surrounding environment. The constructability must be assessed as the park is a place frequently used by people of the community. There are many aspects of constructability that must be discussed in order to know what the monetary and timely costs are, as well as to ensure that construction does not (as much as possible) disturb the daily lives of the citizens that utilize the general area.

The monetary cost of this bridge will be discussed in the Results sections, where a materials cost estimate was done for both bridge alternatives. All of the materials are ones that can either be built and shipped directly from the manufacturer, reducing the construction time. The other materials, concrete and the rebar, were assumed to be cast-in-place which can also reduce the construction time and skilled work that needs to be paid for.

The bridge will pass through Institute Park partially passing over the existing Institute Pond. For this project the cost analysis will help in determining the economic constructability of the bridge. This will also serve as a baseline for how long it will take the bridge to be constructed. Once the amount of materials was found, Project Management practices were used to find the price of the material and labor (Plotner, S. C. , 2019).

Health & Safety

In order for the structure to become a reality, the design must comply with an array of health and safety standards. This includes making sure that necessary maintenance equipment can use the bridge as well. The following references were used as guides for designing in compliance with the necessary standards:

<u>Reference</u>	<u>Application</u>
American Association of State Highway and Transportation Officials (AASHTO)	<ul style="list-style-type: none"> ● Load and Resistance Factor Design (LRFD) ● Width of walking and bike lanes ● Codes for the minimum design loads for buildings and other structures
American Institute of Steel Construction (AISC)	<ul style="list-style-type: none"> ● Steel design with aid of their Steel Manual
American Concrete Institute (ACI)	<ul style="list-style-type: none"> ● Codes pertaining to structural concrete
American Society of Civil Engineers (ASCE)	<ul style="list-style-type: none"> ● ASCE Code of Ethics
Americans with Disabilities Act (ADA)	<ul style="list-style-type: none"> ● Reference as aid in improving the design to comply with ADA standards ● Width of walking lanes and grade of bridge to accommodate wheelchairs and other disability equipment
Massachusetts State Building Code 780	<ul style="list-style-type: none"> ● State specific Loading Conditions and Loading Combinations ● Annual Snow Load and wind Load for the city of Worcester was also found in this document

Professional Licensure

Professional licensure is an important part of any type of engineering and is a recognized standard by industry. It serves not only to show that the engineer is capable of completing the job, but is also a representation of their dedication to upholding a certain standard and quality of work. Degrees from ABET-accredited school provide the opportunity to pursue a professional license if the individual decides to do so. MQP replicates the professional practice by providing a solution to a complex design problem while addressing real world issues.

WPI's MQP ties together with professional licensure as it teaches the students how to deal with real world issues. There is no formal course that is offered in professional licensure and so the intention is that by the time they graduate, students should have an understanding of their field such that they may be able to put things in their own words in the form of an MQP. The MQP acts almost like a precursor to the first project of an engineer's career. MQP students must explore every aspect of their project just as though it was owned and being executed by a large company.

Professional Practices require engineers to have, or take steps, to possess a PE license. To get a PE license, one must take and pass the Fundamentals of Engineering Exam (FE Exam) in their focus, in this case the Civil Engineering one would be taken. Once the FE Exam is taken and passed, the person is considered an Engineer in Training (EIT). As an EIT, the person will work with someone who has their PE license for at least 4 years. Once the EIT has completed their 4 years of working with the PE license holder, they can take the PE Exam. Once they pass the PE Exam and get their necessary licensure, the person can sign, seal and submit their own work.

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Executive Summary

Recently, WPI has moved to making Salisbury Estates, a partially WPI owned property, a place for Undergraduate Housing overflow resulting in more and more students needing to walk through Institute Park to get to the main part of campus. Within Institute Park there are two existing structures, one close to Salisbury Estates and the other across the street from Goddard Hall, a laboratory on the main part of campus. As of the time of this project, there is only a foot beaten path going through Institute Park connecting the two structures. With Worcester's yearly weather patterns, this beaten path is snow covered and not plowed. During these months students can not walk through the park and, instead, need to find another way to campus.. This capstone design project proposes the idea of a bridge connecting the two existing structures.

When deciding on the span and conceptual design for this bridge, a preliminary site analysis was done to identify the structures and the dimensions of the bridge. The openings of the two structures were measured and the width of the bridge was determined. Because this bridge is intended for use throughout the day, lighting and benches were added to the conceptual design. Bike lanes, look out areas, and a ramp that follows ADA guidelines were also added to the conceptual design to ensure that the bridge could be used by all.

There are many different materials that this bridge could be constructed out of. For this project two alternatives were analyzed. The first material that was analyzed was traditional reinforced concrete. For this material the slabs, beams, girders and columns were all sized using *The Reinforced Concrete Design Handbook Design Aid* (ACI, 2015). The alternative material used was a sandwich structure composite with a concrete core and rigid plastic outer layers on the top and bottom. This lightweight alternative slab would be produced in pieces with spacers being placed in the wet concrete and taken out before adding the rigid plastic layers. This material was used only to size the slab, the beams, the supporting girders and columns were sized using reinforced concrete.

Further research into this bridge would need to include footing sizes and a soil analysis of the park. After a cost estimate of materials, it was found that using the sandwich structure composite slab would reduce the size of the columns and also reduce the overall costs of materials.

Introduction

The focus of this MQP is to demonstrate the capabilities and applications of lightweight construction alternatives. Specifically, an alternative to traditional bridge design was explored.

Whether it be part of their commute to and from school/work or just to enjoy a walk in nature, it is common amongst the people of Worcester to utilize Institute Park in some form. Its most popular use is as a venue for many cultural and recreational events. Institute Park is also home to Salisbury Estates, which is a WPI-owned housing complex where many university affiliated people live. The residents range from undergraduate students to PHD candidates and their families, and all of these people need to commute from Salisbury Estates to the main campus area. This commonality is why we have chosen Institute Park as the location of our project.

People who regularly travel from Salisbury Estates to WPI or visa versa, have had to walk around the pond in Institute Park (see Figure 1). Having the bridge go from Salisbury Estates and end near the Goddard Hall Building, would not only shorten people's commutes, but would also serve as a social piece of architecture for the residents of the surrounding area. Institute Park is a lush green that encourages outdoor activities; the addition of this bridge would further enhance the sense of community people feel from this park. Having the bridge go over a part of the pond adds a new part of the park for people to explore and enjoy. The bridge would bring with it benches, lighting, and other aesthetic aspects that are included in the analysis of the expected load combinations.

Due to the wide range of persons that will have access to the bridge, many factors must be considered when designing the bridge and how it, and the surrounding area, will be used. Some of these factors include: the estimated snow load, projected foot and bike traffic and what, and how maintenance equipment will have access to the bridge. The bridge needs to be wide enough for snow plows and street sweepers to access easily, especially in the winter and spring months.

Two materials were used to explore sizing the members of the proposed bridge. Reinforced concrete is the material most common for bridges and was the first material option explored. The alternative explored is a sandwich structured composite (SSC) as lightweight concrete slabs. The SSC is made using a custom mold to create pseudo-honeycomb like structures that include rebar for added structural integrity. The design and performance of this alternative was analyzed for the purpose of finding a lighter material that holds the same expected load combinations.

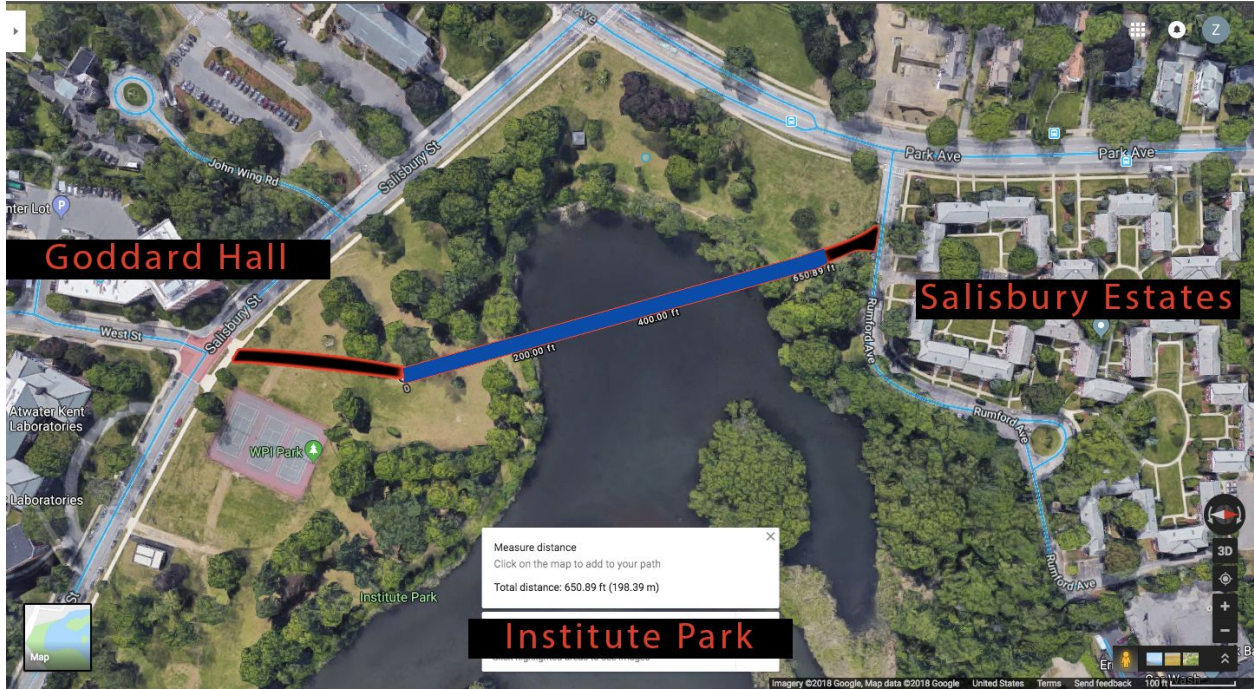


Figure 1: Map showing intended span of bridge (image via: <https://www.google.com/maps/>).

Background

Institute Park was created in 1887 when Stephen Salisbury III donated 17 acres of his family's land to the city's park commission to contribute to the open network forming in Worcester. Since then it has been utilized as a public green space for the residents of the surrounding Worcester area. The park also houses a stage which is used to host events. These events create an environment for community building, encouraging residents, and other users of the park.

Salisbury Pond was not initially constructed for recreational use. It is an artificial lake that was the result of a dam erected by Stephan Salisbury II to provide power for the wire factory run by Ichabod Washburn. (Institute park master plan,2007)

Need Assessment

This academic year, 2018-2019, WPI Residential Services decided to move most of the upperclassmen residents of Founders Hall to Salisbury Estates. This displacement of over 100 students led to more people needing to walk from Salisbury Estates to the "on hill campus" during the day. The need for the bridge was further evident when the site analysis was taking place. While there is a sidewalk that goes down Park Avenue and onto Salisbury Street, there is no way to cut through the park. From years of residents walking the same path to and from Goddard Hall, their footprints have made an informal walkway. The need for this bridge is reflected in this footpath. The bridge will have a length of 650 ft, stretching directly from a gazebo by Salisbury Estates to a similar gazebo just across the street from Goddard Hall.

Introduction of Materials

A. Traditional Reinforced Concrete Slabs

The traditional method of making reinforced concrete slabs involves laying down steel reinforcement with chairs and pouring concrete over them. The steel bars add strength and flexibility to the slab and allows its to be used with greater load combinations. In general, concrete can withhold compression forces but can not withstand much tension forces. The steel bars help the slab resist loads when both compression forces and tension forces occur within the cross section of the slab.

For the traditional reinforced concrete slab, the rebar spans along the length of the bridge (50ft) throughout the slab. Concrete girders were placed on the outer faces of the slabs to support the slab and the designed beams. These girders, from an elevation view, connect the columns along the span of the bridge. The traditional reinforced concrete slab has the rebar running along to span to help the concrete withstand the tension forces within the concrete, when a load is

applied. This can be said for all of the members, as all of them will be sized using traditional reinforced concrete, even when calculating for the SSC slab.

B. Sandwich Structured Composite (SSC)

A sandwich structured composite (SSC) consists of two relatively thin and firm faces separated by a thick, lightweight core material. The lightweight core material is usually in the form of a honeycomb pattern as it is naturally the best shape to achieve peak lightness while reducing material usage (Chamberland, M., & Chamberland, M. 2015, July 22). Often, higher stiffness and strength can also be achieved. In Figure 2 the mold with the cutout for the connector can be seen with the connector alongside.

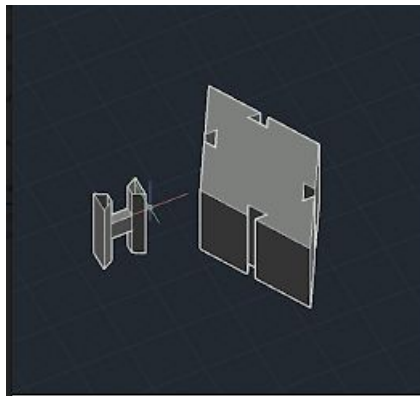


Figure 2: CAD drawing of mold (right) and connectors(left)

For the purpose of this project a variant of the composite was designed. A diamond shape was used that when aligned, channels that were not previously available in the honeycomb pattern allow for the implementation of steel reinforcement. The composite will be formed using a mold that creates the diamond shape in a sturdy manner to allow for accurate casting.

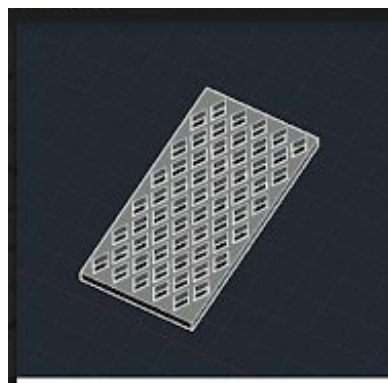


Figure 3: CAD drawing of cast slab with mold removed

Once the concrete core (see Figure 3) has been cast and cured, the SSC is completed with the addition of the two outer faces which will be thin and rigid plastic plates. The important property of the plastic that was necessary was the flexural modulus of elasticity. This property determined the deflection of the plastic which in turn not only determines if the plastic can be

used in a structurally sound way but also the ‘feeling of safety’ for the users of the bridge. While it is true that deflections beyond the recommended levels can be reached safely, whether they would almost deter persons from using the structure if they invoked fear or doubt about its use. Additionally, the plates must withstand not only the specified load combinations but the wear and tear of consistent walking. Durability must be considered alongside the strength of this material. A stiff material with a relatively high flexural modulus of elasticity would prove to be hard enough to withstand this wear and tear.

