PCI Big Beam Competition Design DRAFT #003

2018-2019

Northern Arizona University

The B.E.A.M Team

Seth Max

Jordan Phelps

Jacob Schaniel

Christian Soutus

Technical Advisor: Dr. Joshua Hewes

TPAC

Alan Erickson

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Engineering Design

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M_{CR} = Cracking Moment
M_n = Nominal Capacity
P = Prestress force
A = Cross Section Area
A_{PS} = Area of Prestress
A_S = Area of Tension Steel
A'_S = Area of Compression Steel
d_P = Depth of Prestressing

d = Depth of Tension steel
d' = Depth of Compressive steel
e = Eccentricity
S_b = Section Modulus
f_r = Rupturing Stress
f_y = Yield Stress of Steel
f_{PS} = Nominal stress of Prestress strands

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Acknowledgement

The PCI Big Beam Competition team would like to thank Dr. Hewes with his guidance in learning and executing proper precasting/prestressing designs for the competition. The team would also like to thank the TPAC representatives, Gabriella Wilson and Jeff Grimsley, with assisting the team with design requirements, concrete properties, and design suggestions. The team would also like to thank CEMEX and Utilite for their donations of concrete material for our mix design.

1.0 Project Introduction

The Precast/Prestressed Concrete Institute is a technical institute that develops, maintains, and disseminates codes for the design, fabrication, and erection of precast concrete structures [1]. PCI holds an annual national and global Big Beam Competition that allows engineering students to design and manufacture a concrete beam that follows all the criteria set by PCI [2]. The design criteria for this year's competition consists of building a beam that is no longer than 20 feet, and has two point loads applied offset to the center of the beam. The guidelines for the competitions also include that the beam does not crack below 20 kips and fails in-between 32 and 40 kips.

The competition has seven different judging criteria that the team will be taking into consideration during the design process. The majority of the points awarded to teams is in the design accuracy judging criteria. The team must fall within the cracking and failure load limits or points will be deducted from the overall score. Another judging criteria that must be considered is to design the lowest costing and lowest weight concrete beam. This cost and weight will be considered during design by possibly using lightweight concrete and minimal reinforcement strands in the design. Aside from falling within the upper and lower loading limits, teams will be judged on accurate predictions of when the beam will crack and fail. The designed beam will also be judged for having the highest deflection at failure. The last judging criteria's includes the quality of the report, practicality, innovation, and conformance with code. In addition to the competition requirements set by PCI, additional deliverable will need to be completed. The capstone deliverables that will be completed include: 30% report, 60% report, 90% report, final report, website, and U-Grad presentations. Not part of the capstone requirements, there are many steps towards the project's completion. This includes shop drawings, beam transportation, predicted design/failure calculations, testing, and the analysis of results.

2.0 Technical Section

This section includes all of the technical considerations that the team had to consider during the concrete mix design and the cross sectional design of the beam.

2.1 Concrete Mix Design

Concrete is a widely used structural component that can be casted for a large array of projects. Given a project like the PCI Big Beam, it is important that the concrete used performs to its expectations. These expectations are derived from a number of different properties.

2.1.1 Proportioning

2.1.1.1 Portland Cement

Portland cement is one of the main components in concrete. When combined with water, a cementitious paste is created that becomes workable and malleable, though as it cures it becomes a much stronger substance. Portland cement and water are a great combo together, though the mixture becomes even stronger with the addition of extra materials.

2.1.1.2 Aggregate Types

Aggregates are important elements in the design of a strong concrete mix. Aggregate is normally broken rock that when combined with the cementitious paste, creates a new paste commonly what we know as concrete. An ideal concrete mix contains a spread of aggregate sizes. This will allow the smaller aggregate to interlock between larger ones, increases the contact forces of the mixture. Experimenting with different aggregate sizes and proportions is the basis for concrete mix designing. It is an iterative process resulting in optimal concrete mixes

2.1.1.3 Admixtures

One of the more recent innovations with concrete design, is the inclusion of admixtures. Admixtures are either a chemical and/or mineral based substance that once added to the concrete mixture, certain properties will change depending on the type of admixture. Pozzolanic materials, such as Slag or Fly Ash, are capable of acting as a partial substitute for Portland cement. Adding Pozzolanic materials is beneficial for reducing the cost of the concrete cost.

