To: Mukarim Syed, Plant Manager, TPAC and Gabriella Wilson, Head Engineer, TPAC

From: The Reinforcers: Nicole Neilson, Natalie Noroian, Elena Mae Reyes, and Jacquolyn Crowley

Date: September 23, 2020

Re: Final Proposal

Dear Mukarim and Gabriella,

Attached below is the Reinforcer's final proposal. Detailed in the final proposal is the project understanding, scope of services/research plan, schedule, staffing plan, and cost of engineering services for the PCI Big Beam project. If you have any questions about the document, feel free to contact Jacquolyn Crowley at jkc265@nau.edu.

Thank you,

The Reinforcers

PCI Big Beam Competition

Company Name: The Reinforcers

Team Members: Elena Mae Reyes, Jacquolyn Crowley, Natalie Noroian, Nicole Neilson

DRAFT #4

11/23/2020

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List of Abbreviations

PCI: Precast/Prestressed Concrete Institute

ACI: American Concrete Institute

ASTM: American Society for Testing and Materials

UHPC: Ultra High-Performance Concrete

CAD: Computer-Aided Design

NAU: Northern Arizona University

CEIAS: College of Engineering, Informatics, and Applied Sciences

CENE: Civil and Environmental Engineering

TA: Technical Advisor

GI: Grading Instructor

FE: Fundamentals Exam

PE: Professional Engineer

EIT: Engineer in Training

COVID: Coronavirus Disease

1.0 Project Understanding

1.1 Project Purpose

The purpose of this project is to challenge individuals to create an innovative design of a precast/prestressed concrete beam for the PCI Big Beam Competition in Spring 2021. The problem that must be solved is to design a functional precast/prestressed concrete beam that can carry a total load between 32 and 40 kips without cracking under the total applied service load of 20 kips.

1.2 Project Background

The Precast/Prestressed Concrete Institute (PCI) was founded in 1954 as a technical institute and trade association for the precast/prestressed concrete structures industry. Each year, the institution invites students around the world to participate in the PCI Big Beam Competition where their entries will be judged based on the following criteria:

1. Design accuracy
2. Lowest cost
3. Lowest weight
4. Largest measured deflection at maximum total applied load
5. Most accurate prediction
6. Report quality
7. Practicality, innovation, and conformance with code

Northern Arizona University's capstone teams have been participating in the competition since 2013. In 2018, the capstone team participating in the competition that year received recognition for the best report, and in 2017, that year's capstone team achieved sixth place.

The Reinforcers will utilize and request sponsorship from TPAC (an Encon Company located in Phoenix, Arizona) as the PCI Producer Member. For the 2020-2021 PCI Big Beam Competition, each team must construct a precast/prestressed concrete beam following the 2020-2021 official rules. Precast concrete is concrete that is cast in a controlled environment, away from the project site. Prestressed concrete is concrete that primarily contains steel in tension, which increases the load-carrying capacity, allows for greater spans, and reduces cracks in the concrete.

The PCI Big Beam Competition specifies that the beam must span 20 feet and be designed to support its dead load, along with two applied service live loads. Since this 20-foot specification is defined between the center-to-center of bearing, the construction of the beam will likely be extended to include between 2-3 feet of concrete on both ends of the beam. The Reinforcers have decided to utilize the inch-pound version of units through all design and construction of the concrete beam. Official rules for the design competition define the testing methods and specifications for each component of the beam. Additionally, all aspects of the beam are required to meet the provisions of ACI 318-19 for a precast/prestressed beam, interior exposure. A cost analysis of the beam, based on actual strength, will also be completed for judging with the competition.

1.3 Technical Considerations

To complete the design and construction of the precast/prestressed concrete beam, structural analysis, concrete mix design analysis and design techniques should be implemented as technical considerations.

1.3.1 Structural Analysis

The structural analysis will determine the highest load capacity that the concrete beam can withstand. Following the 2020-2021 PCI Beam Competition rules, a total of three loads must be applied to the beam: the dead load, and two applied service (unfactored) live loads of 10 kip each. The live load weights can be found in Section 5.3 in the ACI 318-19 Code. To comply with the PCI Competition design accuracy, the beam must carry at least a total factored live load of 32 kip, must not have a total peak applied load of more than 40 kip, and shall not crack under the total applied service load of 20 kip. The total applied load must be calculated as the sum of the two applied point loads.

Analysis must be conducted to determine the amount of displacement in the beam when load is applied at the midspan, and a deflection graph must be presented. The maximum total applied load, total applied cracking load, and midspan deflection at maximum total applied load must all be calculated. The beam will be loaded using two unsymmetrical point loads, 3 feet apart, having one-point load 6 feet from a support and the other 11 feet from the opposite support. This loading configuration can be found in Figure 1 below.

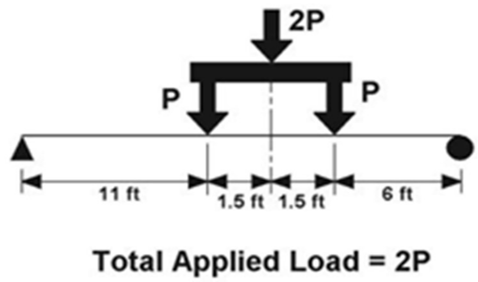


Figure 1. Load Configuration [1]

Analysis must also be conducted to determine the 28-day compressive and tensile strengths of the beam. The compressive strength must be in accordance with ASTM C39 and the tensile strength must be in accordance with ASTM C78 or C496.