Before any real SSCs can be constructed a model was tested using RISA models and hand calculations against a traditional reinforced concrete slab. The intended result should be that the SSC proves to be much lighter than the traditional reinforced concrete slab resulting in smaller members, reducing the estimated cost of the bridge.

C. Steel Reinforcement

Because both methods, reinforced concrete and SSC, utilize steel reinforcement for the tensile stress and strain within the system, the amount of reinforcing steel needs to be determined for each design/material. Because of the configuration differences between the SSC and the reinforced concrete, the rebar needs to be sized differently. In traditional reinforced concrete the rebar is laid in a particular direction, with the rebar parallel to each other. However in the case of the SSC the rebar will form a grid where they overlap, which means that they will only be touching when reacting with one another. These new reactions mean that the forces throughout the concrete will be varied compared to a traditional slab. Also, because the slab is the main difference between the two designs, the beams, girders, columns and footing will need to be adjusted as to how much steel is needed to support the loading combinations of the slab.

Design Criteria

A. Loading Combinations

Although the structure may not always or ever be under every design load, it must withstand all of the possible load combinations in order to be considered safe. The combinations can be made up of a variety of effects ranging from live and dead loads to snow and wind loads. When designing a structure, one must consider the load combinations that it will be under. The values of these loads also changes depends on where the structure is located, its intended use, and the materials that it is made out of. For this bridge, the Massachusetts State Building Code 780 (Office of Public Health and Safety, 2018) was referred to because the bridge is to be placed in Worcester, MA. The State Building Code presents a list of applicable equations as well as individual values for the loads that would be analyzed. These loads (Table 1) were later used to evaluate the load combinations (Table 2) to determine which load combination would govern the

dimensions and elements of the span across the width of the bridge. The governing load combination was determined by using RISA (Appendix B). Each Load Combination loaded to the bridge and the Load Combination that produced the largest moment was the Load Combination that governed. (Table 2). Because the Massachusetts State Building Code does not have a live load value specifically for bridges, the live load value used was for walkways and elevated platforms.

Table 1: Table of values of loads used. Values came directly from Table 1604.10 in the Massachusetts State Building Code 780.

Type of Load	Value of Load for Worcester, MA
Snow Load	55 psf
Basic Wind Load (vertical direction)	26.07 psf
Live Load	60 psf

B. Accessibility

The designed structure must comply with regulations set forth by the Americans with Disabilities Act (ADA). It must be accessible by all persons, which means considering persons that may not be able to walk and their personal means of mobility. The overall walking surface must not have a slope steeper than 1:20 (ADA 402.2) The ramps and curb ramps however, are allowed to be steeper. The cross slope of walking surfaces shall not be steeper than 1:48 (ADA 403.3). Handrails along said walking surfaces with running slopes not steeper than 1:20 they shall comply with 505 (ADA 403.6). Signs are more legible for persons with low vision when characters contrast as much as possible with their background. Additional factors affecting the ease with which the text can be distinguished from its background include shadows cast by lighting sources, surface glare, and the uniformity of the text and its background colors and textures (ADA 703.5.1).

Design Tools

A. AutoCAD

AutoCAD is a computer-aided design software for 2D and 3D drawings. For this project, AutoCAD was used to demonstrate the construction and dimensions of the SSC. Because the composite can be used in different shapes, the one being analysed for this project was designed and presented in this format.

Firstly, the mold was designed as it is the determining factor of the shape of the resulting core of the SSC. The mold consists of a diamond-shaped piece with grooves; the connecting piece would slide into a groove of two separate diamond pieces connecting them. The mold was then used in repetition to design the core of the SSC.

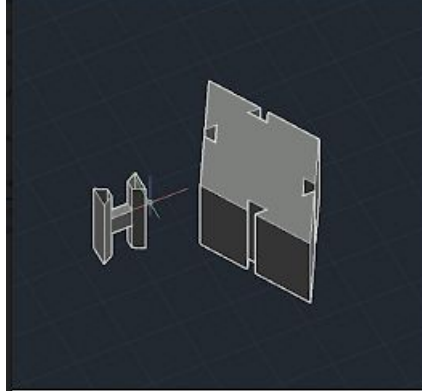


Figure 4: CAD drawing of mold (right) and connectors(left)

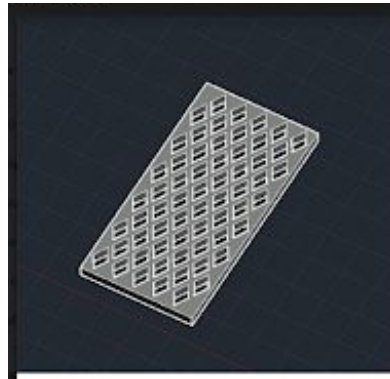


Figure 5: CAD drawing of cast slab with mold removed

The design began as a plan view, and upon completion, the pieces were extruded to create 3D solids. The core of the SSC was then modeled using 3D printing to get a better idea of the shape and aid in presentation at the project presentation day. 3D printing will not be the construction method for the actual SSC as it must be cast using the molds.

B. RISA

RISA is a computer software that can be used to analyze the forces within a structure. The 3D version of RISA was used to accommodate the large span, as well as to get an understanding how the loading and stresses would be affected. With the the SSC, it was especially crucial to understand the load path and internal reactions of the material to further understand how the orientation of the rebar would affect the bridge as a whole. Below is the RISA Model from an elevation view of the bridge. The program did not have enough points to accommodate the 650 ft span of the design so all members and joints were sized down by 10 for the RISA Model. The columns were later removed from the RISA model because of an error pointed out by the program. The lateral distance between each node is 50ft (5 squares) and the heights of each node are as follows: 0, 5ft (0.5 squares), 10ft (1 square), 15ft (1.5 squares), 20ft (2 squares). The grade of the ramp is 1%, which is within ADA regulation.

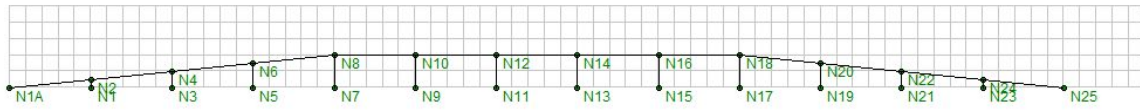


Figure 6: 2D RISAs Model without loading.

For this project, RISAs was used to find the resultant forces of the governing load combination on the bridge and its members (Appendix B). The bridge was designed in RISAs using the expected materials, member sizes and loading combinations to further confirm that the member sizes calculated will be sufficient in holding the loads that the bridge will need to support.

C. Microsoft Excel

Microsoft Excel is a computer spreadsheet program that can be used to organize and evaluate equations. After hand calculations for the sizing of each member of the bridge were done, the equations and values were incorporated within Microsoft Excel. The Microsoft Excel calculations/sheets were created for their use in this project in hopes of further application to make calculations in a professional setting faster to compute.

Methodology

Site Analysis

Before any designs or calculations could have been created, the site of the bridge had to be analyzed and evaluated. A preliminary walkthrough of the site was completed, marking down structures, bodies of water and general topography. While doing the site analysis, both the starting and end point of the bridge were measured to make sure that the intended width of the bridge could be incorporated within the already existing structures. Both structures (gazebos) were measured (Figures C2-C3, in Appendix C) and the place where the bridge would connect to each of the structure was determined. Because of the hexagonal shape of both gazebos, there were two possible options for where the bridge could connect. Photographs were taken approaching both gazebos from the angle in which the bridge would be connecting.

Conceptual Design

Preliminary designs of the bridge being examined were made to further investigate its capacities. The design had to not only be practical, but also aesthetically pleasing as it will be in a public space. The design highlighted that the bridge was to be used not only for pedestrians but for cyclists alike.

Various elevations and perspective sketches were created in order to solidify the concept for the design. The first factor considered was where the bridge would begin and end. After the site analysis, it was determined that it would span from the gazebo in front of Salisbury estates, to the gazebo nearest Goddard Hall. In order to visualize this, an elevation view (Appendix D1) was created; this view displays the span of the bridge in relation to the gazebos as well as the grade for the slope of the bridge.

A plan view (Figure D2 in Appendix D) was then sketched in order to begin designing the dimensions of the bridge, mainly the part that would be used by pedestrians. The aspects taken into consideration were:

- The width of the sidewalk for pedestrians.
- The width of each bike lane for cyclists
- Rest stops on either side for observing the park and surroundings
- Spacing for lighting
- Handrails

Finally a perspective view (Appendix D3) was drawn up to get a better sense of how the bridge would look as a pedestrian standing on it. This final sketch helped to solidify the design before the RISA model was completed.

Structural Design Work

When doing the structural design portion, the loads and forces were analyzed (Table 1), and these were consistent for all materials. Each state releases a state building code with loading combinations and values for each region, town and city, these values (Table 2) were used when determining the values for the Load Combinations. RISA, a computer software, was used to get the shear and moment diagrams (Appendix B) as well as the exact values for the maximum and minimum values. The necessary members for the bridge were sized using each of the aforementioned materials.

Table 2: Table of Load Combinations that were evaluated to determine which would be the governing for the bridge.

Load Combination	Maximum Moment resulting from Load Combination	Governing Load Combination?
1.4D	3.4 kip-ft	NO
1.2D + 1.6S + L	3.6 kip-ft	NO
1.2D + L + 0.5S	3.6 kip-ft	NO
1.2D + 1.6W + L + 0.5S	3.7 kip-ft	NO
1.2D + 1.6W + 0.5S	3.7 kip-ft	Yes, Governing Load Combination
0.9 D + 1.6 W	2.5 kip-ft	NO

Determining Plastic For SSC

When deciding on which plastic to use for the SSC, the material properties of each plastic offered was looked at. Curbell Plastics' interactive properties table was used to determine four candidate plastics (see Table 3). The plastic chosen was the one with the highest strength and the most information available through the manufacturer to allow the material created in RISA to best reflect the material provided by the manufacturer. Many of the plastics with the highest strength had little to no material properties reported on the manufacturer website so those plastics were ruled out.

Table 3: Candidate Plastics via Curbell Plastics

Material	Flexural Strength (PSI)	Flexural Modulus of Elasticity	Available Thickness (INCHES)
ABS	9,100	304,000	0.060 – 4.000
G-10/FR04 Glass Epoxy	60,000	2,400,000	0.010 – 2.000
PCTFE	9,570-10,300	200,000-243,000	0.125 – 2.750
GPO-3 Thermoset	18,000 - 25,000	1,500,000	0.031 – 2.000

To determine the thickness of plastic to use for the SSC Slab, the ASD Method was used. Because the tested plastics were not regularly used, a factor of safety of 4 (AASHTO, 2018) was used for the strength of the material to be tested in RISA. For these calculations, the Flexural Strength of the ABS Material was divided by the factor of safety, in this case 4, and compared to the maximum stress in the RISA Model. If the factored strength was larger than the stress found in the RISA Model, then it was concluded that the thickness of of the material was able to be used for the slab. The stress data from RISA allowed for comparison against the tested strength of the Plastics.

Sizing Members/Features using Reinforced Concrete

Once the design for the bridge was completed, the members were sized accordingly for all materials. For the traditional bridge material, reinforced concrete, the ACI Manual was used for reference on strength and thickness, as needed. For the sizing of the rebar for the reinforced concrete structure, *The Reinforced Concrete Design Handbook Table A-1* (ACI, 2015) was used to reference ASTM standard reinforcing bars and their nominal cross sectional areas.. This publication allowed for industry standards to be used when determining the rebar size that would be recommended. For the lightweight concrete alternative in a SSC (*Sandwich-structured composite 2017*) the above manuals were used as reference material when evaluating the dimensions offered by manufacturers and selecting particular products for design. In RISA the thickness of the plastic was changed each time to a thickness offered by the manufacturer. Stress maps were generated (Appendix I), and the maximum stresses were compared to the strength of the plastic, after the factor of safety was used.

Bridge Verification

Once all calculations for sizing the members were completed, the bridge and the specifics of the materials suggested, the members were placed into RISA to ensure that the member sizing was checked with the other members determined. For example, after the slab was designed

(Appendix E) the RISA Model was updated with the recommended reinforcements so the beam and girder designs would account for the weight of the slab. A final evaluation for the RISA model showed that the structure was stable.

Results

Reinforced Concrete Option

Table 4: Table of the calculated dimensions and reinforcement for the Bridge if it were constructed with only Reinforced Concrete.

Type of Member	Dimensions	Reinforcement per Feature	Quantity of rebar needed
Slab	50' x 8" x 20'	6#5	13
Beam	8" x 14.5" x 20'	4#6	65
Girder	8" x 14.5" x 50'	4#6	13
Column	12"(diameter) x 20' (maximum height is 20', individual height dependent on where they are along the span of the bridge)	6#6	28

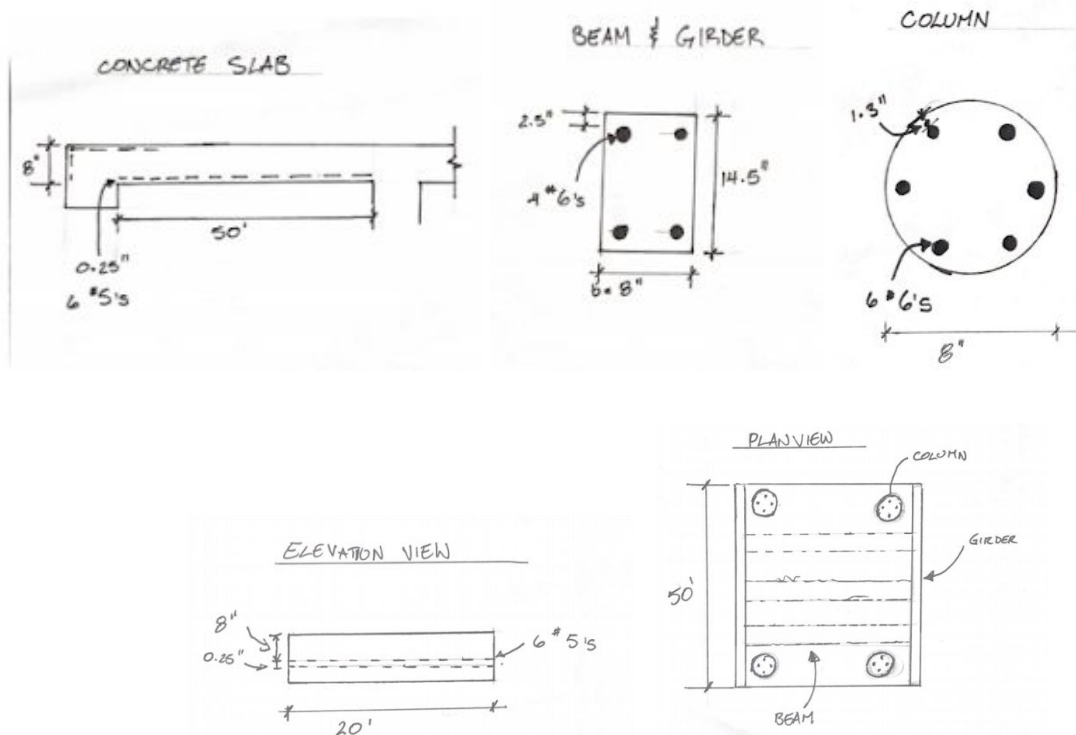


Figure 7: Engineering Sketches of the reinforced concrete features that were sized. Each part of the figure depicts what the cross section of that feature would look like, according to the calculations done

As shown in Table 3 and Figure 7 the reinforced concrete members' dimensions were calculated and sized. The concrete slab was found to need to be 8" thick with 6#5 steel reinforcements running through each 50' x 20' slab segment. For this bridge, 13 of these slabs would be needed for the entire length of the bridge. The beam was found to need to be 8" x 14.5" with 4#6 steel reinforcements running the 20' span of the bridge. These beams would rest on a girder, that would transfer the load from the beams to the columns. This girder was found to need to be 8" x 14.5" x 50' to allow for the 5 beams along this span to transfer the load from the 5 beams in this length to the columns at either end of the girder. The columns calculated were circular, with a diameter of 12" and 6#7 steel reinforcements. Dependent on its location along the span, the height of the column could vary but the tallest the column would be is 20' tall.

