PCI Big Beam Competition Design
DRAFT #004

2018 – 2019

The B.E.A.M. Team

Seth Max

Jordan Phelps

Jacob Schaniel

Christian Soutus

November 19, 2018

CENE 476

Capstone Preparation

Table of Contents

1.0 Project Understanding

1.1 Project Purpose

The PCI Big Beam Competition is a nationwide engineering event where students are required to design a precast/prestressed reinforced concrete beam and accurately predict the failure at a calculated load. The team will explore the process of structural design and make predictions on the cracking moment, length of deflection, and moment capacity of the concrete beam [1]. This design project is competition based, which means the team will represent Northern Arizona University against a wide range of universities across the nation. By the conclusion of the design project, the team will be capable of designing and analyzing a prestressed concrete beam, constructing a website, and learning to maintain client relations.

1.2 Project Background

1.2.1 Competition

The competition for this design project is funded by a PCI Producer Member. The precasting company that will be assisting the team is TPAC, located in Phoenix, AZ. TPAC will provide the building materials, the casting of the beam, and the technical aspects. Once the beam has been designed and constructed, judging for the competition requires the following criteria:

- Design accuracy
- Lowest cost
- Lowest weight
- Largest measured deflection at maximum total applied load
- Most accurate prediction,
- Report quality
- Practicality, Innovation, and Conformance with code

The beam design will maximize the bending deflection, while also ensuring the beam will not crack before 20 kips and failing between 32-40 kips [1].

A final report consisting of two discussion sections is required by the competition board. These sections include the structural design and the concrete mixture used. The structural design will contain detailed characteristics, specifically, the design calculations, a prediction of the cracking load, the maximum applied load, and a prediction of the deflection [1]. The mix design requires a measured unit weight, slump, air content, and 28-day compressive and tensile strengths. A project report and final video, that explains the design process and testing results, is required.

1.3 Technical Considerations

1.3.1 Structural Design

Designing a precast/prestressed concrete beam will require structural analysis and basic mechanics. These engineering methods will be used to design the cross-sectional area and reinforcing needed to ensure that the beam will not fail before or after the acceptable loading range. The design for the beam will follow all constraints and criteria set forth by the PCI organization, while also abiding by the specifications and standards by organizations such as the American Concrete Institute and American Society for Testing and Materials.

1.3.2 Concrete Mix

An important aspect in designing the concrete beam is understanding the concrete properties. Concrete strength is related to the composition build-up within the mixture. Determining the desired concrete mix will be one of the preliminary steps in designing the cross-sectional area.

1.3.3 Software

Multiple programs can assist the team throughout the design and construction process of the concrete beam. Initially, RISA will perform an analysis for the different cross sectional areas. The Response 2000 software will help to confirm hand calculations performed for the beam design. AutoCAD will draft the different cross sections and floor plans.

1.4 Potential Challenges

Potential challenges that are likely to occur during the project include time constraints, schedule conflicts, lack of materials, and design conflicts. Given that we will submit our beam design to TPAC for fabrication, TPAC will require a sufficient lead time to cast and deliver the beam to Flagstaff.

1.5 Stakeholders

Stakeholders for this competition include Northern Arizona University, Dr. Joshua Hewes, TPAC, and the PCI organization. These stakeholders show an interest in our project, and will be expecting to view the results of the competition.

2.0 Scope of Services

2.1 Task 1: Competition Understanding

The big beam competition is setup with a variety of judging categories. These judging categories each contain a great amount of description, which is why understanding how the competition will be scored is crucial.

2.1.1 Task 1.1 Loading Conditions

The loading conditions for the 2018-2019 competition has changed from the previous year's guidelines. The location for the two point loads is no longer at midspan. The two point loads have shifted to the right, which effects the calculations required.

2.1.1.1 Task 1.1.1 Determination of Max Moment

With the shift of the point loads, the maximum moment seen in the beam for this setup will be less than the maximum moment of a beam with centralized point loads. This new addition to the competition guidelines will affect the overall design of the beam structure.

2.1.2 Task 1.2 Competition Scoring

There are seven categories that have a role in the overall scoring process. The category with the most points associated with it deals with the design accuracy. The next three categories, are based on the results of the other competing teams. Two categories are awarded based on the judge's thoughts on the report quality, the practicality, innovation, and compliance with code.

2.1.3 Task 1.3 Material Specification

The beam and concrete designs need to follow the ASTM and ACI 318-14 regulations.