1.3.2 Concrete Mix Design Analysis

The beam must be made primarily of concrete which includes cement, coarse aggregates, fine aggregates, and water. Other materials such as pozzolans, fibers, lightweight aggregates, admixtures, and Ultra-High-Performance Concrete (UHPC) have been permitted by the PCI Beam Competition. Concrete properties such as: unit weight of concrete, slump, air content, and tensile strength must be recorded. Tpac will provide a selection of concrete mix designs which will be analyzed and assessed by the team in order to determine the best mix. Testing the concrete mix designs will be done using concrete cylinder testing.

Aggregates shall meet ASTM C33 or ASTM C330 (Lightweight Aggregates). Chemical Admixtures shall meet ASTM specifications D98, C494, C260, or C1017. Mineral Admixtures shall meet indicated ASTM specifications and be silica fume (C1240), class C or F fly ash

(C618), class N metakaolin (C618), or Grade 100 or 120 ground granulated blast-furnace slag (C989). Portland Cement conforms to ASTM C150.

1.3.3 Design Techniques

The most important technical aspect of the design are the techniques of precast/prestressed beams. The design must meet the provisions of ACI 318-19 precast/prestressed beam interior exposure. The goal of these techniques is for the beam to be able to withstand the maximum amount of load it will be subject to. The beam must be designed to resist load primarily through flexure, bending or curving. Bearing pads and/or bearing plates may be used at the beam supports and/or under the loading. The pads or plates must not exceed 6 inches in length along the midspan.

Efficient beam design must consider beam width, height, cross-sectional area, and length. According to the PCI Competition rules: a simply supported span of 20 feet from center to center of bearing must be designed for, and the cross-sectional area is open to any, but the top surface must be flat and horizontal.

Reinforcement in the beam must be completely embedded in the beam and meet applicable spacing cover requirements as stated by ACI 318-19. All reinforcing steel must meet one of the following ASTM specifications: A615, A616, A706, A775, A934, A185, A497, A184, A884, A416, A886, A910, A722, or A1035. Longitudinal tension reinforcing shall be pretensioned and/or post-tensioned. Bar or mesh may be used for shear reinforcement within the beam. Non prestressed or prestressed top steel is allowed within the beam design.

1.4 Potential Challenges

Potential challenges and constraints that may influence the project include cost, weight of concrete, and time. The cost of the beam that will be designed is an important element of the project because the budget of the team will affect what materials and resources the team may use. Cost may be calculated with the guidance on the final page of the PCI Big Beam Competition official rules. Additionally, the cost of the beam is a determining factor in whether or not the team will be a strong competitor in the PCI Big Beam Competition. The constraint of cost will be overcome through having a sponsoring body cover costs and minimizing costs through performing cost analysis before carrying out the project.

Another constraint to be considered is the weight of concrete. Similar to cost, points will be awarded to the team based on the weight of the beam. The team will perform material and structural analysis before construction to minimize the weight of the beam. Lightweight aggregates will also be strongly considered to minimize the weight of the concrete used in the beam. Lastly, the team is challenged with completing the project within a time frame between August 15, 2020 and July 15, 2021. With a detailed schedule and commitment to team deadlines, the team can create a beam within the time restrictions given.

1.5 Stakeholders

Dr. Robin Tuchscherer is the technical advisor for the team, and he will be given credit for all of his contributions to the PCI Big Beam Competition submissions. If the team does not perform well, Dr. Tuchscherer's reputation could be negatively impacted, making him a stakeholder. The team will be representing NAU in the competition, which reflects onto the university and its ability to educate their students. TPAC is fabricating the beam for the competition and their name will be associated with the team's submission. TPAC also sponsors the student team and constructs the beam without cost to the university, using their resources; therefore, they are a stakeholder in the project. PCI created the competition and is taking their time to judge the entries. They also award significant cash prizes and can gain attention from this competition.

2.0 Scope of Services/Research Plan

2.1 Task 1: Prestressed Design

This task includes the team's introduction to information regarding prestressed design in reinforced beams. Dr. Tuscherer will be teaching the team about prestressed design and analysis. The approximate time frame for this task is about 4 weeks during the Fall 2020 semester, consisting of weekly meetings on Friday afternoons.

2.1.1 Task 1.1: Introduction to Prestressed Design

Dr. Tuscherer will be informing the team about the basics of prestressed design for concrete beams. These sessions will be accomplished through Zoom and recorded for reference. The team will alternate between note takers on the prestressed design for future use in analysis.

2.1.2 Task 1.2: Analysis Methodology

Analysis methodology that will be used for the structural analysis portion of the project will be taught during this time. The sessions will be accomplished via Zoom and recorded for reference. Analysis methodology will be shown through MathCAD and supported by excel spreadsheets.

2.2 Task 2: Concrete Mix Design Analysis

Concrete mix design analysis entails the essential items important to selecting the mix design for the final PCI beam. This major task includes concrete mix research, concrete mix testing, and the selection of the concrete mix that will be used for the PCI beam. Reports for the concrete mix testing will be provided.

2.2.1 Task 2.1: Concrete Mix Research

Concrete mix research includes identifying what items should be considered in the concrete mix in compliance with our client's material availability and the PCI Big Beam contest rules for preliminary testing. These items to consider would include aggregates and chemical admixtures.

2.2.2 Task 2.2: Concrete Mix Testing

The team will complete concrete mix testing on 20 cylinders of a lightweight concrete mix and 20 cylinders of a heavyweight concrete mix provided by Tpac. A 28-day tension and compression test will be completed following ASTM C496 guidelines for the tension test and ASTM C39 guidelines for the compression test.

2.2.3 Task 2.3: Selection of Concrete Mix

After testing concrete specimens, the team will determine the best concrete mix for the PCI beam design through a decision matrix with all of the mixes considered. The criteria for the decision matrix will be determined by the judging criteria for the PCI Big Beam Competition.