Sandwich Structured Composite

Determining the deflection under the expected load combinations is crucial in the selection of a candidate material for the rigid outer plates. Although the flexural modulus of elasticity and flexural strength may be able to withstand the forces present, the deflection plays a vital role in the "feeling of safety" of those using the bridge. There can be safe levels of deflection that visually do not meet a user's standards for trusting the structure. Therefore, the ideal combination of flexural strength and deflection will define the best candidate plastic for the rigid outer plate.

Table 5: Candidate plastics for rigid layer of SSC. This information came from a plastic company by the name of Curbell Plastics. Retrieved from: <https://www.curbellplastics.com/Research-Solutions/Plastic-Properties>

Material	Flexural Strength (PSI)	Flexural Modulus of Elasticity (PSI)	Available Thickness (INCHES)
ABS	9,100	304,000	0.060 – 4.000
G-10/FR04 Glass Epoxy	60,000	2,400,000	0.010 – 2.000
PCTFE	9,570-10,300	200,000-243,000	0.125 – 2.750
GPO-3 Thermoset	18,000 - 25,000	1,500,000	0.031 – 2.000

The candidate plastics were judged based on their flexural(yield) strength, and the flexural modulus of elasticity (see Table 5). The ABS material was chosen because this material had the most information provided by the manufacturer. The calculations for the ABS material were done using the ASD method and a Factor of Safety of 4. These resulting calculations were compared to the stress map generated by RISA (Appendix I) which allowed for a thickness to be confirmed for the sandwich structure composite. If the factored strength was larger than the stress found in the RISA Model, then it was concluded that the thickness of of the material was able to be used for the slab. The stress data from RISA allowed for comparison against the tested strength of the Plastics.

The rest of the bridge's members were then sized using reinforced concrete. Because of the sandwich structure composite having different resulting forces, there were some noticeable changes in the sizing of the members (see Table 6).

Table 6: Table of the calculated dimensions and reinforcement for the Bridge if it were constructed with the sandwich structure composite slab.

Type of Member	Dimensions	Reinforcement per Feature	Quantity needed
Slab (sandwich structure composite)	50' x 8" x 20'	N/A	13
Beam	8" x 14.5" x 20'	4#6	65
Girder	8" x 14.5" x 50'	4#6	13
Column	8"(diameter) x 20' (maximum height is 20', individual height dependent on where they are in the bridge)	4#6	28

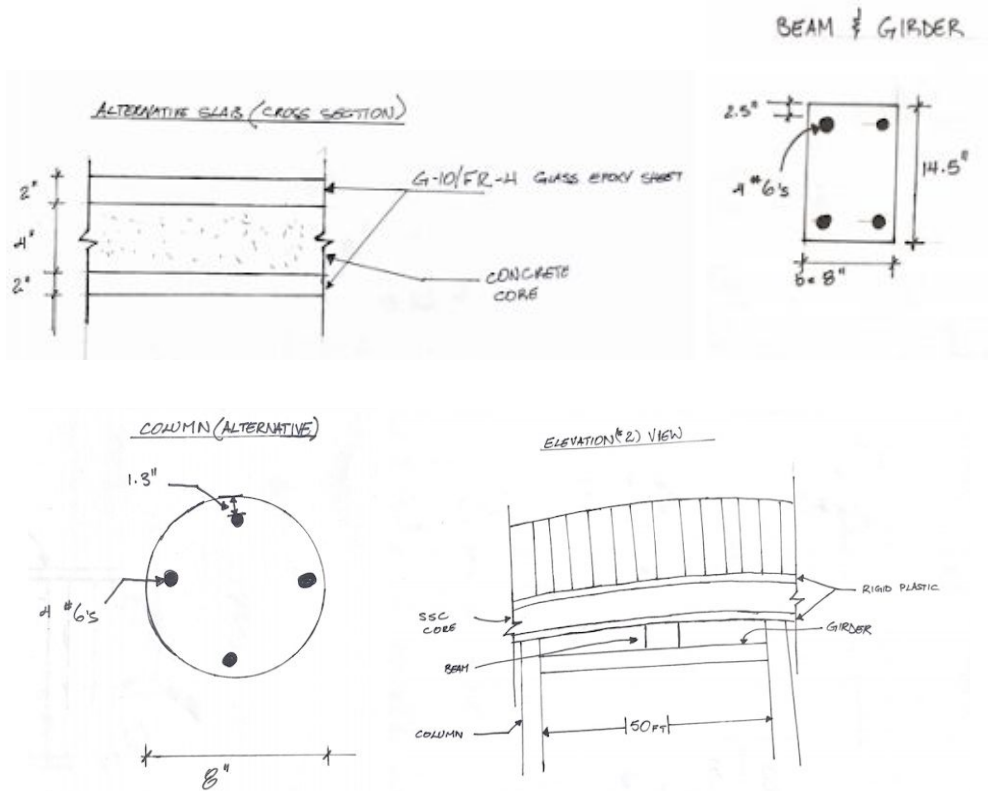


Figure 8: Engineering Sketches of the reinforced concrete features that were sized with the sandwich structure composite slab. Each part of the figure depicts what the cross section of that feature would look like, according to the calculations done. The first sketch is of the cross section of the sandwich structure composite.

As shown in Table 6 and Figure 8 the reinforced concrete members' dimensions were calculated and sized using the sandwich structure composite slab. The beam was found to need to be 8" x 14.5" with 4#6 steel reinforcements spanning the 20' width of the bridge. These beams would be supported by girders, that would transfer the load from the beams to the columns. This girder was found to need to be 8" x 14.5" x 50' to allow for the 5 beams along this span to transfer the load from the 5 beams in this length to the columns at either end of the girder. The columns calculated were circular, with a diameter of 8" and 4#6 steel reinforcements. Dependent on where in the bridge the column would be placed, the height of the column could vary but the tallest the column would be is 20' tall.

Cost Estimate

Table 7: Table of the cost estimate of materials using a reinforced concrete slab and reinforced concrete members.

Type	Materials	Bridge Component	Unit	\$/unit	Quantity	Cost (\$)
Traditional Concrete Slab	Concrete					
	<i>Concrete, Handmix 4000psi</i>	Slab	C.F	8.40	104,000.00	873,600
		Beam	C.F	8.40	150,800.00	1,266,721
		Girder	C.F	8.40	75,400.00	633,361
		Column	C.F	8.40	330,200.00	2,773,681
	Rebar	Slab	ton	1,790.00	0.81	1,458
		Beam	ton	2,125.00	3.90	8,288
		Girder	ton	2,125.00	1.98	4,199
		Column	ton	2,200.00	1.62	3,554
					Total Cost (\$)	5,548,821

Table 8: Table of the cost estimate of materials using the sandwich structure composite slab and reinforced concrete members.

Type	Materials	Bridge Component	Unit	\$/unit	Quantity	Cost (\$)	
Alternative Slab	Concrete						
		<i>Concrete, Handmix 4000psi</i>	Slab	C.F	8.40	52,000.00	436,800
			Beam	C.F	8.40	150,800.00	1,266,721
			Girder	C.F	8.40	75,400.00	633,361
			Column	C.F	8.40	247,650.00	2,080,261
		Rebar	Beam	2 ft	2,125.00	3.90	8,288
			Girder	2 ft	2,125.00	1.98	4,199
			Column	2 ft	2,200.00	1.08	2,376
		Plastic	G10/FR-4 Glass Epoxy Sheet	C.F	1,095.00	160.49	175,741
			Plastic Glazing	S.F.	29.34	26,000.00	762,840
						Total Cost (\$)	5,370,587

After the cost estimate was completed, the price of the traditional bridge was \$5,548,821.00 and the alternative was \$5,370,587. These prices were calculated from RSMMeans (Plotner, S. C. , 2019) for the materials and estimated labor costs.

Conclusion and Recommendations

Along with the proposed bridge design, this project also included the creation of Excel Sheets. These sheets helped with the sizing of members and kept the work neat so flaws in the calculations could be found easier than with traditional hand calculations. Through these Excel Sheets, the members were sized, and it was found that the beams and girders sizes were the same for both the reinforced concrete sandwich structure composite slabs. While the beams and girders were sized the same, the columns were subjected to different axial forces and moments so the column sizes were found to be different. Using the sandwich structure composite slab, the columns sized to be half of the calculated size of the columns sized for the reinforced concrete slab. After a cost estimate of materials, it was found that using the sandwich structure composite slab would reduce the size of the columns and also reduce the overall costs of materials.

The estimated cost of using the sandwich structure composite slab was \$5,549,000 with the estimated cost of using the reinforced concrete slab being \$5,730,000. The saving with using this sandwich structure composite, with two-inch glass epoxy on the outside of a four-inch concrete slab would save the owner \$178,000 on materials if the bridge were to be constructed as calculated from this project.

Due to limitations in the team's knowledge of foundations and soil mechanics, the footings for the columns were not sized as proposed in the initial project proposal. Further research into this bridge would need to include footing sizes and a soil analysis of the park. This further analysis would also include the environmental impacts that this bridge would have on the existing pond, in both a short term and longer term scope. Total cost estimates will also include the cost of footings, electricity, lights and labor costs, among other things. While this cost estimate was not complete, the members were sized and analyzed to determine the amount of materials needed for these calculations.

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APPENDIX A: PROPOSAL



Pedestrian Bridge in Institute Park using Sandwich Structured Composite Structural Design Major Qualifying Project Proposal

Presented by:

Alisa Da Silva & Zebadiah Yap-Chung

Presented to:

Professor Leonard Albano and the Worcester Polytechnic Institute
Civil Engineering Department

In partial fulfillment of the requirements for
the Degree of Bachelor of Science

2018-2019
MQP LDA-1903

Abstract

This proposal works as preliminary investigation and planning for the completion of an MQP focusing on a pedestrian bridge in Institute Park running from Salisbury Estates to Goddard Hall. This proposal also addresses some background information on the possible materials that are to be used when designing the bridge. Three different materials: steel, reinforced concrete and a sandwich-structured composite were chosen as the materials that will be analyzed for this project. A cost estimate will be determined using RS Means, a cost analysis method that was determined through research of this subject. The proposed amenities for the bridge will also be included in this cost estimate. A GANTT chart was also created and agreed upon by the group members in order to have a timeline of when major project point should be completed.

Introduction & Problem Statement

The focus of this MQP is to demonstrate the capabilities and applications of lightweight construction alternatives. Specifically, we will be exploring alternatives to traditional bridge design.

Whether it be part of their commute to and from school/work or just to enjoy a walk in nature, it is common amongst the people of Worcester to utilize Institute Park in some form. Its most popular use is as a venue for many cultural and recreational events. Institute Park is also home to Salisbury Estates, which is a WPI-owned housing complex where many university affiliated people live. The residents range from undergraduate students to PHD candidates and their families, and all of these people need to commute from Salisbury Estates to the main campus area. This commonality is why we have chosen Institute Park as the location of our project.

People who regularly travel from Salisbury Estates to WPI or visa versa, have had to walk around the pond in Institute Park. Having the bridge go from Salisbury Estates and end near the Goddard Hall Building, would not only shorten people's commutes, but would also serve as a social piece of architecture for the residents of the surrounding area. Institute Park is a lush green that encourages outdoor activities, the addition of this bridge would further enhance the sense of community people feel from this park. Having the bridge go over a part of the pond adds a new part of the park for people to explore and enjoy. The bridge would bring with it benches, lighting, and other aesthetic aspects that are included in the analysis of the expected load combinations.

Due to the wide range of persons that will have access to the bridge, many factors must be considered when designing the bridge and how it, and the surrounding area, will be used. Some of these factors include: the estimated snow load, projected foot and bike traffic, and what & how maintenance equipment will have access to the bridge. The bridge needs to be wide enough for snow plows and street sweepers to access easily, especially in the winter and spring months. The two alternatives to the traditional concrete slab bridge will be presented are a sandwich structured composite as lightweight concrete slabs, and steel design alternatives for various parts of the bridge. The sandwich structured composite is made using custom mold to create pseudo-honeycomb like structures that include rebar and will be utilized to make lightweight concrete slabs for bridges. The design and performance of these alternatives will be analyzed for the purpose of finding a lighter material that holds the same expected load combinations.