2.1.2 Cylinder Testing

2.1.2.1 Compressive

A compressive cylinder test involves determining the capacity and the strength that a specific concrete mix can withstand, given an applied load. This test evaluates the performance of concrete by examining its superior characteristic, compressive strength. The process begins by creating a concrete batch with specific proportions. Each batch of concrete is poured into a test cylinder and left to cure for a specific amount of days. A 3-day and a 28-day curing time are common for concrete mixes. On the 28th day, the cylinder is placed on a hydraulic press in preparation for testing. The press provides a gradual increasing load that breaks the cylinder. The applied load is then recorded, which represents the compressive strength of the concrete mix.

2.1.2.2 Tensile

The tensile cylinder test is also known as the split cylinder test. It involves placing a 4x8 inch cylinder horizontally on a hydraulic press and applying force. This method determines the strength of the cylinder in tension because of the fact that horizontal load is applied. The indirect forces applied to the cylinder to replicate tensile stress causes cracks throughout the entirety of the beam, splits in half, which then the tensile strength is recorded.

2.2 Structural Design

The following section explains all of the different technical considerations that the team had to look into while working on the structural design of the prestressed concrete beam.

2.2.1 Mathcad Programming

The team used a software called Mathcad to insert all of the raw equations suggested by the PCI handbook and the ACI 318-14 code for the prestressed concrete designs. Mathcad was used instead of Excel since Mathcad displays all of the equations and is an easier step-by-step software to follow. The main components of the Mathcad programming included calculations for the center of mass, moment of inertia, flexural strength, loss of prestress, moment of cracking, nominal moment, and shear design.

2.2.1.1 Cracking Moment

The cracking moment is when the moment within the beam is exceeded and cause the concrete to start to crack. The cracking moment calculation is important for our design because one of the judging criteria for the competition states that the concrete member should not crack before 20 kips. In order to increase the cracking moment, the right section modulus must be designed to ensure the beam does not crack before 20 kips. The cracking moment equation is displayed below

Equation 1 $$M_{CR} = S_b\left[\frac{P}{A} + \frac{Pe}{S_b} + f_r\right] - M_{nc}\left(\frac{S_b}{S_b} - 1\right)$$

M_{CR} = Cracking Moment
P = Prestress force
e = Eccentricity
A = Cross Section Area
Sb = Section Modulus

2.2.1.2 Nominal Capacity

The nominal capacity is another important calculation that needs to be performed while designing the concrete beam. The nominal capacity is defined as the total load capacity that the beam member can experience before failing. The use of the prestressing strands increase the nominal capacity, allowing for a shallower and longer concrete beam. The Nominal capacity equation is below.

Equation 2 $$M_n = A_{PS}f_{PS}\left(d_P - \frac{a}{2}\right) + A_S f_y\left(d - \frac{a}{2}\right) + A'_S f'_S\left(\frac{a}{2} - d'\right)$$

Mn = Nominal Capacity
A_S = Area of Tension Steel
A_{PS} = Area of Prestress
A'_S = Area of Compression Steel
f_{PS} = Nominal stress of Prestress strands
d = Depth of Tension steel
d' = Depth of Compressive steel
d_P = Depth of Prestressing
f_y = Yield Stress of Steel

2.2.2 Response 2000

Response 2000 is a finite element model that analyzes the sections of various reinforced concrete structural models. The program requires the input of conditional applied loads to the structure. The structure characteristics including dimensions, concrete properties, prestressing layout, and reinforcement layout are required for the most efficient results. It then runs the structure through a simulated model that generates the occurring shear, bending moment, and deflection at any loading condition. The results include multiple diagrams that display deformation, the deflected shape, shear force diagram, and bending moment diagram.