2.3 Task 3: Beam Design Structural Analysis

Task 3 consists of the major portion of the PCI Big Beam Competition, the structural analysis. The team's structural analysis for the beam will be completed by the end of January of 2021 to stay on track with construction deadlines. Many subtasks will follow to ensure that every point of the analysis is completed as a team.

2.3.1 Task 3.1: Create Different Beam Designs

As a team, eight to ten different beam designs will be created to develop a suite of potential ideas for the final beam design. Each design will have slight changes within each of the subtasks below: cross-section, stirrups, reinforcement, and dimensions. Changing the variables of each design will be an important step to evaluating the performance of each beam, to help decide on the best design.

2.3.1.1 Task 3.1.1: Create Cross-Sections for the Beam

The team will design eight to ten different cross-section with various dimensions. Cross sections will be created on Excel to compare the effects of each dimension. This will assist in determining the final beam design as well as what dimensions need to be altered.

2.3.1.1.1 Task 3.1.1.1: Determine Reinforcement Configuration and Rebar Size e

Adequate reinforcement design will be important for the final beam design in order to increase the overall strength. Reinforcement configuration and rebar size will also be based on ACI 318-19 code, following Chapter 9: "Beams" and Chapter 25: "Reinforcement Details". This task will also depend on what Tpac has available.

2.3.1.1.2 Task 3.1.1.2: Select Dimensions of the Beam

Dimensions of the beam will be determined based on the cross section and the placement and size of the chosen rebar. The ACI code requires certain spacing between rebar and cover of the concrete. This task will utilize the two previous tasks to select dimensions that meet the code and will perform well.

2.3.1.2 Task 3.1.2: Flexural Design

A complete flexural design for each of the 10 beams will be performed by the team. According to the PCI Big Beam Competition rules, the beam must resist load primarily through flexure. The team will use their knowledge from the reinforced concrete design course to complete the analysis and determine the nominal flexural capacity using the equivalent stress block.

2.3.1.3 Task 3.1.3: Shear Design

Adequate stirrup type and material will be chosen to help the beam resist shear at the beams end supports. Stirrup design will be based on ACI 318-19 code, following Chapter 9: “Beams” and Chapter 25: “Reinforcement Details”. The different types and material of the stirrups will be based on what Tpac has available for construction.

2.3.2 Task 3.2: Final Beam Selection

The final beam design used for the competition will be selected using a decision matrix. Each beam design will be scored based on the PCI Competition rules. The objective is to select the beam that is the cheapest, lightest, and has the highest deflection. All of the beams will be compared in an excel file where all of the characteristics can be evaluated. The highest scoring beam will be used as the final design.

2.3.3 Task 3.3: Refined Predictions

After deciding on a final beam design to proceed with, the team will model and analyze the beam using RESPONSE software to calculate/estimate losses for a more refined prediction. The team will also calculate the beam deflections using EXCEL software. This task will be completed before the team creates official shop drawings.

2.4 Task 4: Shop Drawings

The team will design shop drawings, using AutoCAD software, for Tpac to use in the fabrication of the prestressed beam. The official drawings are essential to the project because they will represent the final beam design chosen by the team. They will also guide Tpac in creating the mold for the beam. Therefore, the drawings will need to be clear and detailed, and the team will be open to feedback from Tpac. The shop drawings will be completed and sent to Tpac around mid-February: four weeks before the fabrication.

2.5 Task 5: Oversee Concrete Pour on Fabrication Day

The fabrication of the beam will be done by Tpac at their Phoenix location during mid-March of 2021. The team will travel to Phoenix for the fabrication day to ensure that all stirrups and reinforcing are located correctly per the shop drawings before the final concrete pour. As engineers, it is the team's job to ensure that everything is done correctly the first time and that the team is present for immediate response.

2.6 Task 6: Testing the Beam

The final PCI beam will be tested around mid-April of 2021. The testing will be performed as instructed by the contest rules. The contest rules must be followed for the contest submission to be accepted.

2.6.1 Task 6.1: Equipment Set-Up

Ensure the beam is set up per contest rules. More details on the specified beam set up are located on page 5 of the PCI Big Beam Competition rules. The beam must be tested as a simply supported span of 20 ft, center-to-center of bearing. If the beam is not set up appropriately, then the team's submission will not be accepted.

2.6.2 Task 6.2: Final Predictions

Before loading the beam, the team will make final predictions for record based on the provided test cylinders from Tpac that were poured with the beam. This testing will be completed the day before testing day to ensure that the results are as accurate as can be. The team will verify curing using the test cylinders to ensure it has reached the 28-day strength specified. The test values will be inputted into RESPONSE software to make the final predictions.

2.6.3 Task 6.3: Load Beam Until Failure

The beam will be loaded until failure. Team members will record a video of the test as required by the contest submission. The loads that will be applied are specified by the PCI Big Beam Competition rules.

2.6.4 Task 6.4: Measure the Beam Deflection

The beam deflection will be determined through a load/midspan deflection graph from the loading test. The load/midspan deflection graph must show a peak load as required by the contest rules.

2.7 Task 7: Impacts

Throughout the project the impacts will be evaluated. This is essential to understanding any positive and negative outcomes of the project. This will be done by assessing social, environmental, and economic impacts.

2.7.1 Task 7.1: Social Impacts

Social impacts will be evaluated by assessing the performance of the team throughout the project. This is important because the team's performance can affect NAUs relationship with Tpac.