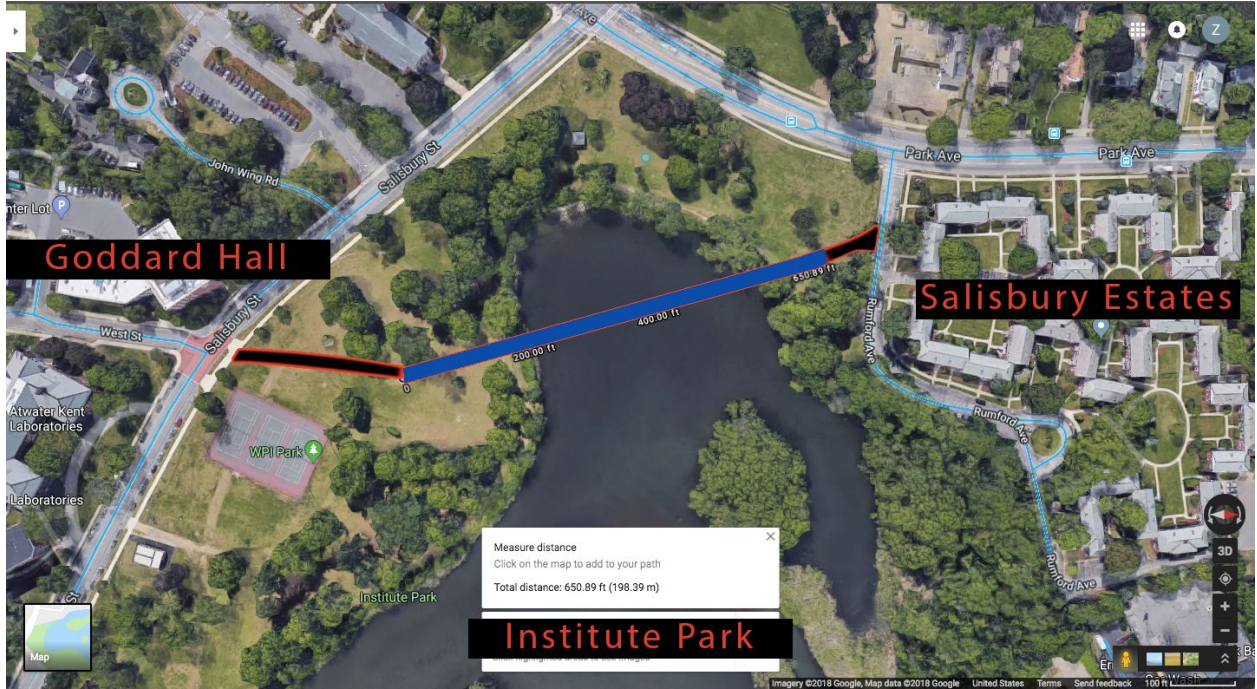


Figure 1: Map showing intended span of bridge.

Background

Institute Park was created in 1887 when Stephen Salisbury III donated 17 acres of his family's land to the city park's commission to contribute to the open network forming in Worcester. Since then it has been utilized as a public green space for the residents of the surrounding Worcester area. The park also houses a stage which is used in company with the surrounding space to host events. These events create an environment for community building boosting the bond between residents and other users of the park.

Salisbury Pond was not initially constructed for recreational use. It is an artificial lake that was the result of a dam erected by Stephan Salisbury II to provide power for the wire factory run by Ichabod Washburn. (Institute park master plan.2007)

Need Assessment

This academic year, 2018-2019, WPI Residential Services decided to move most of the upperclassmen resident of Founders Hall to Salisbury Estates. This displacement of over 100 students led to more people needing to walk from Salisbury Estates to the "on hill campus" during the day. The need for the bridge was further evident when the site analysis was taking place. While there is a sidewalk that goes down Park Avenue and onto Salisbury Street, there is no way to cut through the park. From years of residents walking the same path too and from Goddard Hall, there footprints have made a type of pseudo-walkway. The need for this bridge is reflected in this pseudo-walkway.

Introduction of materials

A. Sandwich Structured Composite

A sandwich structured composite consists of two relatively thin and firm faces separated by a thick lightweight core material. The lightweight core material is usually in the form of a honeycomb pattern as it is naturally the best shape to achieve peak lightness while reducing material usage. Often, higher stiffness and strength can be achieved.

B. Steel framing

Because both methods, reinforced concrete and sandwich structured composites, utilize steel framing for the tensile stress and strain within the system, the amount of steel needs to be determined for each design/material. Different steel frames need to be sized because of the different strengths in the two materials, sandwich structured composite and reinforced concrete.

C. Traditional reinforced Concrete Slabs

Method of making concrete slabs that includes laying down steel reinforcement with chairs and pouring concrete over it. The addition of steel bars and strength and flexibility to the concrete and allows its to be used with greater load combinations.

Design Criteria

A. Loading Combinations

When designing a structure, one must consider the load combinations that it will be under. The combinations can be made up of a variety of things ranging from live and dead loads to snow and wind loads. The values of these loads also changes depends on where the structure is located, its intended use and the materials that it is made out of.

B. Accessibility

The designed structure must comply with regulations set forth by the Americans with Disabilities Act (ADA). It must be accessible by all persons, which means considering persons that may not be able to walk and their personal means of mobility. This includes routes to the structure and entry to the structure.

Design Tools

A. Revit

Revit is a computer software that can, and will, be utilized to make 3D renderings of structures. For this project, a rendering of the conceptual drawings will be made and used to help visualize what the bridge will look like. Revit has a large library of amenities to add to designs, and this feature will be used when adding benches, lights and other recreational pieces to the bridge. Revit will also be used to show where railings and signs will be located, as outlined in the AASHTO Manual.

B. AutoCAD

AutoCAD is a computer aided design software for 2D and 3D drawings. For this project, AutoCAD will be used to demonstrate the construction and dimensions of the sandwich structured composite. Because the composite can be used using different shapes, the one being analysed for this project will be design and presented in this format.

C. RISA

RISA is a computer software that can be used to analysis the forces within a structure. For this project, RISA will be used to find the forces acting in certain members once the load combinations are determined. The bridge must be designed in RISA using the expected materials and then the forces are calculated using this program. Using RISA will reduce the time needed to find the forces but will also reduce some complications that may occur when analysing an indeterminate structure.

D. ArcGIS

ARCGIS is a global information system (GIS) that collects data and can be used to create maps based on this data. As WPI students, we have access to an entire library of ARCGIS data. This data will be used to determine the soil profile of Institute Park. Because the equipment needed to determine the soil profile can not be used by the students at the time of the project, the

data from ARCGIS will be used to analyse the soil. The soil profile will be used to design the footings for the columns of the bridge.

Methodology

Site Analysis

Before any designs or calculations can be made, the site of the bridge must be analyzed and evaluated. A preliminary walkthrough of the site will be completed, marking down structures, bodies of water and general topography. Then, the site will be further evaluated using ArcGIS, taking down specific elevations and topographical features. Once both the preliminary data and ArcGIS data is collected, they are to be combined to make a comprehensive map of the area along and around where the bridge will be located. Once the surface is mapped out, a soil analysis must be done to ensure the weight of the bridge can be held up by the soil and also used for designing the footings. . These two things will have to be done all along the path of the bridge before bridge design can begin.

Conceptual Design

Preliminary Designs of the bridge being examined must be made to further investigate its capacities. The design must not only be practical, but also aesthetically pleasing as it will be in a public space. The design will highlight that the bridge be used not only for pedestrians but for bicyclists alike. An Elevation view, as well as other perspectives of the bridge, will be part of the initial deliverables. The cross section, width, length and grade will also be included in the conceptual designs. Lighting and benches will also be factored into the calculations so the amount used throughout the bridge should also be determined. While the costs associated with these items will not be used at the time of conceptual designs, the placement of these amenities needs to be determined so they are accounted for moving forward. Multiple options, ranging in price and efficiency, will be analyzed before determining what and how much of these amenities will be used in the conceptual designs.

Structural Design Work

When doing the structural design portion, the loads and forces will be analyzed, and these will stay consistent for all materials. Major weather such as average snow and rain will be researched and taken into consideration when doing loading conditions and load combinations. While this bridge is meant for pedestrial use, loads for maintenance equipment and snow removal will also be taken into consideration when determining load combinations. Lateral loads such as wind and seismic will also be considered when designing and sizing members. RISA, a computer software, will be used to get the shear and moment diagrams as well as the exact values for the maximum and minimum values. The necessary members for the bridge will be sized using each of the aforementioned materials and their respective source materials.

Superstructure Design (part above ground)

Once the design for the bridge is completed, the members can be sized accordingly or all materials, AASHTO website and manuals will be consulted. For the traditional bridge material, concrete, the ACI Manual will be used for reference on strength and thickness, as needed. For the steel structure analysis the AISC Manual will be referenced for possible member sizes. This publication will also be used for connectors that may be needed to attach members together. For the lightweight concrete alternative in a sandwich structured composite (*Sandwich-structured composite 2017*) will be used as reference material when determining the dimensions necessary to hold the loads identified. For each material the following features will be sized: columns, slab, footing and the beams and girders that make of the frame.

Substructure Design (part underground)

The columns of the bridge need to be planted and secured in the ground. Footing needs to also be designed for the columns that are holding the bridge up. This design will come after the columns are the slab are designed to make sure that the footing can accommodate the weight of the structure along with the expected load combinations. When designing footing, AASHTO manuals will be consulted. Also the bearing capacity will be determined during the site analysis portion and utilized when designing the footing. A soil profile figure will be constructed and presented when configuring this design.

Bridge Verification

Once all calculations for sizing the members are done, the bridge and the specifics of the materials suggested, will be placed into a computer software as an extra check for the work done.

Cost Analysis/Table

Once all calculations for sizing the members and determining how much material is needed for each alternative, a cost analysis table will be constructed and analyzed. This table will help in the forming of the conclusion of which material is most cost effective for this bridge.

Deliverables

When the design of the lightweight alternative bridges has been completed, there will be a set of deliverable that will be presented. These deliverables will demonstrate the work done and our intentions for implementation. The final project will consist of a report containing sections outlining the design process for each alternative and how the optimal design was chosen. This report will also contain a sketch of the bridge analyzed and a completed cost analysis table. These sections also include hand calculations that have been verified through the use of computer software to show differences in methods. There will also be a completed Poster that will be presented at WPI's Project Presentation Day. Below is a GANTT chart of the intended work. This has been updated to when the proposal was submitted.

MQP Schedule

Select a period to highlight at right. A legend describing the charting follows.

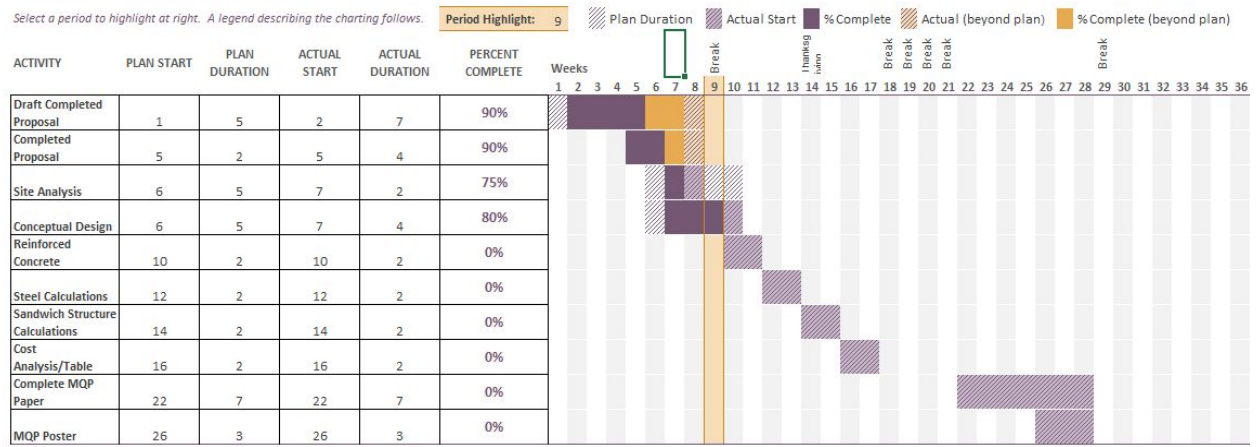


Figure 2: GANTT Chart representing MQP Project Schedule

Initial Schedule of Activities and Breakdown of the Project

Term	Activities	Due Dates
A	Rough Draft Complete Proposal	09/28/2018 <ul style="list-style-type: none"> Each week leading up to this date 2 sections will be uploaded to canvas to show progress
	Design Profile of Bridge <ul style="list-style-type: none"> Top Sides Elevation View 	10/10/18
	Define Components of Design <ul style="list-style-type: none"> Length Width Major Members/pieces Loads 	10/10/18
B	Complete Bridge Design	10/26/2018
	Evaluate Alternatives <ul style="list-style-type: none"> Concrete Steel Lightweight alternative 	11/09/2018 11/21/2018 12/07/2018
	Cost Analysis Table <ul style="list-style-type: none"> Determine most cost effective 	12/14/2018
C	Complete Report <ul style="list-style-type: none"> Bi-Weekly Submittals of draft 	02/28/2018
	Complete Poster Design/Presentation	02/28/2018

Capstone Design Statement

Worcester Polytechnic Institute (WPI) project based learning, specifically the Major Qualifying Project (MQP), provides a capstone design experience that is in line with that required by the Accreditation Board for Engineering and Technology (ABET). As an institution providing ABET accredited degrees, WPI requires students to incorporate various engineering standards into their MQP's. It is expected that students will utilize the engineering experience from their 4 years of undergraduate studies and apply it to a real-world problem. This factor is important as it is a reflection of the work that graduating students will have to do in their profession as engineers. By addressing real-world issues, they will be exposed to real life constraints and standards that are not discussed in the classroom.

Economics

When addressing the economics of a project, one must consider the various budgetary constraints that will affect the decisions made before and throughout its completion. These decisions pertain to things such as the design of the structure, the materials to be used, the methods that will be used to construct it as well as any possible changes that would require additional funding. For the purpose of this project, design, materials and construction methods will be analyzed. After each feature is sized using the material that is being analyzed at that time, a cost estimate table will be constructed. This cost estimate table will include how much it would cost to construct this feature; RS Mean will be used to estimate costs of construction for each material.

Environmental Impacts

Before construction can begin, the environmental impacts of the structure must be explored. Examination must be conducted in order to discover any constraints that already exist within the landscape. Consideration must be taken for where the structure will be located, its potential to disturb the surrounding environment, methods of preventing or mitigating any negative impacts and environmental concerns such as wildlife and protected wetlands. For this project, the soil mechanics and compression factor will be determined. Also, because the bridge is being designed to go over the existing lake, the impacts to the lake will also be researched. There are columns that are designed to be put in the lake so the soil mechanics of the lake as well as how the ecosystem will be affected by this construction must be analyzed.