2.1.4 Task 1.4 Testing Specification

Concrete mixes will need to be tested and follow all ASTM testing regulations. A PCI producer member will also be needed to confirm these standards were followed during the the testing of the beam.

2.2 Task 2: Beam Design

The bulk of the work for this project is to create the most optimal design to meet all judging criteria. The three main components included into the optimal design are the concrete mix design, and the cross sectional shape design, and the pre-stress/reinforcement design.

2.2.1. Task 2.1: Mix Design

2.2.1.1 Task 2.1.1 Portland Cement Type

The cement will have a major factor on the overall strength and attributes of our concrete mix. There are five major types of Portland cement, with different proportions of silica, calcium oxide, alumina, and iron oxide for the major components. The choice of cement will impact the heat of hydration chemical reaction (cure time) and will also have an impact on the concrete mixes compatibility with admixtures.

2.2.1.2 Task 2.1.2 Aggregate Type and Gradation

The choice aggregate, size, and shape will have a major impact on the overall strength of the concrete. A variation of gradations consisting of coarse sized aggregate of up to a maximum size of ¾ of an inch, combined with fine aggregates smaller than ⅜ of an inch. The aggregates overall will account for 60 to 80 percent of the total mix. The use of locally available aggregates will make our concrete mix more economical and practical.

2.2.1.3. Task 2.1.3 Water to Cement Ratio

The water to cement ratio is an important factor in mixing concrete. Potable water, that doesn't have an odor, can be used to make the Portland cement paste. This will impact the workability, cure time, and strength of the mix.

2.2.1.4 Task 2.1.4 Additional Admixtures

The use of chemical and/or mineral admixtures can be used in the mix design. Pozzolanic materials are popular mineral admixtures that are the by-product of industrial processes, such as fly ash or slag. Pozzolanic materials act as a partial substitute for Portland cement, which makes use of waste products and reducing manufacturing cost. Chemical admixtures can be added to control the heat of hydration process, improve workability, and decrease shrinkage or cracking.

2.2.2 Task 2.2 Material Testing

2.2.2.1 Task 2.2.1 Acquiring Materials

Materials for mix design will be acquired from Cemex. Once materials are available, different mixes will be casted for testing.

2.2.2.2 Task 2.2.2 Casting Test Cylinders

Test cylinders will be casted with our designed mix and collecting commercially standard test cylinders from Cemex. These test cylinders will be in two different sizes, such as 4 by 8 inches or 6 by 12 inches. The testing of a minimum of four cylinders for each concrete mix will be performed. The test results will provide the 3 day compressive/tensile strength and 28 day compressive/tensile strength of the concrete mix.

2.2.2.3 Task 2.2.3 Split Cylinder Test (Tensile Strength)

ASTM C496 will be used to test the tensile strength of concrete. This is achieved by laying the test cylinder on its long side and loading the cylinder at the tip of the circular side of the cylinder. This load will apply internal stresses of tensile force to the cylinder until failure. Concrete is very weak in tension but tensile strength of the mix is needed to determine the amount of reinforcement.

2.2.2.4 Task 2.2.4 Compression Test (Compressive Strength)

ASTM C39 will be administered for the compressive strength of each mix. This lays the cylinder on its flat circular side and loads the test cylinder in compression for failure. The compressive strength is critical for accurate structural analysis.

2.2.2.5 Task 2.2.5 Mix Design Finalized

The team will determine whether or not the design created will be used for the final beam design. The team will also compare the results from our testing with respect to TPAC ready mixes.

2.2.3 Task 2.3 Geometrical Analysis

2.2.3.1 Task 2.3.1 Mathcad Programming

Structural analysis and calculations that need to be performed for the beam design will be performed using Mathcad. Mathcad is a computer software that is similar to excel, though Mathcad is easier to read and display work. Mathcad will be formatted to determine the required calculations for different beam cross sections. The use of the section properties for each cross section will be used for the following calculates:

- Moment of Inertia
- Cracking Moment
- Nominal Moment
- Deflection
- Moments Due to Stressing
- Moment of Prestressed
- Modulus of Rupture
- Transform Section Approach
- Prestress Losses
- Service Performance

All calculations on Mathcad will also be ran using the software, Response 2000. This software determines the strength of a concrete beam with respect to different load types like shear and moments. The results from the analysis will then be used to determine the reinforcement layout. The rebar grade and prestressed cable size will need to be chosen to design a beam that will meet the requirements for the competition.