2.7.2 Task 7.2: Environmental Impacts

Environmental impacts will be evaluated by assessing the amount of pollution produced during the production of cement. This is important for understanding the impacts of concrete production on the environment.

2.7.3 Task 7.3: Economic Impacts

Economic impacts will be evaluated by assessing the cost of the beam for Tpac. The cost of the beam is required for submission with the PCI Big Beam Competition. The contest also has cash prizes that will be considered for constructing and analyzing the beam.

2.8 Task 8: Deliverables

This task includes the team's deliverables that will be required throughout the project. The following subtasks exist to keep the team on task and to show the progress that is made.

2.8.1 Task 8.1: 30% Submission Report & Presentation

The 30% submission requirements will be determined by the milestones, and their requirements, and include the submission of a report and presentation.

2.8.2 Task 8.2: 60% Submission Report & Presentation

The 60% submission requirements will be determined by the milestones, and their requirements, and include the submission of a report and presentation.

2.8.3 Task 8.3: 90% Submission Report & Draft Website

The 90% submission requirements will be determined by the milestones, and their requirements, and include the submission of a report and presentation.

2.8.4 Task 8.4: Video of Testing

A video must be provided for the testing of the beam, showing the highlights of the test and the failure of the beam for verification purposes. This deliverable is required for submission with the PCI Big Beam Competition.

2.8.5 Task 8.5: Website

A website will be created by the team using Bootstrap or Dreamweaver and published to the CEIAS server. The website will provide information about the team, client, technical advisor, and the project.

2.8.6 Task 8.6: Final Report for CENE 486 and the PCI Big Beam Competition

A final report on the project will be submitted at the end of the Spring 2021 semester, even though the PCI Big Beam Competition does not require submission until July 15th, 2020. This report will describe the entire project and what was accomplished throughout Fall 2020 and Spring 2021. One report will be completed and submitted for both CENE 486 and the PCI Big Beam Competition, with modifications made to each report following their respective guidelines. The PCI Big Beam Competition requires a cost analysis, estimated by following the guidance of the table given in Page 7 of the PCI Big Beam Competition requirements. Additional requirements for the PCI Big Beam Competition report is provided on Page 2 of the PCI Big Beam Competition requirement document.

2.8.7 Task 8.7: Final Presentation

The team will present their work done for the project at the end of the Spring 2021 semester. The presentation will be created on PowerPoint.

2.9 Task 9: Project Management

Each member of the team will trade off being the project manager to ensure everyone contributes an equal amount and gains the same skills. The project manager will be responsible for keeping the team and the project on task. Each member of the team will also keep each other on task and hold each other accountable to ensure professional and complete submissions.

2.9.1 Task 9.1: Meetings (Team, Client, TA, and GI)

The project manager is responsible for organizing meetings between the team, including the client, technical advisor, and the grading instructor, as necessary. It is important that meetings run smoothly and are efficient at covering important tasks and goals moving forward.

2.9.2 Task 9.2: Schedule Management

The rotating project manager will also be responsible for making sure that all deliverable deadlines are met as a team. This entails assigning tasks to all team members, giving dates for when tasks should be completed, and giving feedback to ensure quality work.

2.9.3 Task 9.3: Resource Management

The rotating resource manager will be responsible for ensuring that all resources needed for the progression of the project are available. This includes, analysis software, analysis knowledge resources, design software for shop drawings, concrete cylinders for testing, and other fabrication resources needed from Tpac.

2.9.4 Task 9.4: Tpac Coordination

2.9.4.1 Task 9.4.1: Obtaining Concrete Mix Data

The team will coordinate with Tpac to obtain the air content, slump, and measured unit weight of their lightweight and heavyweight concrete mixes. This information is necessary to obtain in order to make accurate predictions for failure.

2.9.4.2 Task 9.4.2: Obtaining Test Cylinders

The team will need to coordinate with Tpac to arrange receiving concrete cylinders for testing during October and September 2020. The team will test a total of 20 lightweight concrete cylinders, and 20 normal weight concrete cylinders for a total of 40 cylinders. The team will coordinate this task through email with Tpac.

2.9.4.3 Task 9.4.3: Beam Fabrication/Team Travel to Tpac Location

The team will need to coordinate with Tpac by providing clear shop drawings to follow for the fabrication, as well as a deadline to complete fabrication. Coordination will also be needed to arrange the team traveling to Tpac's Phoenix location for fabrication day. The team will complete this task by providing shop drawings early to allow for revisions before fabrication day, and communicating over email to arrange a fabrication day.

2.10 Exclusions

The PCI Big Beam Competition requires that the beam be constructed and tested by the team; therefore, there are not many exclusions to the team's design. The following exclusions to the project are provided below.

2.10.1: Create Concrete Test Specimens

For the initial concrete testing done by the team which will determine which mix design will be used for the final design, testing cylinders will be created by Tpac. Tpac will provide 20 cylinders of their lightweight mix, and 20 cylinders of their normal weight mix.

2.10.2: Beam Fabrication

An exclusion to the project is that Tpac will be completing the entire construction of the concrete form, configuring the reinforcement in the beam, and pouring the concrete into the mold. The team will oversee this fabrication process to ensure the beam design matches the shop drawings.

2.10.3: Transporting the Beam/Test Cylinders to Flagstaff

Although it is not listed as a major task, transporting the fabricated beam to Flagstaff is an exclusion that Tpac will oversee with dates worked out between Tpac, NAU, and the team. Tpac will also provide test specimens for the team to use when deciding on a concrete mix and with the beam when they transport it to Flagstaff. The specimens that will come with the beam will be used to verify curing before the team tests the beam to failure.