Ethics

The American Society of Civil Engineers (ASCE) has a code of ethics that lists the 7 canons of professional practice for Civil Engineers. These canons will be followed, to the best of our ability, when designing the bridge and its features. The first canon of "Hold Safety Paramount" will be the main focus for this project. This canon focuses on the principle of sustainable development; referring to making the

bridge safe for public use as well as sustainable for years to come. The other canons, while equally as important, focus on the professional practice and honor that comes with being a professional engineer. As for canon 7, “Continue Professional Development”, this project will prove to follow that canon unintentionally as is the nature of this project. (ASCE, 2017) When sizing the features, a factor of safety that has been identified by the ASCE will be used. The method that will be used to size each feature will be the LRFD method.

Health & Safety

In order for the structure to become a reality, the design must comply with an array of health and safety standards. This includes making sure that necessary maintenance equipment can use the bridge as well. The following references will be used as guides for designing in compliance with the necessary standards:

<u>Reference</u>	<u>Application</u>
American Association of State Highway and Transportation Officials (AASHTO)	<ul style="list-style-type: none"> ● Load and Resistance Factor Design (LRFD) ● Width of walking and bike lanes
American Institute of Steel Construction (AISC)	<ul style="list-style-type: none"> ● Steel design with aid of their Steel Manual
American Concrete Institute (ACI)	<ul style="list-style-type: none"> ● Codes pertaining to structural concrete
American Society of Civil Engineers (ASCE)	<ul style="list-style-type: none"> ● ASCE 7 - codes for the minimum design loads for buildings and other structures ● ASCE Code of Ethics
Americans with Disabilities Act (ADA)	<ul style="list-style-type: none"> ● Reference as aid in improving the design to a disable friendly standard ● Width of walking lanes and grade of bridge to accommodate wheelchairs and other disability equipment
NFPA 70 National Electric Code 2014	<ul style="list-style-type: none"> ● Codes on lighting and electrical matters

Constructability

The constructability of a project addresses how it will be built with decisions based on analysis of the constraints of the surrounding environment. The constructability must be assessed as the park is a place frequently used by people of the community. There are many aspects of constructability that must be discussed in order to know what the monetary and timely costs are, as well as to ensure that construction does not (as much as possible) disturb the daily lives of the citizens that utilize the general area. These aspects include but are not limited to:

- ❖ The techniques that will be used to construct the structure
- ❖ The cost of equipment, machinery & fuel required for construction
- ❖ The level of difficulty of constructing the structure / The level of skill required
- ❖ Time
 - The amount of time that it would take to construct the structure
 - The best time to conduct construction without causing any disruptions to the lives of the citizens
- ❖ The local climate & weather conditions and patterns during the time of construction
- ❖ The transportation distances, site accessibility

The bridge will pass through Institute Park partially passing over the exist lake. For this project the cost analysis will help in determining the economic constructability of the bridge. This will also serve as a baseline for how long it will take the bridge to be constructed. Once the amount of materials is known, we can use Project Management practices to determine approximately how long construction will last. The site accessibility will be evaluated when initial site visits occur. From personal experience the proposed site does not have many restrains; there are trees and small inclines. With further analysis the environmental constraints will be identified and considered when designing the footing of the bridge.

Professional Licensure

Professional licensure is an important part of any type of engineering and is a recognized standard by industry. It serves not only to show that the engineer is capable of completing the job, but also as a representation of their dedication to upholding a certain standard and quality of work. Degrees from ABET accredited school provide the opportunity to pursue a professional license if the individual decides to do so. MQP replicates the professional practice by providing a solution to a complex design problem while addressing real world issues.

WPI's MQP ties together with professional licensure as it teaches the students how to deal with real world issues. There is no formal course that is offered in professional licensure and so the intention is that by the time they graduate, students should have an understanding of their field such that they may be able to put things in their own words in the form of an MQP. The MQP acts almost like a precursor to the first project of an engineers career. MQP students must explore every aspect of their project just as though it was owned and being executed by a large company. Other schools with capstone design requirement have at their disposal: a responsible instructor, guest lecturers, ways to address ethical issues and writing assignments. These in combination with other facilities that may be available provide a capstone design experience that prepares a student for the working world as an engineer.

Conclusion

The culmination of this MQP will produce a design package for a pedestrian bridge through Institute Park. The implementation of this bridge will add to the aesthetic value of the park while improving on the experience for persons who use the park for commuting. It will serve to promote the use of Institute Park and the new usable space where the bridge passes of the pond.

The bridge will span from the Salisbury Estate Properties to an area in the park in front of the Goddard Hall building. At each end of the bridge there will be a continued pathway towards Goddard Hall. The bridge and pathways will be split into a bike lane and a walking lane. Over the pond there will be a rest stop on either side with benches to allow persons to sit and enjoy the surrounding nature. The bridge will be lit sufficiently so that persons may commute at night using the most cost efficient fixtures. This structure should boost the areas overall use of bicycles, decreasing carbon emissions and traffic congestion.

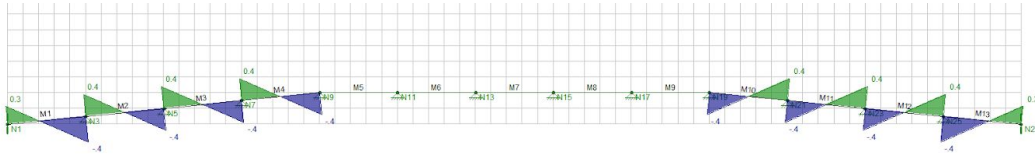
References

Institute park master plan. (2007). Retrieved from <http://www.institutepark.org/masterplan.pdf>

Sandwich-structured composite (2017). Retrieved from

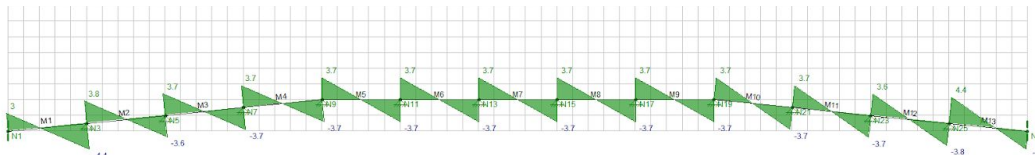
https://en.wikipedia.org/w/index.php?title=Sandwich-structured_composite&oldid=792578867

APPENDIX B: RISA ANALYSIS



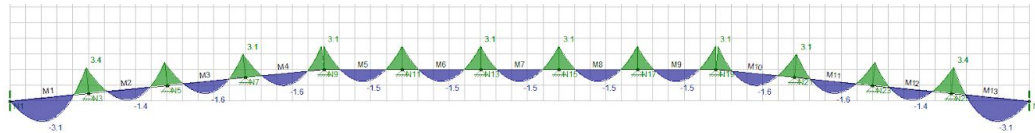
Results for LC 1, 1.4D
Member Axial Forces (K)

Figure B1: The resulting axial forces displayed graphically for the 1.4D Load Combination.



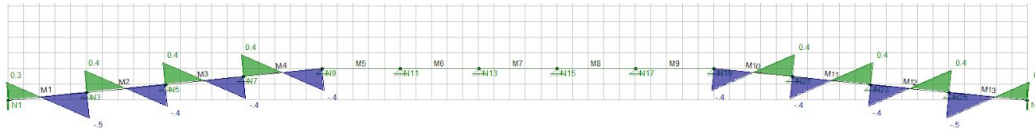
Results for LC 1, 1.4D
Member Shear Forces (K)

Figure B2: The resulting shear stresses, at the joints, displayed graphically for the 1.4D Load Combination.



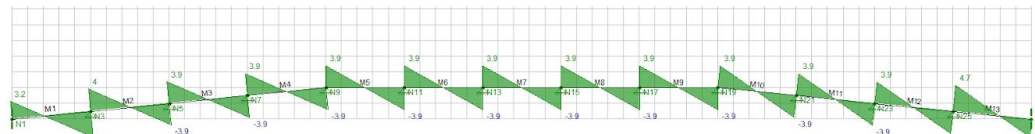
Results for LC 1, 1.4D
Member Bending Moments (K-ft)

Figure B3: The resulting moment diagram displayed graphically for the 1.4D Load Combination.



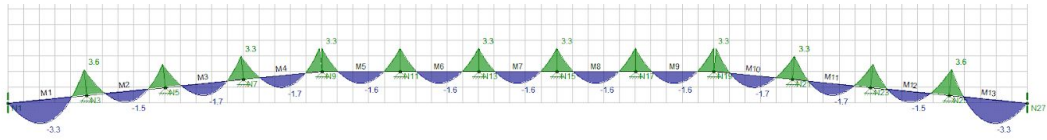
Results for LC 2, 1.2D + 1.6S + L
Member Axial Forces (K)

Figure B4: The resulting axial forces displayed graphically for the 1.2D + 1.6S + L Load Combination.



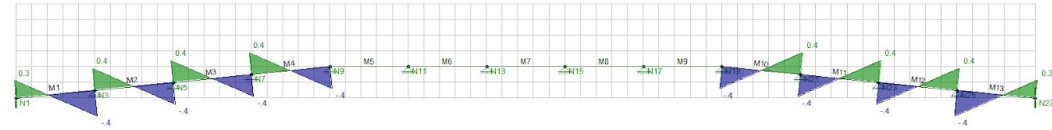
Results for LC 2, 1.2D + 1.6S + L
Member Shear Forces (K)

Figure B5: The resulting shear stresses, at the joints, displayed graphically for the 1.2D + 1.6S + L Load Combination.



Results for LC 2, 1.2D + 1.6S + L
Member z Bending Moments (k-ft)

Figure B6: The resulting moment diagram displayed graphically for the 1.2D + 1.6S + L Load Combination.



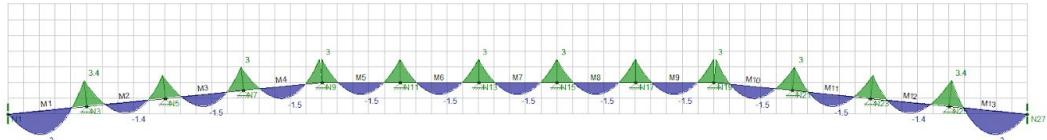
Results for LC 3, 1.2D + L + 0.5S
Member y Axial Forces (k)

Figure B7: The resulting axial forces displayed graphically for the 1.2D + L + 0.5 S Load Combination.



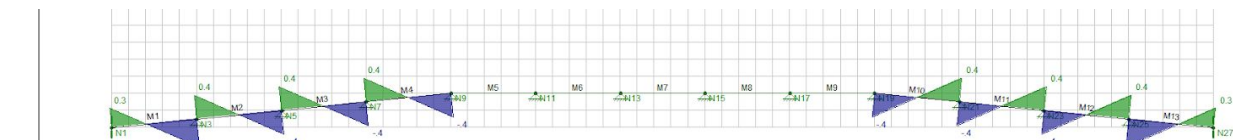
Results for LC 3, 1.2D + L + 0.5S
Member y Shear Forces (k)

Figure B8: The resulting shear stresses, at the joints, displayed graphically for the 1.2D + L + 0.5 S Load Combination.



Results for LC 3, 1.2D + L + 0.5S
Member z Bending Moments (k-ft)

Figure B9: The resulting moment diagram displayed graphically for the 1.2D + L + 0.5 S Load Combination.



Results for LC 4, 1.2D + 1.6W + L + 0.5S
Member Axial Forces (k)

Figure B10: The resulting axial forces displayed graphically for the 1.2D + 1.6W + L + 0.5S Load Combination.

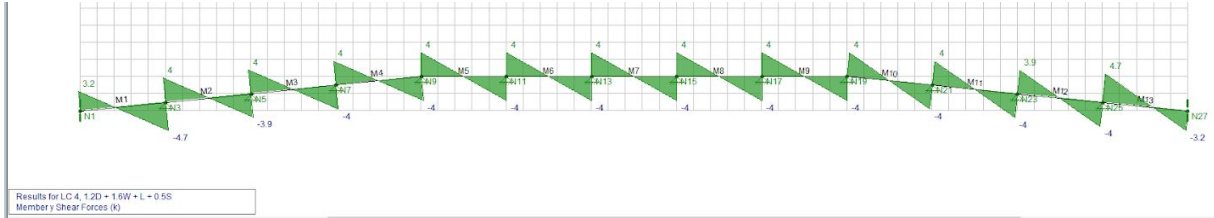


Figure B11: The resulting shear stresses, at the joints, displayed graphically for tht 1.2D+1.6W+0.5S Load Combination.

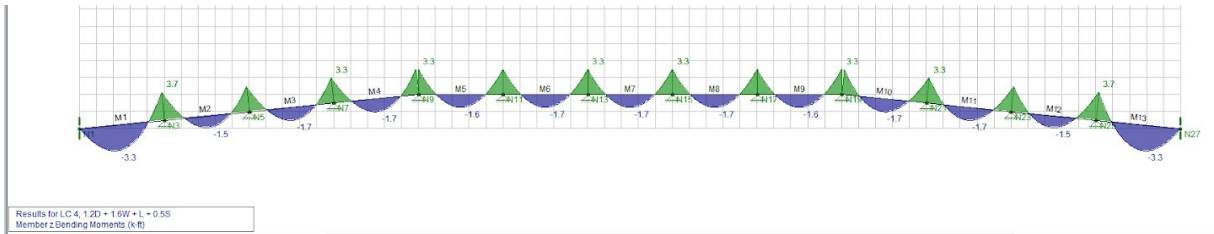


Figure B12: The resulting moment diagram displayed graphically for the 1.2D+1.6W+0.5S Load Combination.

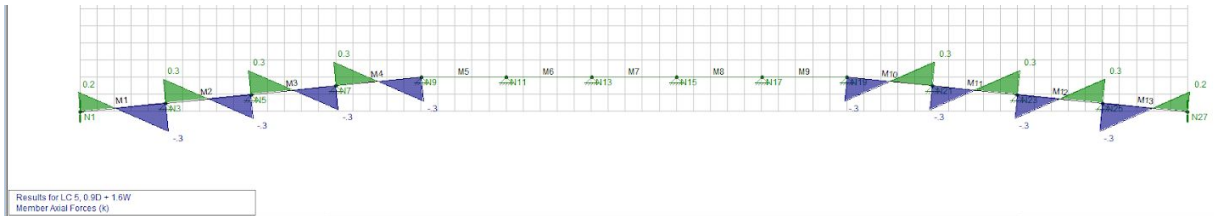


Figure B13: The resulting axial forces displayed graphically for the 0.9 D + 1.6 W Load Combination.