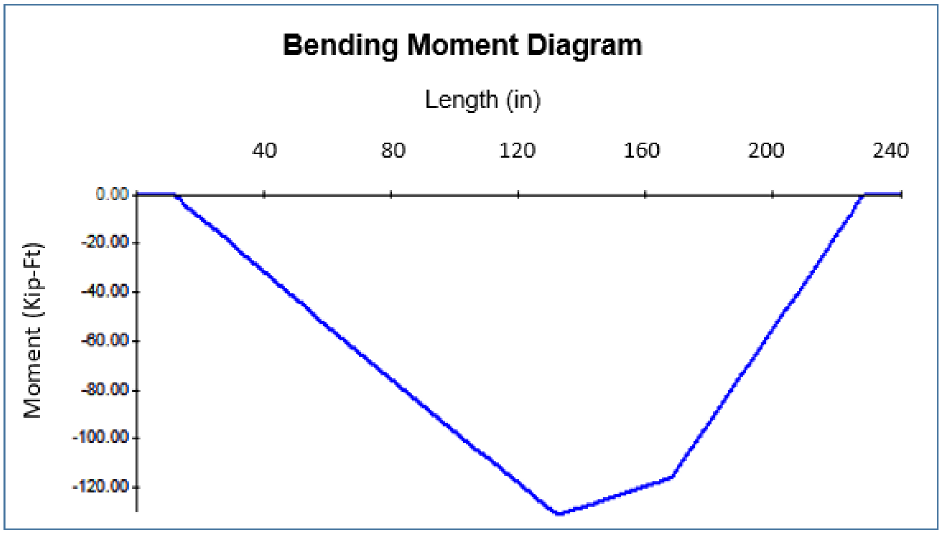


Figure 1 Bending Moment Diagram from Response 2000

Depicted above, the bending moment diagram (BMD), shows the location of the maximum moment at 10 feet from the left support. The BMD also provides the moment at any location along the span of the beam.

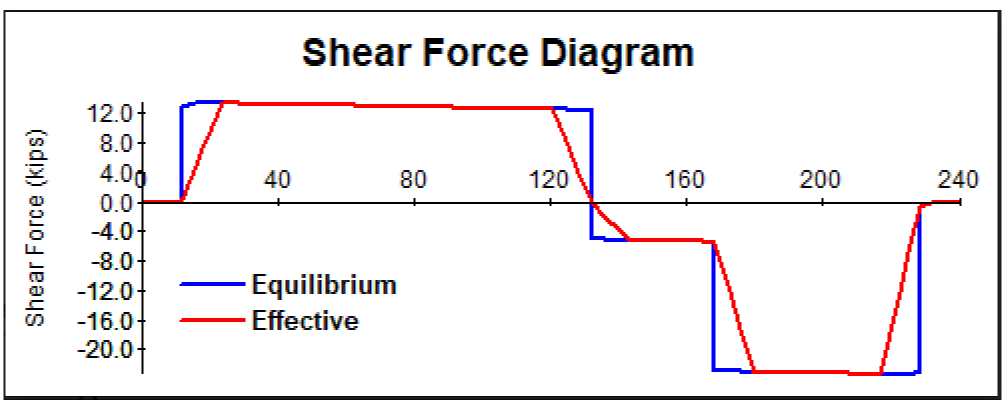


Figure 2 Shear Force Diagram from Response 2000

The shear force diagram (SFD) displays the internal shear stresses across the span of the entire beam. Stirrup design and spacing is determined using the values off of the SFD. Maximum shear happens at the far right support due to the applied point loads causing a larger reaction and shear force.