3.0 Schedule

The schedule is outlined on a Gantt chart with the total duration spanning from September 2020 to May 2021. The total duration of the project is predicted to be 213 days. The major tasks within the schedule include the selection of concrete mix, beam design structural analysis, shop drawings, fabrication, testing of the beam, and the deliverables for the 486 course and the PCI Big Beam Competition. The selection of the concrete mix is predicted to be completed by November 20, 2020. In order to accomplish this task on time, the team is working with Tpac to receive concrete cylinders to run multiple tests to evaluate performance and decide on the best mix. The beam design structural analysis task is predicted to be completed by January 31, 2021.

The team will accomplish this task by completing preliminary tasks before the end of the Fall semester in 2020 and selecting the best and final design near the beginning of the Spring semester in 2021. The shop drawings, fabrication, and testing of the beam are all predicted to be completed by March 15, 2021. Each of these tasks will build off of each other and, in order to stay on schedule, will be completed by the expected completion date. Each of the course deliverables for 486 are clearly outlined in the Gantt chart and will be met by the team accordingly. The PCI Big Beam Competition deliverable to submit a video of the beam testing and a final report is predicted for completion by April 16, 2021.

3.1 Critical Path

The critical path for this project begins during prestressed design and includes concrete mix design analysis, beam design structural analysis, shop drawings, overseeing the concrete pour on fabrication day, testing the beam, the team's 90% submission, website, and the final report for CENE 486C and the PCI Big Beam Competition. Each of these tasks are dependent on each other to proceed with the project because if there is a delay on any of these tasks then the subsequent tasks will need to be pushed back. Therefore, it is essential that these tasks are completed on time. To ensure that the team finishes these tasks by their end date weekly meetings will be conducted to keep the team on track and to discuss the schedule along with what needs to be completed by the end of the week. The team will also work closely with Tpac to ensure they receive the shop drawing on time so they can create the beam.

4.0 Staffing Plan

4.1 Positions

To complete the design, construction, and testing of the prestressed/precast concrete beam, the following staff positions, along with their associated abbreviations, were determined as follows:

1. Senior Level Engineer - SENG
2. Project Manager - PM
3. Engineer in Training - EIT
4. Lab Technician - LBT
5. Drafter/CAD Operator - DRF

These staff positions would likely exist for this project outside an educational environment and each position would have their own tasks to complete. However, each team member of The Reinforcers will be responsible for fulfilling all of the positions identified above during the project.

4.2 Qualifications for Personnel

The following staff titles and positions along with their qualifications can be found below. It is important that the personnel meet all of the qualifications listed.

4.2.1 Senior Level Engineer

A senior level engineer needs to have passed the FE and PE and have acquired a bachelor's degree in civil engineering. They must have also completed four years of training as an EIT and obtained their professional engineering license. At least eight years of experience as a practicing engineer is required.

4.2.2 Project Manager

A project manager must have at least five years of experience working as an engineer in the field of interest. Passing the FE is required and professional engineering certification is preferred.

4.2.3 Engineer in Training

An engineer in training needs to have passed the FE and obtained their EIT certification. They must also have a bachelor's degree in engineering.

4.2.4 Lab Technician

A lab technician must have a highschool diploma and at least two years of previous experience working in the field of interest.

4.2.5 Drafter/CAD Operator

A drafter must have completed an associate's degree pertaining to drafting or have acquired certification from the American Design Drafting Association. They must also be proficient with AutoCAD and have attention to detail. Two-years experience is preferred.

4.3 Design Project Hours

The table found in Appendix B is a breakdown of the hours that will be spent for each task outlined in the scope section of this proposal. These hours were determined by how long each task is projected to be completed. The drafter is expected to spend the second to least amount of time on the project because they will only be present when putting together shop drawings, overseeing the concrete pour, and while putting the deliverables together. Therefore, they are expected to spend approximately 90 hours on the project. The senior level engineer has more experience in the field, and mainly needs to make important decisions on the project and provide guidance to the team. They also will delegate tasks to the engineer in training so they can gain experience. The engineer in training is expected to spend 250 hours on the project, but the senior level engineer is expected to spend 98 hours. The lab technician will not be present during the beam design structural analysis but will complete the concrete and lab testing which is why they are projected to spend about 69 hours on the project.

5.0 Cost of Engineering Services

The total cost of engineering services includes all personnel cost, travel cost, supply cost, and subcontracting cost. The personnel cost is based on the total hours and billing rate each position will be working throughout the project. The travel cost accounts for the transportation costs to get project tasks accomplished. The supply cost is determined by the lab equipment and software needed to perform analysis on concrete in addition to creating the shop drawings of the design of the beam. The subcontracting cost is from the work done by Tpac to produce several vital pieces to develop the PCI beam. Detailed below is how each cost is determined and justified.

5.1 Personnel Cost

The personnel hours are based on the billing rate for each position and the total hours they will be working on this project. The total cost of personnel is determined to be $70,310. The billing hourly rate for the senior engineer, project manager, engineer in training, lab technician, and drafter is $200, $160, $90, $50, and $60 respectively. These billing rates were determined by roughly basing the values off of the billing rates for KPFF Consulting Engineers located in Irvine, California and modifying them for lowered cost of living in Flagstaff, AZ. The total cost was determined by multiplying the hourly rates for each position by the number of hours each position will be working for the project. The personnel costs breakdown can be found in Table 1 below.