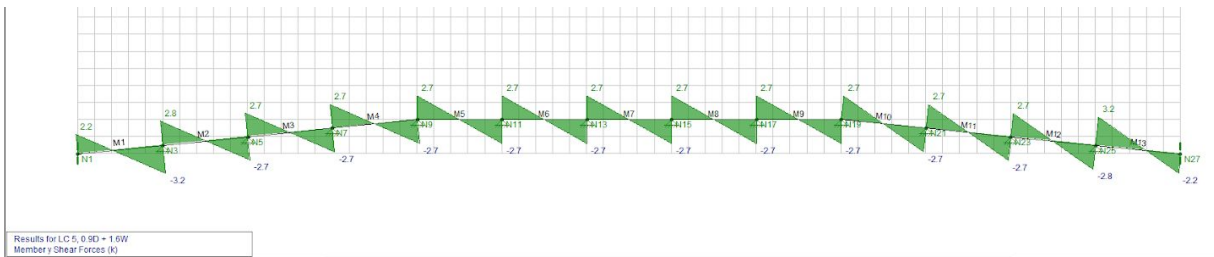


Figure B14: The resulting shear stresses, at the joints, displayed graphically for the 0.9 D + 1.6 W Load Combination.



Figure B15: The resulting moment diagram displayed graphically for the 0.9 D + 1.6 W Load Combination.

APPENDIX C: SITE PICTURES AND BRIDGE PLACEMENT

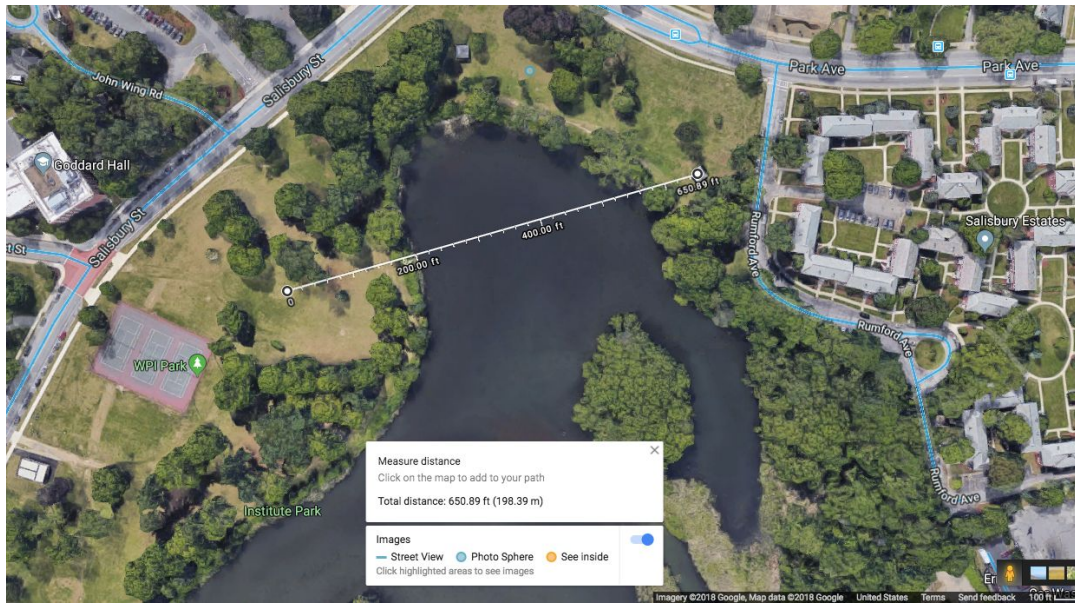


Figure C1: Neither gazebos were visible on Google Maps so approximate locations were used for determining the total length of the bridge. This screenshot of Google Maps helps to better portray where the bridge will be located.



Figure C2: The gazebo closest to Goddard Hall has a doorway that is currently 11.5' in width. This doorway is the closest one to the lake and Salisbury Estates gazebo.



Figure C3: The gazebo closest to Salisbury Estates has a doorway that is currently 5' 7" in width. This doorway is the closest one to the lake and Goddard Hall gazebo.



Figure C4: The gazebo closest to Salisbury Estates. This image is from the direction where the bridge would be running.



Figure C5: The gazebo closest to Goddard Hall. This image is from the direction where the bridge would be running.

APPENDIX D: CONCEPTUAL DRAWINGS

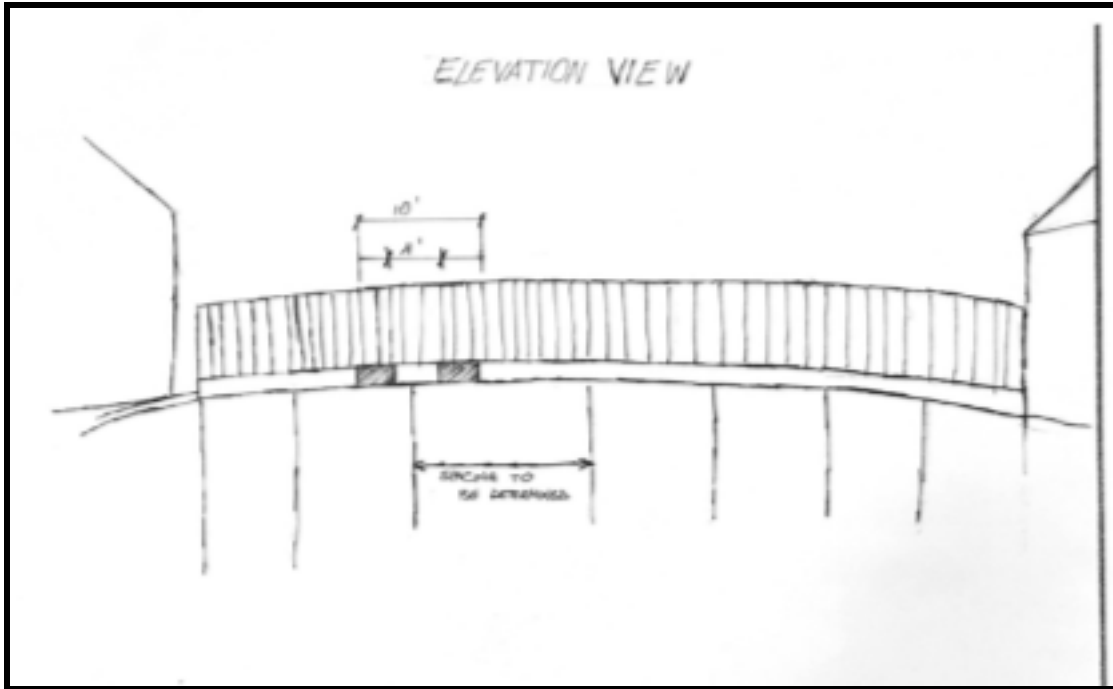


Figure D1: Elevation view of initial concept for bridge design

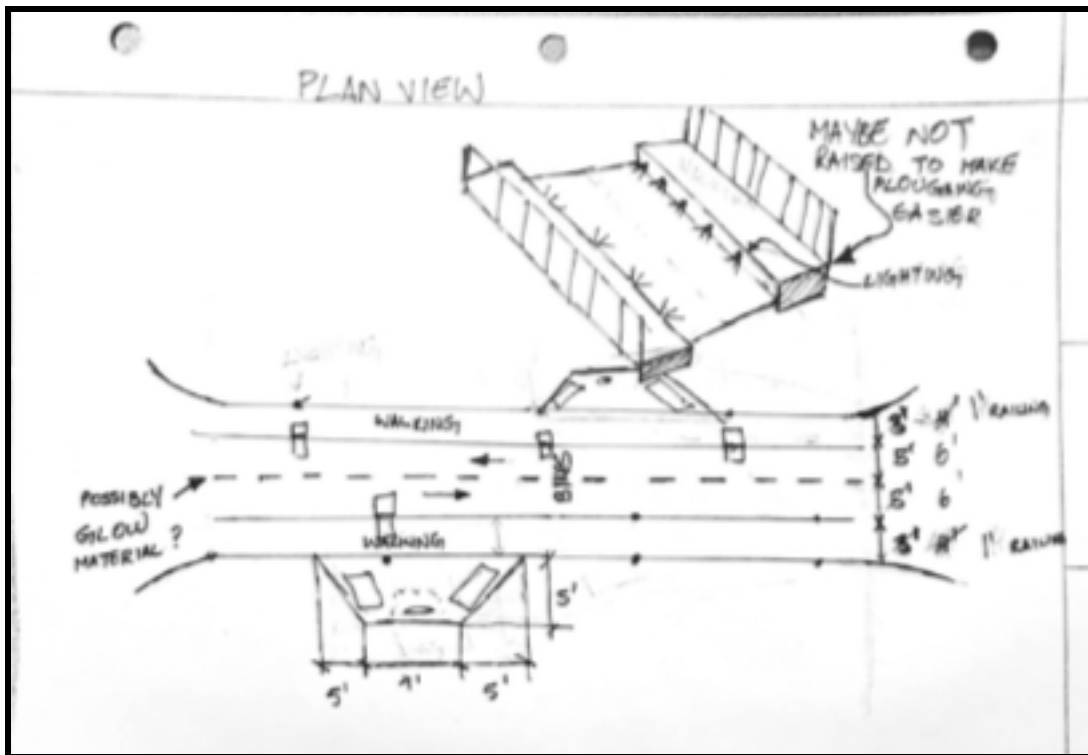


Figure D2: Plan view of initial concept for bridge design

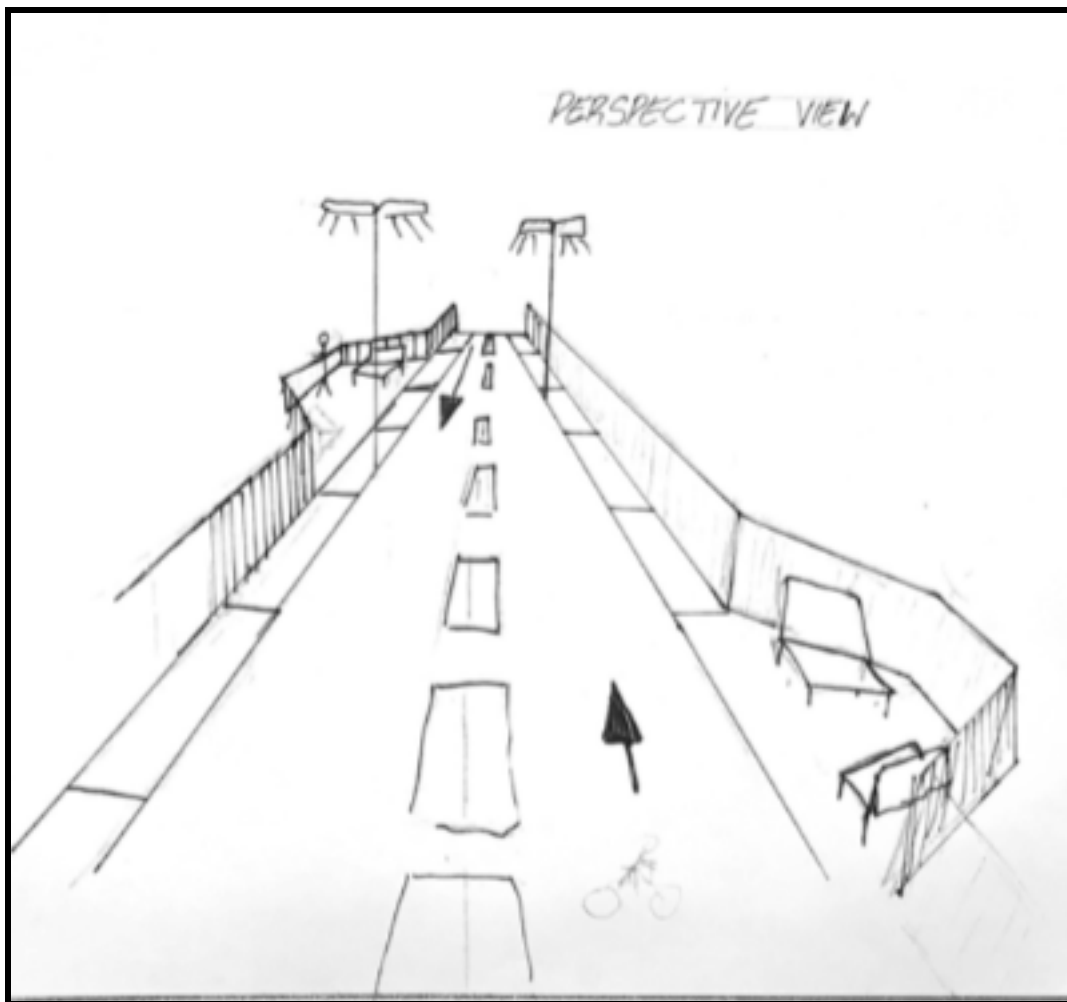


Figure D3: Perspective view of initial concept for bridge design

APPENDIX E: SLAB DESIGN CALCULATIONS USING REINFORCED CONCRETE

Known Quantities		Units
f_y	60	ksi
E (A26 steel)	29,000	ksi
f_c	4	ksi
L	20	feet
γ_c	0.15	pcf
b	12	inches
W _{dd}	0.015	kip/feet
WL	0.06	kip/feet
WS	0.055	kip/feet
cover	0.25	inches
ϵ_t	0.004	
ϵ_u	0.003	

Minimum Thickness $(L \cdot 12) / 28$ 8.57 inches
 Rounded to: $h =$ 9 inches

W_s $\gamma_c \cdot (b/12) \cdot (h/12)$ 0.107 kip/feet
 W_d W_{dd} + W_s 0.122 kip/feet
 W_u 1.2W_d + WL + 0.5 WS 0.23 kip/feet

RISA Data
 Mu_{Support} -3.3 kip-ft
 Mu_{Middle} 3.7 kp-ft

β_1 $0.85 - 0.05[(f_c - 4) / 1]$ 0.85
 P_{max} $0.85 \cdot \beta_1 \cdot (f_c / f_y) \cdot (\epsilon_u / (\epsilon_u + \epsilon_t))$ 0.0206
 P_{0.005} $0.85 \cdot \beta_1 \cdot (f_c / f_y) \cdot (\epsilon_u / (\epsilon_u + 0.005))$ 0.0181

$\phi =$ 0.9

$$\mu_{Support} = \phi * P0.005 * f_y * b * d_{min}^2 * (1 - (0.59 * P0.005 * (f_y / f_c)))$$

dmin^2=	(Mu_Support)/(phi * P0.005 * fy * b * (1-(0.59*P0.005*(fy/fc))))	0.34
dmin=	SQRT(dmin^2)	0.58
d=	h-0.75-0.25	8