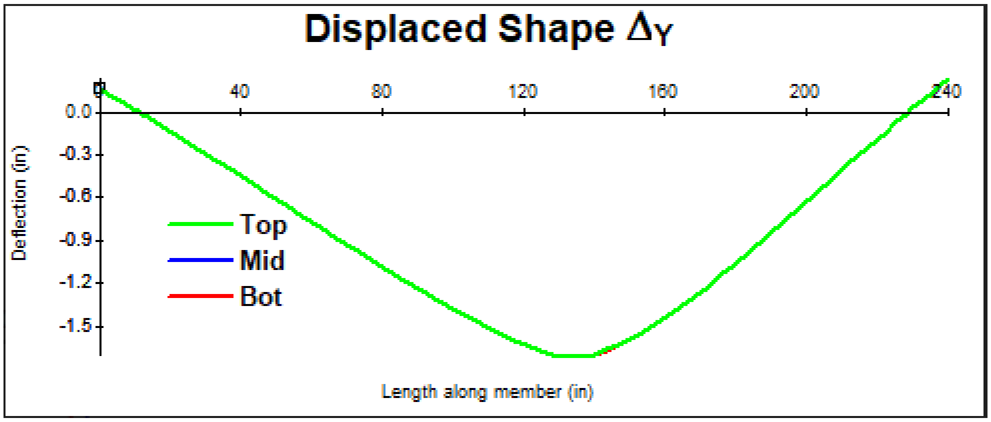


Figure 3 Deflection Diagram from Response 2000

The deformed shape is shown above with the maximum deflection of around 4.8 inches. This happens at the location under the first point load 10 feet from the left end support. Normally in a real world project, minimal deflection is generally preferred, though as part of the competition we are striving for max deflection for max points.

2.2.3 Prestressed Design

Prestressing is an engineering method that increases the overall capacity of a structural element. The process involves the tensioning of steel strands are placed in the casting bed and the concrete is casted around and bonds to the prestressing steel. Once the concrete has cured to the appropriate concrete strength for transfer, the strands are released causing a compressive force within the beam. The use of prestressing when designing a concrete beam helps induce a negative bending moment within the beam that helps counteract the positive moment bending due to the live loads on the member. The use of prestressing allows for shallower and longer span concrete beam to be manufactured.

2.3 Alternative Designs

The following section explains the decision process for the mix design and cross sectional design.

2.3.1 Mix Design Considerations

The team decided the optimal mix design based off the compressive and tensile strength tests, modulus of elasticity, and the unit weight of the concrete. The team has designed six different mixes that will be considered for the final decision. From the six batches, two of them were significantly better than the rest for various reasons. Mix #2 proved to be the strongest in compressive strength by containing a 28-day strength of 11,015 psi, but was a heavy mix, weighing 149.5 lb/ft^3. This mix consists of the proportions that are listed in the table below.

Table 1 Concrete Mix #2

	STRONGEST BATCH (4 cylinders)	
	ratio	lbs
Portland Cement	0.22	13.143
Water	0.06	3.483
Sand	0.31	18.401
Aggregate	0.39	23.658
Accelerator	0.02	1.314
Total	1.0	60.0

The most optimal design from the concrete mix testing process was Mix #6. This batch was the lightest in weight of all the others, 108 lb/ft^3, while also containing a very high 28-day compressive strength of 7943 psi. The table below displays the batch proportions.

Table 2 Concrete Mix #6

	OPTIMUM BATCH (4 cylinders)	
	ratio	lbs
Portland Cement	0.22	9.858
Water	0.06	2.612
Fine Aggregate	0.31	13.801
Coarse Aggregate	0.39	17.744
High-Range Water Reducer	0.02	0.986
Total	1.0	45.0

The team has also considered using the lightweight and normal weight concrete that TPAC manufactures. Mix #6, the optimum batch, resembles the lightweight mix that TPAC uses in production and is the most realistic for the beam's design, though through further analysis it was determined that the tensile strength of the light weight mix will cause the beam to crack when the strands were released. In the end, our final mix design is one of Tpac's normal weight 8,000 lb/in^2 mix.

2.3.2 Cross-sectional Considerations

Once the Mathcad program was properly formatted and checked for accurate results, the team ran five different cross sections through the program to try and find the optimal design. Each cross sections weight, and costs of manufacturing, and innovational design were compared to each other. The decision matrix for the cross sections designed can be found in Appendix 1.

2.4 Final Design Recommendations

This section provides a final design recommendation that the team submitted for the PCI Big Beam Competition. This recommendation considers the final mix design and cross sectional design.

2.4.1 Concrete Mix Recommendations

After calculating and designing a cross-section that would be suitable for the project, the team determined that the lightweight mix design has a high potential of cracking from the prestressing moment during release and calculated the stress on the top of beam to be very close to exceeding our maximum capacity. As a result, the normal weight TPAC mix, 144 lb/ft^3, is appropriate for the determined cross-section design and the compressive strength of this mix is 8000 psi. By using the normal weight mix, this allows a reduction and a more conservative value for compressive stress on the beam and a higher cracking capacity.