2.2.3.2 Task 2.3.2 Decision Matrix

The decision matrix uses a scoring system that breaks up the characteristics of the concrete mixture and geometrical design. Mix design is a complex balancing act with many conflicting variables, every ingredient chosen for the mix will come with an advantage and a disadvantage. The decision matrix will allow the team to determine which concrete mixture performs best with our reinforcement design at the lowest weight, highest compressive capacity, lowest cost, and highest deflection.

2.3 Task 3 TPAC Manufacturing

2.3.1 Task 3.1 Finalize Beam Design for Shop Drawings

The final design of the beam will be used to create a shop drawing on AutoCAD and will be submitted to TPAC to manufacture.

2.3.2 Task 3.2 Shipping

The beam requires a 28-day curing time before the beam can be shipped to the testing location at Northern Arizona University in Flagstaff, Arizona.

2.4 Task 4 PCI Big Beam Final Testing

2.4.1 Task 4.1 Predict Results

The predicted values for our beam design will need to be given to a third party member. This will ensure that no modifications can be made to the prediction values.

2.4.2 Task 4.2 Test Beam

Testing of the beam will be done at Northern Arizona University 28 days after the beam is casted by TPAC.

2.4.3 Task 4.3 Make a Video

A video is required to be submitted displaying the highlights and failure for verification purposes of the test. Visible scales showing the beam deflection need to be visible in the video provided.

2.5 Task 5 486 Deliverables

2.5.1 Task 5.1 Final Report

A written final report will be provided of the methods used for analysis, as well as results from the testing of the beam.

2.5.1.1 Task 5.1.1 30% Submittal

A 30% report will be written establishing the methods used for the analysis of the geometrical cross section and concrete mix design.

2.5.1.2 Task 5.1.2 60% Submittal

The 30% report will be upgraded into a 60% report by adding recorded data that was collected from the beam testing.

2.5.2 Task 5.2 Website Design

The final website will showcase the final design, report, and testing of the beam.

2.5.3 Task 5.3 U-Grad Presentations

The final presentation will display the team's final product to the capstone instructors, faculty on campus, and to any stakeholders who have interest in the competition results. This is the chance for our team to share our results in a professional setting, and defend our final design.

2.6 Task 6: Project Management

2.6.1 Task 6.1: Project Management

2.6.1.1 Task 6.1.1 Technical Advisor Meeting

The team will meet with the advisor every week to discuss progress on both the beam design and the concrete mixture

2.6.1.2 Task 6.1.2 Grading Instructor Meetings

Each meeting with the grading instructor will take place prior to deliverable submissions in order to receive input, and afterwards to solicit the appropriate feedback.

2.6.1.3. Task 6.1.3 Team Meetings

The objectives of the team meetings include: discussing the week's agenda, completing the applicable deliverables from capstone and the technical advisor, and updating each other on the progress towards final testing.

2.6.1.4 Task 6.1.4 Scheduling

A schedule will be generated into a Gantt chart and will be followed accordingly. The generated Gantt chart will also be update throughout the project to establish current progress of the project.

2.6.1.5 Task 6.1.5 TPAC Communication and Beam Transportation

Communication will need to be consistent with TPAC to ensure that the beam will be manufactured by the desired delivery date. Communication with a shipping company will also need to be established in order for the beam to be properly transported to the testing location at Northern Arizona University in Flagstaff, AZ.

2.6.1.6 Task 6.1.6 Billable Hours

Hours spent working on the design for the beam will be recorded and billed accordingly.

2.7 Project Limitations

The competition requires that the team uses a producer member to provide expertise, all materials, beam fabrication, beam transportation to the testing facility, and disposal. This, then limits the team's ability to cast the beam themselves because of the lack of resources.

A full and complete design would include more detail in understanding the chemical composition of additives as they are used in the concrete design mix. Since the requirements of the competition do not require the creation of our own additives, professionally tested additives will be used.

2.7.1 Challenges

There is a fairly large distance between the TPAC manufacturing plant and concrete lab testing facility that makes transportation of the beam difficult. It is also required that one member of the team be present during the casting of the beam, which may be a far trip. The distance of transportation of the beam also creates a scheduling issue because the time it takes for the beam to reach the testing site may be lengthy and must be accounted for.