Sizing for Steel Reinforcements

a	asumed	1 inches
As	(Mu_Support)/(phi * fy * (d-0.5a))	0.01 inches^2
a	(As*fy)/(0.85*fc*b)	0.01 inches
As_Support	(Mu_Support)/(phi * fy * (d-0.5a))	0.01 inches^2
a'	a*(As_Support/As)	0.01
As_Middle	(Mu_Middle)/(phi * fy * (d-0.5a))	-10.78 inches^2
As_min	P0.005 * b * h	1.86 inches^2 1.8 3#7 1.86 6#5

Recommended Reinforcement

Check for Shear Reinforcements

phi =		0.75
Vu	1.15*(0.5*Wu*L)-(Wu*d)	0.920
phiVc	phi^2*SQRT(fc)*b*d	272.571
phiVc	greater than	Vu so no shear reinforcement is needed

APPENDIX F: BEAM DESIGN CALCULATIONS USING REINFORCED CONCRETE

Known Quantities		Units
f_y	60	ksi
Esteel	29,000	ksi
Econcrete	4,030	ksi
f_c	4	ksi
L	20	feet
γ_c	150	pcf
W _{dd}	0.015	kip/feet
W _L	0.06	kip/feet
W _S	0.055	kip/feet
cover	0.25	inches
ϵ_t	0.005	
ϵ_u	0.003	
Φ	0.9	

Predictions

b=	0.83 ft	10 inches
h=	1.67 ft	20 inches

Calculations

W ₁	$0.36 \cdot b$	0.30
W _s	$(\gamma_c \cdot b \cdot h) / 1000$	0.21 kip/feet
W _d	W _{dd} + W _s	0.223 kip/feet
W _u	$1.2W_d + W_L + 0.5 W_S$	0.35 kip/feet
β_1	$0.85 - 0.05[(f_c - 4) / 1]$	0.85
P _{max}	$0.85 \beta_1 (f_c / f_y) (\epsilon_u / (\epsilon_u + \epsilon_t))$	0.0181
R _u	$(\Phi \cdot P_{max} \cdot f_y \cdot (1 - 0.59 \cdot (P_{max} \cdot f_y / f_c)))$	0.8194582582

RISA Data

M _u	3.7 kip-ft
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Sizing for Steel Reinforcements

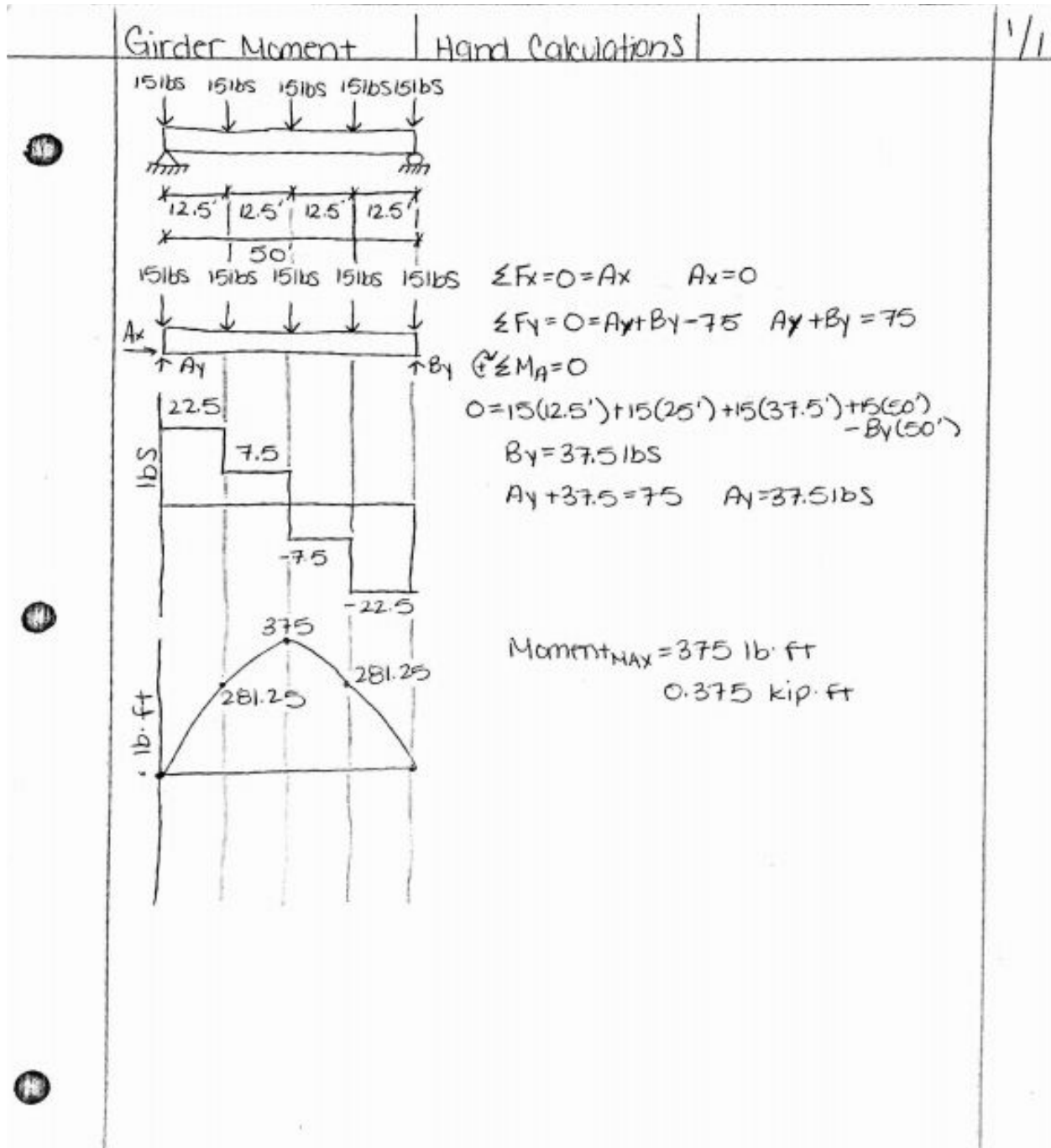
bd^2	M_u/R_u	4.515178123	
	Assume $d=1.5b$	$bd^2 = 1.5b^3$	
b	$(bd^2/(1.5^2))^0.3$	1.09 minimum b	
	$b=$	8 inches	
	$d=$	12 inches	because of relationship $d=1.5b$
	$h=$	14.5 inches	because of relationship $h= 2.5+d$

Recalculate with known values

W_1	$0.36*b$	0.24	
W_s	$(\gamma_c * b * h)/1000$	0.12 kip/feet	
W_d	$W_{dd} + W_s$	0.121 kip/feet	
W_u	$1.2W_d + W_L + 0.5 W_S$	0.23	
		$0.35 > 0.23$	confirmed

A_s	$b*d*p$	1.73 in ²	
		1.76 #6	Recommended Reinforcement

APPENDIX G: GIRDER DESIGN CALCULATIONS USING REINFORCED CONCRETE



Known Quantities		Units
f_y	60	ksi
Esteel	29,000	ksi
Econcrete	4,030	ksi
f_c	4	ksi
L	50	feet
γ_c	150	pcf
W _{dd}	0.015	kip/feet
WB	0.015	kip/feet
cover	0.25	inches
ϵ_t	0.005	
ϵ_u	0.003	
Φ	0.9	

Unit Weight of Beam

Assumptions

b=	0.83 ft	10 inches
h=	1.67 ft	20 inches

Calculations

W ₁	$0.36 \cdot b$	0.30
W _s	$(\gamma_c \cdot b \cdot h) / 1000$	0.21 kip/feet
W _d	W _{dd} + W _s	0.223 kip/feet
W _u	$1.2W_d + 3WB$	0.31 kip/feet
β_1	$0.85 - 0.05[(f_c - 4) / 1]$	0.85
P _{max}	$0.85 \cdot \beta_1 \cdot (f_c / f_y) \cdot (\epsilon_u (\epsilon_u + \epsilon_t))$	0.0181
R _u	$(\Phi \cdot P_{max} \cdot f_y \cdot (1 - 0.59 \cdot (f_y / f_c)))$	0.819

Hand Calculations

M _u	0.375 kip-ft
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Sizing for Steel Reinforcements

bd^2	M_u/R_u	0.4576194043	
	Assume $d=1.5b$	$bd^2 = 1.5b^3$	
b	$(bd^2/(1.5^2))^0.3$	0.55 minimum b	
	$b=$	8 inches	
	$d=$	12 inches	because of relationship $d=1.5b$
	$h=$	14.5 inches	because of relationship $h= 2.5+d$

Recalculate with known values

W_1	$0.36*b$	0.24	
W_s	$(\gamma_c * b * h)/1000$	0.12 kip/feet	
W_d	$W_{dd} + W_s$	0.121 kip/feet	
W_u	$1.2W_d + 3W_B$	0.19	

A_s	$b*d*p$	1.73 inches ²	
		1.76 #6	Recommended Reinforcement

APPENDIX H: COLUMN DESIGN CALCULATIONS USING REINFORCED CONCRETE

Known Quantities		Units
f_y	60	ksi
E _{steel}	29,000	ksi
E _{concrete}	4,030	ksi
f_c	4	ksi
L	20	feet
γ_c	150	pcf
W _{dd}	0.015	kip/feet
W _L	0.06	kip/feet
W _S	0.055	kip/feet
cover	1.3	inches
ϵ_t	0.005	
ϵ_u	0.003	
ρ	0.03	
Φ	0.65	

Assumptions

$h =$ 12.00 inches Circular Column

RISA Data

P_b 0.4 kip MAX AXIAL LOAD
 M_u 3 kip-ft

Calculations

γ' $(h - 2 \cdot \text{cover})/h$ 0.78
 e M_u/P_b 90.00
 e/h e/h 7.50
 K_n from chart 0.22
 b $(P_b)/(\Phi \cdot f'_c \cdot K_n \cdot h)$ 0.06 inches

R_n from chart 0.14
 b $(P_b \cdot e)/(\Phi \cdot f'_c \cdot R_n \cdot h^2)$ 0.69 inches
 $b =$ 12.00 inches

A_s $\rho \cdot (h/2)^2 \cdot \pi$ 3.39 inches²
 3.6 #6 **Recommended Reinforcement**

APPENDIX I: STRESS MAPS USING THE ABS PLASTIC

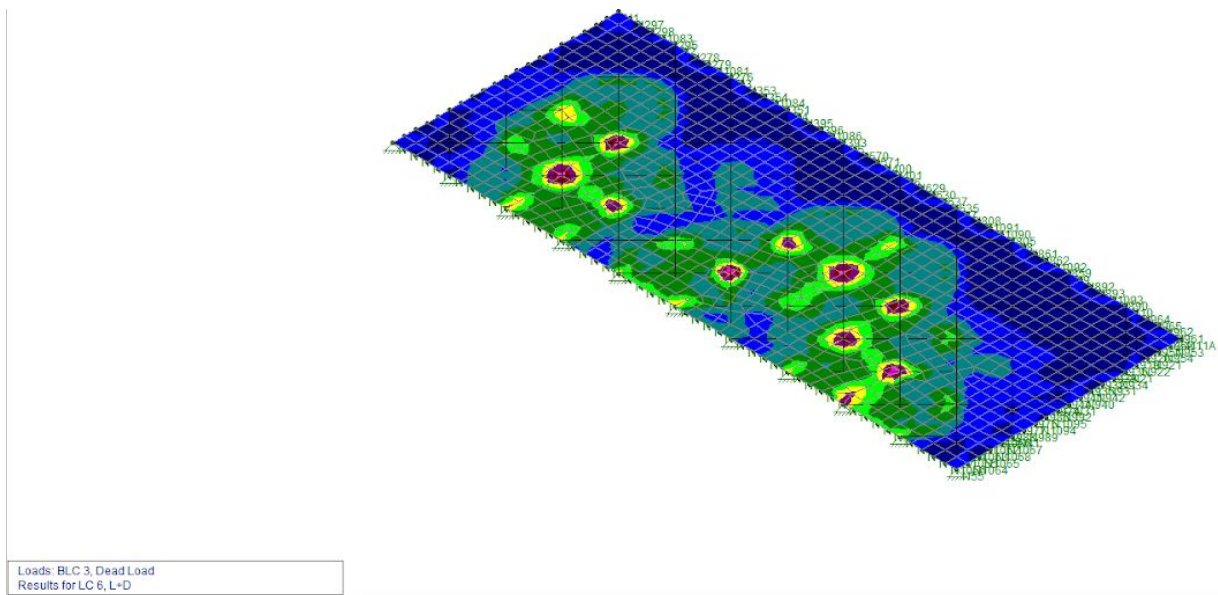
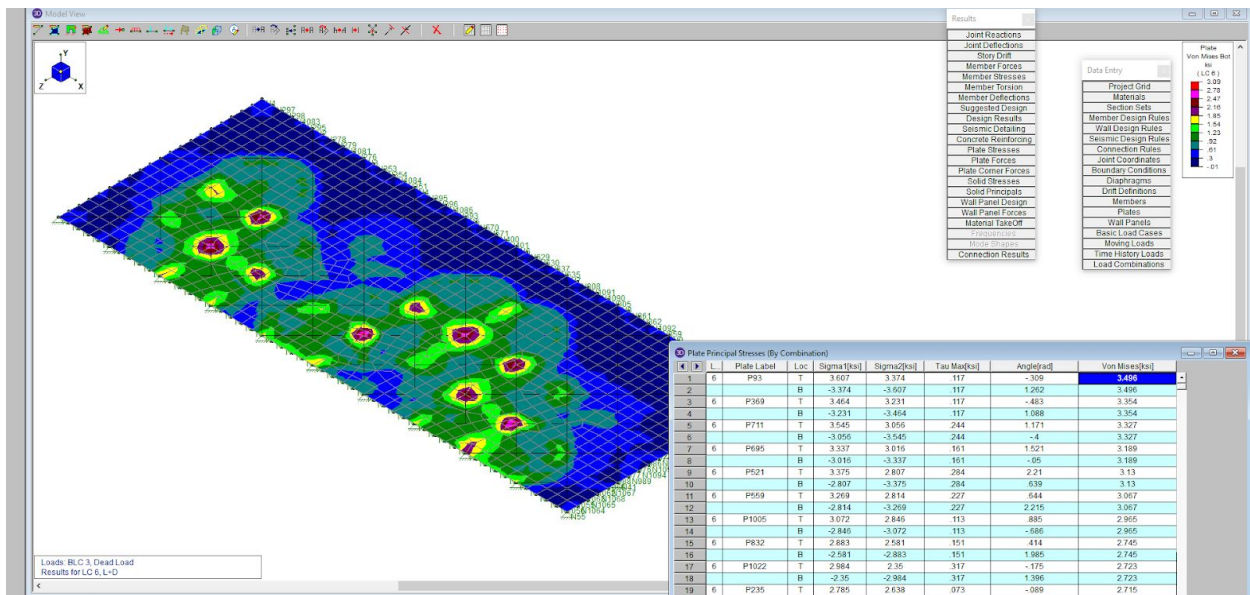
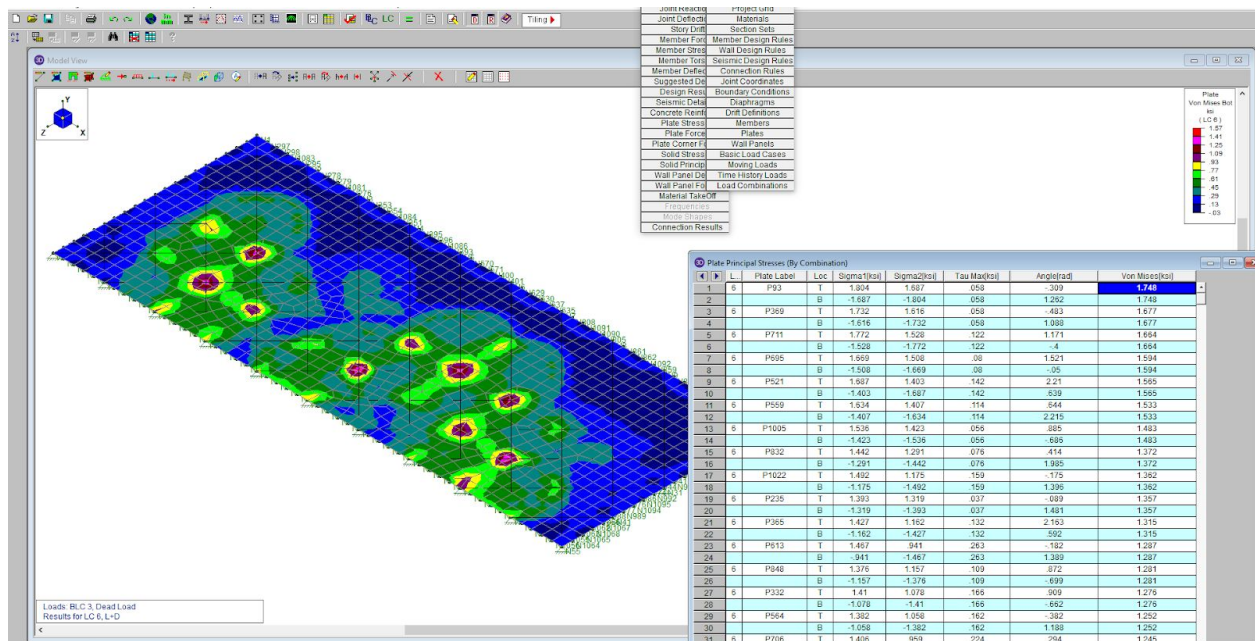