Table 1. Breakdown of Personnel Cost

Personnel Breakdown			
Classification	Hours	Rate, $/hr	Total Cost
SENG	98	$200.00	$19,600.00
PM	121	$160.00	$19,360.00
EIT	250	$90.00	$22,500.00
LBT	69	$50.00	$3,450.00
DRF	90	$60.00	$5,400.00
Total Personnel	628		$70,310.00

5.2 Travel/Transportation Cost

Travel costs for this project will include the necessary travel and transportation to the Tpac facilities in Phoenix, Arizona from Northern Arizona University in Flagstaff, Arizona. The team will need to take two trips to the Tpac facilities: once for collecting the concrete cylinders used to determine the preferred mix offered by Tpac and a second time to supervise the pouring of the concrete for the final beam. Tpac facilities are located approximately 143 miles from NAU, resulting in a total of 572 miles driven for each vehicle. To abide by social distancing requirements for COVID-19, two vehicles will be taken down to Phoenix for both trips. Northern Arizona University Transportation Services has a reimbursement per mile of 44.5 cents for the personal vehicles that will be driven for the trips, resulting in a total cost of $509.08 that will be reimbursed. Van rentals, lodging, or flights will not be necessary for the travel required for this project. The travel costs breakdown can be found in Table 2 below.

Table 2. Breakdown of Travel Cost

Travel Breakdown				
Driving Mileage				
Number of Vehicles	Total Mileage	Reimbursement per Mile (cents)	Total Reimbursement (cents)	Total Reimbursement (dollars)
2	572	44.5	50908	$509.08
Note: Two personal vehicles will be used as transportation to Phoenix				
Note: One trip will be made to pick up test cylinders and another will be made for watching the concrete pour				

5.3 Supply Cost

Supply costs for this project will include lab rental for the testing of the beam and the cylinders. Renting a lab at NAU for a day costs $100. The team will need to rent labs for a total of four days resulting in a cost of $400.00. One day will be used during November to complete the team's concrete mix testing task. The NAU computer lab will also need to be used during February to complete the drafting of the beam cross-section. Once the beam along with its test cylinders are shipped to Flagstaff in April, the team will need to rent a lab for two days to test the cylinders and then the beam. The supplies costs breakdown can be found in Table 3 below.

Table 3. Breakdown of Supply Cost

Supplies Breakdown		
Lab Rental		
Number of Days	Cost per Day	Total Cost
4	$100.00	$400.00
Note: A day will be used in the NAU computer lab for drafting the beam cross-section		
Note: One day will be used for cylinder testing to determine the best mix		
Note: Another day will be used for cylinder testing to check if the 28-day strength of the beam is achieved		
Note: The last day will be used for testing of the prestressed beam		

5.4 Subcontract Cost

Subcontract costs for this project include the costs of the test cylinders, the beam, labor, and delivery of the beam. The cost per cylinder is $5.00. The team will need 40 cylinders for the concrete mix testing and three cylinders to ensure the 28-day strength of the beam is reached resulting in a cost of $215.00. The concrete needed for the beam is estimated to be $200.00 and the cost of the steel is estimated to be $450.00 resulting in a total cost of $650.00. A total of 10 workers will be needed to construct the beam with a pay rate of $50.00 per hour resulting in labor costs of $20,000.00. Delivering the beam to Flagstaff is a 286-mile round trip. The cost per mile is $1.00 resulting in a total cost of $286.00. The subcontract costs breakdown can be found in Table 4 below.

Table 4. Breakdown of Subcontract Costs

Subcontract Breakdown		
Concrete Test Cylinders		
Number of Test Cylinders	Cost per Cylinder	Total Cost
43	$5.00	$215.00
Note: 20 cylinders will be used for testing the lightweight concrete mix		
Note: 20 cylinders will be used for testing the heavyweight concrete mix		
Note: 3 cylinders will be used for confirming the strength of the beam		
Prestressed/Precast Concrete Beam		
Cost of Concrete	Cost of Steel	Total Cost
$200.00	$450.00	$650.00
Labor		
Number of Workers	Rate, $/hr	Total Cost
10	$50.00	$20,000.00
Note: A five-day estimate was used for the time to construct the beam form, pour the beam, and delivery.		
Delivery of Beam to Flagstaff		
Total Mileage	Cost per Mile (Dollars)	Total Cost
286	$1.00	$286.00

5.5 Total Project Costs

The total project costs consider all of the costs discussed above. A summary of the final cost of engineering services can be found in Table 5 below.

Table 5. Summary of Cost of Engineering Services

	Classification	Hours	Rate, $/hr	Total Cost
1.0 Personnel	SENG	98	$200.00	$19,600.00
	PM	121	$160.00	$19,360.00
	EIT	250	$90.00	$22,500.00
	LBT	69	$50.00	$3,450.00
	DRF	90	$60.00	$5,400.00
	Total Personnel	628		$70,310.00
2.0 Travel				$509.08
3.0 Supplies				$400.00
4.0 Subcontract				$21,151.00
5.0 TOTAL				**$92,370.08**