2.7.2 Exclusions

No exclusions will be included in the design process. The design process needs to follow strict restrictions set by the competition general rules.

3.0 Schedule

The scheduling for a project like the PCI Big Beam Competition, follows a fairly linear path. Nearly all task have predecessors that need to be completed in order to start the next task. The total duration of the project starts from the day that teams were assigned until the final report submission on May 10th. The entirety of the project will take 182 days, according to the critical path. The major task for a project like this, includes comprehending the guidelines for the project, working on the beam design, sending our final design to our manufacturer, testing the beam to failure, and creating a presentation and report.

The critical path for this project is displayed in the red path on the Gantt Chart. This is the critical path because it will be the shortest path taken for completion. As long as the team continues to reference the Gantt chart through completion of the project, the team should maintain the correct pace to not fall behind.

4.0 Staffing Plan and Cost of Engineering Services

4.1 Project Roles

4.1.1 Senior Engineer

The senior engineer is responsible for overseeing the project as well as maintaining contact with the client. The senior engineer specific to the PCI Big Beam Competition will take keep contact with the beam manufacturer, keep the team on schedule, and act as a link between management and the design team. This role includes taking time to ensure that the every submission is at the best quality achievable.

4.1.2 Structural Engineer

The structural engineer will take lead in the design process for the optimal cross section and reinforcement layout of the beam. This role includes programming the Mathcad software, taking in considerations from both the project engineer and the lab technician. Once the Mathcad is complete, the structural engineer will run a variety of cross sections,

4.1.3 Lab Technician

The lab technician will be responsible for collecting data on proposed concrete mixes. The lab technician will cast concrete cylinders to be tested for compressive strength, tensile strength, and modulus of elasticity.

4.1.4 Engineering in Training

The EIT will be responsible for drawing cross sectional designs for the concrete beam to be analyzed. The EIT must also perform hand calculations, in order to confirm the equations used in the MathCAD program for the cross-sectional analysis. Concrete pouring and mixing is another requirement of the EIT.

4.2 Matrix of Tasks and Staff Hours

The following table, Table 1, breaks down the total hours required by each team member to complete individual task and subtask. Not every member will work on each task, so the following table displays how many hours are needed to complete the task and who will be executing each task. The total man hours needed for this job is equivalent to 573 hours. The senior engineer will work 124 hours, the structural engineer will work 119 hours, the lab technician works 131 hours, and the engineer in training will work 199 hours.

[2]
Table 1 Matrix of Task Number and Staff Hours

Task vs Staff position (estimated hours)					
Task	**Senior Engineer**	**Structural Engineer**	**Lab Technician**	**EIT**	**Total Hours**
Task 1 Competiton Understanding	-	-	-	-	-
Task 1.1 Loading Condition	2	4	0	2	**8**
Task 1.2 Competion Scoring	2	2	0	1	**5**
Task 1.3 Material Specifications	1	0	3	2	**6**
Task 1.4 Testing Specifications	2	0	5	1	**8**
Task 2 Beam Design	-	-	-	-	-
Task 2.1 Mix Design	8	0	20	8	**36**
Task 2.1.1 Portland Cement Type	2	0	5	2	**9**
Task 2.1.2 Aggregate type and Gradation	2	0	5	2	**9**
Task 2.1.3 Water to Cement Ratio	2	0	5	2	**9**
Task 2.1.4 Additional Admixtures	2	0	5	2	**9**
Task 2.2 Material Testing	-	-	-	-	-
Task 2.2.1 Acquiring Material	0	0	5	12	**17**
Task 2.2.2 Casting test Cylinders	0	0	25	20	**45**
Task 2.2.3 Split Cylinder Test	0	0	30	10	-
Task 2.2.4 Compression Test	0	0	30	10	-
Task 2.2.5 Mix Design Finalized	7	0	15	5	**27**
Task 2.3 Geometrical Analysis	-	-	-	-	-
Task 2.3.1 Mathcad Programing	20	50	0	7	**77**
Task 2.3.2 Decision Matrix	12	12	12	0	**36**
Task 2.3.3 Determination of max moment	4	6	0	0	
Task 3 Tpac Manufacturing	-	-	-	-	-
Task 3.1 Shop Drawings to TPac	6	6	0	22	**34**
Task 4.2 Shipping	2	0	0	6	**8**
Task 4 PCI Big Beam Final Testing	-	-	-	-	-
Task 4.1 Predict Results	15	20	0	10	**45**
Task 4.2 Test Beam	5	5	12	12	**34**
Task 4.3 Video	0	0	0	7	**7**
Task 5 Delilverables	-	-	-	-	-
Task 5.1 Final Report	-	-	-	-	-
Task 5.1.1 30% Submittal	8	4	4	18	**34**
Task 5.1.2 60% Submittal	8	4	4	18	**34**
Task 5.2 Website Design	8	4	4	18	**34**
Task 5.3 U-Grad Presentations	8	3	2	20	**33**
Task 6 Project Management	-	-	-	-	-
Staff Total hours	126	120	191	217	**654**