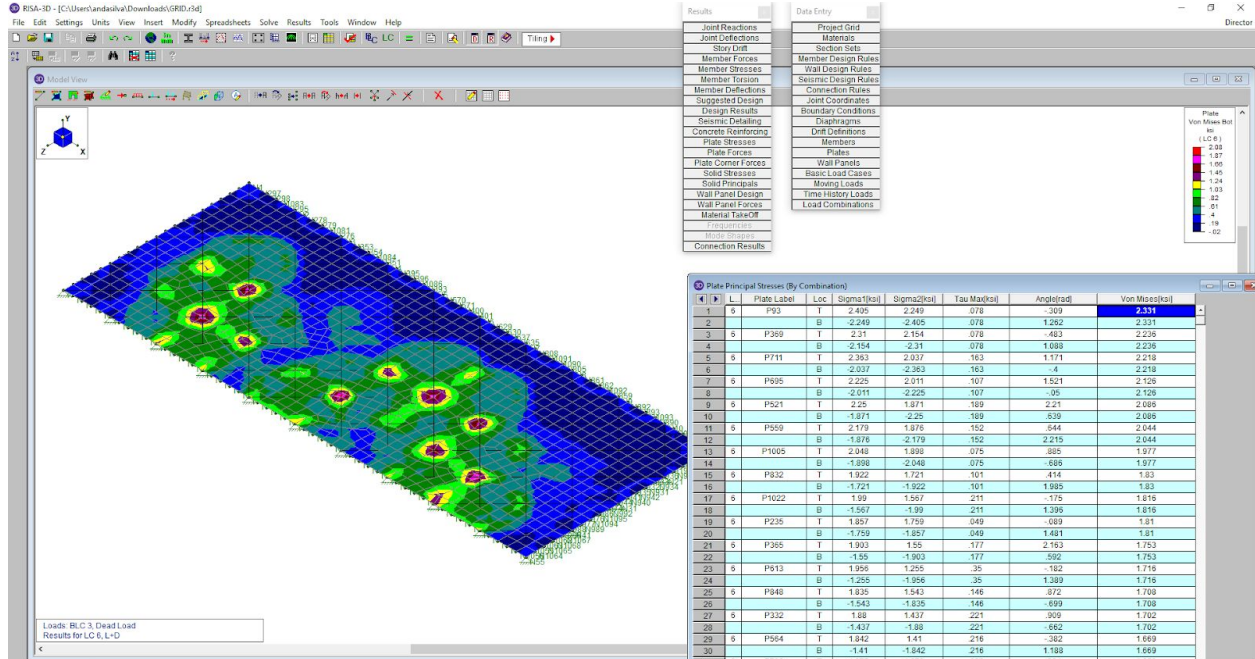
Figure I1: Stress map of ABS Plastic plate subjected to L+D Loading.



Thickness: 1 in
 ABS Strength: 9100 psi
 Factored Strength using 4: 9100/4
 Factored Strength: 2275
 2275 psi < 3496 psi
 Cannot use this thickness

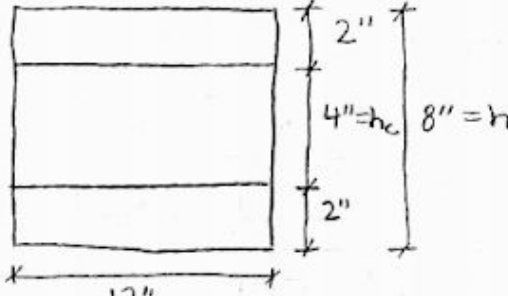


Thickness: 2 in
 ABS Strength: 9100 psi
 Factored Strength using 4: 9100/4
 Factored Strength: 2275
 2275 psi > 1748 psi
 Can use this thickness



Thickness: 1.50 in
 ABS Strength: 9100 psi
 Factored Strength using 4: 9100/4
 Factored Strength: 2275
 2275 psi < 2331 psi
 Cannot use this thickness

APPENDIX J: SLAB DESIGN CALCULATIONS USING SANDWICH STRUCTURED COMPOSITE



$M = 2.47 \text{ k-ft}$
 29.64 k-in
 $\frac{M}{\sqrt{L}} = \frac{29.64}{4} \text{ k-in}$
 $\frac{M}{L} = 7.41 \text{ k-in}$

$$I_1 = \frac{b}{12} (h^3 - h_c^3)$$

$$= \frac{12''}{12} (8'' - 4'')$$

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

$$I_2 = \frac{b}{12} (h_c^3)$$

$$= \frac{12''}{12} (4'')$$

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

$E_1 = 304,000 \text{ psi}$ $E_2 = 3,645,000 \text{ psi}$

$$E_1 I_1 + E_2 I_2$$

$$304,000 \text{ psi} (4 \text{ in}^4) + 3,645,000 \text{ psi} (4 \text{ in}^4) = 15,796 \text{ kip} \cdot \text{in}^2$$

$$\sigma_1(\text{max}) = \frac{M (h/2) (E_1)}{E_1 I_1 + E_2 I_2}$$

$$= \frac{7.41 \text{ kip-in} (8''/2) (304,000 \text{ psi})}{15,796 \text{ kip} \cdot \text{in}^2} = 570.43 \text{ psi}$$

$$\sigma_2(\text{max}) = \frac{7.41 \text{ kip-in} (4''/2) (3,645,000 \text{ psi})}{15,796 \text{ kip} \cdot \text{in}^2} = 3,419.8 \text{ psi}$$

$570.43 < 1748 \text{ psi}$ from RISA model ✓
 2" Thickness can be used

APPENDIX K: BEAM DESIGN CALCULATIONS USING REINFORCED CONCRETE WITH ALTERNATIVE SLAB

Known Quantities		Units
f_y	60	ksi
E _{steel}	29,000	ksi
E _{concrete}	4,030	ksi
f_c	4	ksi
L	20	feet
γ_c	150	pcf
W _{dd}	0.33	kip/feet
W _L	0.06	kip/feet
W _S	0.055	kip/feet
cover	0.25	inches
ϵ_t	0.005	
ϵ_u	0.003	
Φ	0.9	

Predictions

$b=$	0.83 ft	10 inches
$h=$	1.67 ft	20 inches

Calculations

W ₁	$0.36 \cdot b$	0.30
W _s	$(\gamma_c \cdot b \cdot h) / 1000$	0.21 kip/feet
W _d	$W_{dd} + W_s$	0.538 kip/feet
W _u	$1.2W_d + W_L + 0.5 W_S$	0.73 kip/feet
β_1	$0.85 - 0.05[(f_c - 4) / 1]$	0.85
P _{max}	$0.85 \cdot \beta_1 \cdot (f_c / f_y) \cdot (\epsilon_u / (\epsilon_u + \epsilon_t))$	0.0181
R _u	$(\Phi \cdot P_{max} \cdot f_y) \cdot (1 - 0.59 \cdot (P_{max} \cdot f_y / f_c))$	0.819

RISA Data

M _u	2.47 kip-ft
----------------	-------------

Sizing for Steel Reinforcements

bd^2	M_u/R_u	3.014186477	
	Assume $d=1.5b$	$bd^2 = 1.5b^3$	
b	$(bd^2/(1.5^2))^{\wedge}0.3$	0.97 minimum b	
	$b=$	8 inches	
	$d=$	12 inches	because of relationship $d=1.5b$
	$h=$	14.5 inches	because of relationship $h= 2.5+d$

Recalculate with known values

W_1	$0.36*b$	0.24	
W_s	$(\gamma_c * b * h)/1000$	0.12 kip/feet	
W_d	$W_{dd} + W_s$	0.121 kip/feet	
W_u	$1.2W_d + W_L + 0.5 W_S$	0.23	
		$0.58 > 0.23$	confirmed

A_s	$b*d*p$	1.73 in ²	
		1.76 #6	Recommended Reinforcement

APPENDIX L: GIRDER DESIGN CALCULATIONS USING REINFORCED CONCRETE WITH ALTERNATIVE SLAB

Known Quantities		Units	
f_y		60	ksi
E _{steel}		29,000	ksi
E _{concrete}		4,030	ksi
f_c		4	ksi
L		50	feet
γ_c		150	pcf
W _{dd}		0.015	kip/feet
WB		0.015	kip/feet
cover		0.25	inches
ϵ_t		0.005	
ϵ_u		0.003	
Φ		0.9	

Unit Weight of Beam

Assumptions

b=	0.83 ft	10 inches
h=	1.67 ft	20 inches

Calculations

W ₁	$0.36 \cdot b$	0.30
W _s	$(\gamma_c \cdot b \cdot h) / 1000$	0.21 kip/feet
W _d	W _{dd} + W _s	0.223 kip/feet
W _u	$1.2W_d + 3WB$	0.31 kip/feet
β_1	$0.85 - 0.05[(f_c - 4) / 1]$	0.85
P _{max}	$0.85 \cdot \beta_1 \cdot (f_c / f_y) \cdot (\epsilon_u / (\epsilon_u + \epsilon_t))$	0.0181
R _u	$(\Phi \cdot P_{max} \cdot f_y \cdot (1 - 0.59 \cdot (f_y / f_c)))$	0.819

Hand Calculations

M _u	0.375 kip-ft
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Sizing for Steel Reinforcements

bd^2	M _u /R _u	0.4576194043	
	Assume $d = 1.5b$	$bd^2 = 1.5b^3$	
b	$(bd^2 / (1.5^2))^{\wedge} 0.3$	0.55 minimum b	
	b=	8 inches	
	d=	12 inches	because of relationship $d = 1.5b$
	h=	14.5 inches	because of relationship $h = 2.5 + d$

Recalculate with known values

W ₁	$0.36 \cdot b$	0.24
W _s	$(\gamma_c \cdot b \cdot h) / 1000$	0.12 kip/feet
W _d	W _{dd} + W _s	0.121 kip/feet
W _u	$1.2W_d + 3WB$	0.19

A _s	$b \cdot d \cdot p$	1.73 inches ²	
		1.76 #4#	Recommended Reinforcement

APPENDIX M: COLUMN DESIGN CALCULATIONS USING REINFORCED CONCRETE WITH ALTERNATIVE SLAB

Known Quantities		Units
f_y	60	ksi
E _{steel}	29,000	ksi
E _{concrete}	4,030	ksi
f_c	4	ksi
L	20	feet
γ_c	150	pcf
W _{dd}	0.015	kip/feet
W _L	0.06	kip/feet
W _S	0.055	kip/feet
cover	1.3	inches
ϵ_t	0.005	
ϵ_u	0.003	
ρ	0.03	
Φ	0.65	

Assumptions

$h =$ 12.00 inches Circular Column

RISA Data

P_b 6 kip MAX AXIAL LOAD
 M_u 2.47 kip-ft

Calculations

γ $(h - 2 \cdot \text{cover})/h$ 0.78
 e M_u/P_b 4.94
 e/h e/h 0.41
 K_n from chart 0.4
 b $(P_b)/(\Phi \cdot f_c \cdot K_n \cdot h)$ 0.48 inches

R_n from chart 0.18
 b $(P_b \cdot e)/(\Phi \cdot f_c \cdot R_n \cdot h)$ 0.44 inches
 $b =$ 8.00 inches

A_s $\rho \cdot (h/2)^2 \cdot \pi$ 1.51 inches²
1.76 #6 Recommended Reinforcement