2.4.2 Cross-section Recommendations

After completing the proper Mathcad programming and determining the desired concrete mix, the design and analysis of cross sections is now achievable. After iterations of cross sections, and prestressing layouts, the final design of the beam will be 20 feet, and have a hollowed square cross section. The outside base is 9.5 inches, and the total height is 13 inches. The hollow section will be 5.5 inches by 5.5 inches. With this given cross section, the following results are obtained.

Table 3 Estimated Test Results

Estimated Results		
Cracking Load	21.2	Kips
Failure Load	36.4	Kips

This cross section was compared to four others in a decision matrix, and it proved the best option for the competition. It has the smallest cross section area of 98 in2. The approximate weight of the beam is 1960 pounds.

2.5 Manufacturing Costs

The PCI Big Beam competition provides a cost sheet that each team must fill out. The 4 main cost categories that need to be included in the cost include, concrete, prestressing strand, steel weight, and forming. The team had calculated that the total cost for the final hollow box design will cost $ 204.03. The calculations and quantity of material used for the beam can be found in Appendix 2.

3.0 Summary of Engineering Work

3.1 Concrete Mix Design

Prior to the CENE 486C, the team had completed a bulk of the work in CENE 476. Part of the design process involved acquiring “dry” materials to produce concrete mixes. These dry materials were donated by Cemex and Utilite, who are very big companies in the concrete industry. Research was done to understand the general proportions of ingredients that go into a concrete mix. Two team members focused a good amount of energy and time in this section during the CENE 476 semester.

3.2 Cross-section Design

The team also had to perform basic structural analysis on the concrete member to assure it will not fail due to the internal prestressing force once the prestressing strands were released. In order to calculate if the beam would crack at release, the team had to take into consideration all of the moments that are caused by the self-weight and the internal prestressing. To find the stresses (ksi) formed by the moments, the calculated moment (kip*in) had to be divided by the section modulus (in^3) of the concrete member.

3.3 Shop Drawings

Once the team determined the final design from the different cross sections, the final designs shop drawings were produced. The shop drawings were created using AutoCAD and show the elevation view, section cut, and the bill of materials. Dimensioning, clear coverage, and stirrup spacing was detailed in the shop drawings. The bill of materials, also show all of the steel required and the concrete properties that will be used for casting. The shop drawing can be seen in Appendix 3.

3.4 Fabrication and Testing

3.4.1 Rebar Bending Process

In the rebar fabrication process, Tpac subcontracts out the work for rebar bending. The quantity and design of the rebar is determined in the design process. Fabrication of the beam requires that the all steel materials be set prior to the concrete pouring. For the fast production, the steel is normally the first item that is produced in a reinforced concrete project. The beam used for the project contains four prestressed strands, four non-prestressed bars located in the top all with standard hooks, two non-prestressed bars at the critical sections of each end, and finally 34 double-leg open stirrups.

3.4.2 Building the Formwork

Building the formwork is a fairly straightforward process. The formwork is the physical boundary that will be in contact with the outside of the beam. Generally, the formwork is constructed of rigid material like plywood, wood planks, and/or steel sheets. Our project will utilize the plywood sheets in our formwork procedure. This step is very important due to theammount of accuracy needed in taking the dimensions of our beam from the shop drawing, and carefully measuring out the formwork. The formwork is generally connected with screws for a strong hold.

3.4.3 Setting the Steel

Setting all the reinforcing steel will take up the most time in the fabrication process. Depending on the amount of steel encased in the beam, could affect the amount of time needed just for this rebar placement. The first steel to be set is the prestressing strands and the stirrups. The reason that the stirrups and the prestressing strands need to happen together is due to the fact that we are using double leg stirrups that require the prestressing strands run through all of them. Once the prestressing strands are anchored at both ends, there would be no way of setting the stirrups. The prestressing strands are also the only reinforcement that will continue past the beam's formwork. The next step is to set the top longitudinal steel. If you examine the elevation view of the shop drawings, it can be seen that there is nothing that will keep the "rebar cage" from toppling over. Another way to look at it is, if the only outside anchoring comes from the prestressing strands at the bottom, what is to stop the top from falling over if it is pushed. This is why there will need to be rebar chairs, holding up the top bars keeping the rebar cage stable during the concrete casting.