4.3 Staff Position Justifications

The staff positions mentioned above are needed specifically for a project like this to ensure all guidelines are met in accordance to the competition rules.

Table 2 Staff Position Summary

Staff Position Summary		
Staff Position	**Total Hours**	**Justification**
Senior Engineer	126	The senior enginner will have 124 hours contributed to this project. Most of the hours come from overlooking the work from the other roles. The senior engineer spends most of their hours towards the end of the project checking final designs and documentation. This person is also the point of contact for the client.
Structural Engineer	120	The structural engineer spends majority of their time creating the final design of the beam. Majority of the hours are spend in the mathcad programming task of this project. This involves running multiple cross sections in the program.
Lab Technician	191	The lab technichian will contribute a large amount of hours into the mix design and testing phases. The task needing most hours by the lab technichian will be during the mix design phase.
EIT	217	The engineer in training will be contributing the most hours for the project. This person will be spending a bulk of the time helping the other members.
Task Total	654	There are 654 man hours contributed to the completion of this project.

5.0 Cost of Engineering Services

The expected cost to fully complete this project is presented in Table 3 below. The table contains the total cost that each contributing member of the project will earn, the reimbursed travel cost, supply cost, subcontracting cost, and the overhead cost needed. The total cost for the project is $58,423, of which $47225.65 will go to paying the engineering team. $10,336.79 dollars goes into the overhead needed to not pay out of pocket. The cost is broken up into five categories. The breakdown is as follows: Engineering Services, travel cost, supplies, final testing, and the required overhead needed to make profit on the project. The travel cost is pertained to the cost per mile that the team will travel to collect testing materials from Cemex, as well as the trip Tpac in Phoenix.

Table 3 Total Cost of Project

Engineering Services					
Personnel		**Hours**	**Rate ($/hr)**	**Cost $**	
Senior Eng.		126	121	15246	
Struct. Eng.		120	96.525	11583	
Lab Tech.		191	52.8	10084.8	
EIT		217	47.52	10311.84	
Travel (Cost of team driving to these sites)					
Location	**$/mile**	**Round Trip Miles**	**$/round Trip**	**Number of trips**	**Total Travel Cost**
Cemex	$0.55	20	$11.00	4	$44
Tpac	$0.55	300	$165	1	$165
Supplies					
	Initial Cost		**Total Cost**		
Software	$200		$200		
5 Gallon Buckets	$2/bucket		$12		
Safety Glasses	$5		$20		
Casting Molds	$1	per mold	$50		
Paper Supplies	$20		$120		
Printer	$300		$300		
Final Testing					
Service		**Quantity**		**Cost $**	
Beam Delivery		1		$700	
Machine Operations		1		$500	
Force Sensors		12		$150	
Overhead					
Personnel	**Hours/ Work day**	**# of Work Days**	**Available Man Hours**	**Man Hours**	**Overhead Inclusive of Profit $**
4	8	183	5856	573	10336.79
		Total Project Cost			**$59,823**

5.0 References

[1] "Design Resources/ Guides and Manuals," 09 2018. [Online]. Available: www.PCI.org.

[2] R.Crouch, *TPac Casting Pictures,* Phoenix, 2018.

[3] PCI Design Handbook, Chicago : Precast/Prestressed Concrete Institute, 2004.

[4] "Student Competitions," PCI Precast/Prestressed Concrete Institute , 2018. [Online].

[5] S. Max, *Field Work Photographs,* Flagstaff, 2018.

[6] "Prestressing Works - Overview," United Construction Developement, 2015. [Online].

[7] J. Phelps, *Mathcad Programming,* Flagstaff, 2018.

[8] "," Tpac Architectural and Prestressed Concrete. [Online].