6.0 References

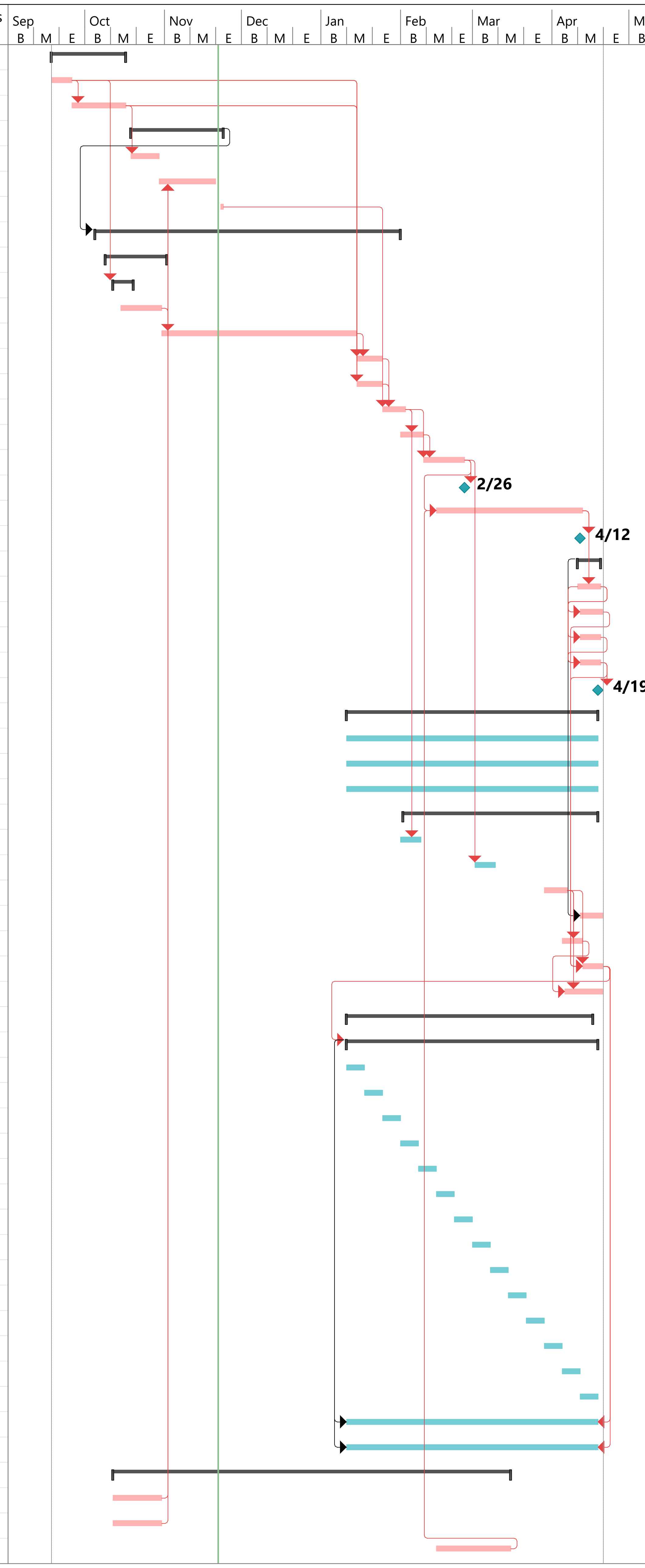
[1] P. C. Institute, "Official Rules for the PCI Engineering Design Competition," 15 August 2020. [Online]. Available: https://www.pci.org/bigbeam. [Accessed 7 September 2020].

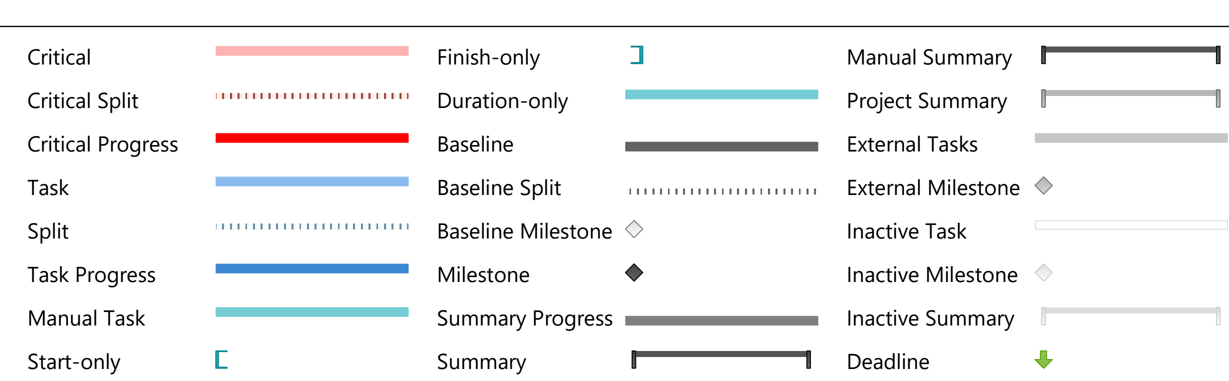
Appendices

Appendix A - Gantt Chart

schedule.mpp

ID	Task Name	Predecessors
1	Task 1: Prestressed Design	
2	Task 1.1: Introduction to Prestressed Design	
3	Task 1.2: Analysis Methodology	2
4	Task 2: Concrete Mix Design Analysis	
5	Task 2.1: Concrete Mix Research	3
6	Task 2.2: Concrete Mix Testing	58,59
7	Task 2.3: Selection of Concrete Mix	
8	Task 3: Beam Design Structural Analysis	4
9	Task 3.1: Create Different Beam Designs	
10	Task 3.1.1: Create Cross-Sections for the Beam	2
11	Task 3.1.1.1: Reinforcement Configuration and Rebar Size	
12	Task 3.1.4: Select Dimensions of the Beam	11
13	Task 3.1.5: Flexural Design	2,3,12
14	Task 3.1.6: Shear Design	2,3
15	Task 3.2: Final Beam Selection	13,14,7
16	Task 3.3: Refined Predictions	15
17	Task 4: Shop Drawings	15,16
18	Beam is now ready to be created.	17
19	Task 5: Oversee Concrete Pour on Fabrication Day	17,60
20	Beam is now ready to test.	19
21	Task 6: Testing the Beam	
22	Task 6.1: Equipment Set-Up	19
23	Task 6.2: Final Predictions	22SS
24	Task 6.3: Load Beam Until Failure	22
25	Task 6.4: Measure the Beam Deflection	22,24
26	Final report is now ready to be written.	25
27	Task 7: Impacts	
28	Task 7.1: Social Impacts	
29	Task 7.2: Environmental Impacts	
30	Task 7.3: Economical Impacts	
31	Task 8: Deliverables	
32	Task 8.1: 30% Submission	15
33	Task 8.2: 60% Submission	17
34	Task 8.3: 90% Submission	
35	Task 8.5: Video of Testing	21SS
36	Task 8.6: Website	34
37	Task 8.7: Final Report	34,23,25
38	Task 8.8: Final Presentation	34,36
39	Task 9: Project Management	
40	Task 9.1: Meetings (Team, Client, TA, and GI)	37
41	Task 9.1.1: Team Meeting 1	
42	Task 9.1.2: Team Meeting 2	
43	Task 9.1.3: Team Meeting 3	
44	Task 9.1.4: Team Meeting 4	
45	Task 9.1.5: Team Meeting 5	
46	Task 9.1.6: Team Meeting 6	
47	Task 9.1.7: Team Meeting 7	
48	Task 9.1.8: Team Meeting 8	
49	Task 9.1.9: Team Meeting 9	
50	Task 9.1.10: Team Meeting 10	
51	Task 9.1.11: Team Meeting 11	
52	Task 9.1.12: Team Meeting 12	
53	Task 9.1.13: Team Meeting 13	
54	Task 9.1.14: Team Meeting 14	
55	Task 9.2: Schedule Management	40SS,37FF
56	Task 9.3: Resource Management	40SS,37FF
57	Task 9.4: Tpac Coordination	
58	Task 9.4.1: Obtaining Concrete Mix Data	
59	Task 9.4.2 Obtaining Test Cylinders	
60	Task 9.4.3: Beam Fabrication/Team Travel to Tpac Location	





Appendix B – Personnel Cost Per Task

Task	SENG hours	PM hours	EIT hours	LBT hours	DRF hours
2.1 Task 1: Prestressed Design					
2.1.1 Task 1.1: Introduction to Prestressed Design	0	0	4	0	0
2.1.2 Task 1.2: Analysis Methodology	0	0	10	0	0
2.2 Task 2: Concrete Mix Design Analysis					
2.2.1 Task 2.1: Concrete Mix Research	0	0	5	0	0
2.2.2 Task 2.2: Concrete Mix Testing	0	0	0	30	0
2.2.3 Task 2.3: Selection of Concrete Mix	1	2	5	0	0
2.3 Task 3: Beam Design Structural Analysis					
2.3.1 Task 3.1: Create Different Beam Designs	2	5	20	0	0
2.3.1.1 Task 3.1.1: Create Cross-Sections for the Beam	0	0	0	0	0
2.3.1.1.1 Task 3.1.1.1: Determine Reinforcement Configuration and Rebar Size	3	0	10	0	0
2.3.1.1.2 Task 3.1.1.2: Select Dimensions of the Beam	3	0	10	0	0
2.3.1.2 Task 3.1.2: Flexural Design	0	5	15	0	0
2.3.1.3 Task 3.1.3: Shear Design	0	5	15	0	0
2.3.2 Task 3.2: Final Beam Selection	2	3	8	0	0
2.3.3 Task 3.3: Refined Predictions	1	2	8	0	0
2.4 Task 4: Shop Drawings	3	0	8	0	35
2.5 Task 5: Oversee Concrete Pour on Fabrication Day	5	5	5	0	0
2.6 Task 6: Testing the Beam					
2.6.1 Task 6.1: Equipment Set-Up	2.5	2.5	2.5	2.5	0
2.6.2 Task 6.2: Final Predictions	3	3	3	3	0
2.6.3 Task 6.3: Load Beam Until Failure	0.5	0.5	0.5	0.5	0
2.6.4 Task 6.4: Measure the Beam Deflection	1	1	1	1	0
2.7 Task 7: Impacts					
2.7.1 Task 7.1: Social Impacts	2	2	5	2	0
2.7.2 Task 7.2: Environmental Impacts	2	2	5	2	0
2.7.3 Task 7.3: Economical Impacts	2	2	5	2	0

2.8 Task 8: Deliverables					
2.8.1 Task 8.1: 30% Submission Report & Presentation	3	3	10	2	2
2.8.2 Task 8.2: 60% Submission Report & Presentation	2	2	6	2	2
2.8.3 Task 8.3: 90% Submission Report & Draft Website	3	3	8	3	2
2.8.4 Task 8.4: Video of Testing	0	0	0	0	0
2.8.5 Task 8.5: Website	4	4	15	3	3
2.8.6 Task 8.6: Final Report for CENE 486 and the PCI Big Beam Competition	3	3	10	2	2
2.8.7 Task 8.7: Final Presentation	3	2	5	3	2
2.9 Task 9: Project Management					
2.9.1 Task 9.1: Meetings (Team, Client, TA, and GI)	40	40	40	0	40
2.9.2 Task 9.2: Schedule Management	2	6	1	1	1
2.9.3 Task 9.3: Resource Management	2	8	2	0	1
2.9.4 Task 9.4: Tpac Coordination					
2.9.4.1 Task 9.4.1: Obtaining Test Cylinders	0	0	0	5	0
2.9.4.2 Task 9.4.2: Beam Fabrication/Team Travel to Tpac Location	3	10	8	5	0
	SENG hours	**PM hours**	**EIT hours**	**LBT hours**	**DRF hours**
Subtotal	98	121	250	69	90
Total (personnel-hours)					628