3.4.4 Mixing the Concrete

The team is using a concrete mix made by Tpac. This mix is normal weight, around 144 lb/ft^3, and will fail in compression at around 8000 psi. The batch is made the morning of the pour, to make sure no water evaporates and changes the concrete properties.

3.4.5 Pouring the Concrete

The concrete pour is a fairly fast process. Once the formwork is in place, and all the rebar is set, the last component of the beam is the concrete. There is precaution to take when casting the beam. We do not want the Styrofoam to shift in this process because it will change the cross section of the beam, which changes the results of our testing. There is also the precaution to take in making sure there are no air bubbles anywhere along the span of the beam. Air bubbles have no strength and will definitely flaw the results. To make sure air bubbles are taken care of, normally the wet concrete mix is vibrated to remove any void spaces. In the case of the concrete mix used on our beam, a self-consolidating concrete (SCC) mix was used and there is no need for any vibration to take place.

3.5 Shipping

3.5.1 Beam Removal from Mold

Part of our design included selecting an adequate lifting device to hoist the beam out of the mold safely, and cause no damages to the beam itself. The best choice for the lifting devices the team used is a CX-28 Coil Wingnut Insert and LP-11 Lift Plate-Swivel, secured with a CB-2 Coil Bolt. The Wingnut Insert will be cast inside the beam, and secured before it reaches the full curing time. Hoisting the beam out of the mold will need to be done cautiously so that no one is injured and the beam stays intact. Both ends of the beam will have a lifting device, from which the lifting cables will connect mid-span to a single lifting point.

3.5.2 Loading and Transportation

Loading and securing the beam on the truck requires the consideration of different potential issues. Securing the beam entails that any sudden stops, turns, or bumps will not adjust the beam from its original position on the truck. One of the larger concerns for our design was making sure that no cracks form along the span during any step in the process, other than after 20 kips of live load is applied. There is a lot of rough road from Phoenix to Flagstaff, especially once getting close to Flagstaff, due to the freeze/thaw conditions of the road.

3.5.3 Beam Unloading and Setup

Once in Flagstaff, NAU Facility Services was on hand to transport the beam off the truck to the outside of the engineering concrete lab. In order to get the beam into the lab, a hydraulic forked lift was used to raise the beam high enough so industrial carts can be set under the beam. The team needed to assure that the beam did not crack on the top, with the increase in stress due to lifting at mid-span. To prevent this, a spreader beam was set between the forks and the beam to distribute the load. Once on the carts, the beam was strapped in and rolled into the lab.

(Currently the beam is still on the carts in the lab. Professor Tuchscherer will be assisting with setup this week since we aren't as familiar with the process. Testing setup will hopefully take a few days and ideally it will be broken beginning of next week.)

3.6 Testing

3.6.1 Test Overview

The test for this project consist of loading the beam with two point loads, perpendicular to the length of the beam. The test starts when the hydraulic press starts applying the point loads. We will be looking for different results in this testing process. The results we will look for include the applied load that causes the first crack at the bottom, the load which cause complete failure of the beam, and maximum deflection at maximum applied load [1]. The test concludes with the failure of the beam.

3.6.2 Test Setup

Prior to testing, the beam is set on the supports of the hydraulic press. As one of the requirements for the competition, a video camera will be set up to record the test from beginning to end. We will be setting up sensors that will record the stress and strain at the bottom of the beam, which will feed data to a computer allowing for the creation of stress-strain curves for our analysis.

3.6.3 Performing the test

The test is performed in the concrete lab using a very large hydraulic press, referred to as "The Hulk". This device will apply the live loads at 10 feet from the left end, and 13 feet from the left end. The loads will be applied simultaneously and equivalently until the beam reacts accordingly. In this process, we will be recoding the deflection of the beam as part of the competition submission. Once the hydraulic press applies enough load to fail the beam, the test will conclude and the data from the test can exported onto the computer.

(This section will be updated as soon as the set up takes place. Most of this information is correct, though we will be talking through the logistics with Professor Tuchscherer.)

3.6.4 Test Analysis

Once the test is concluded, we are now capable of extracting the testing data in the computer program, allowing the team to generate stress-strain curves. With stress-strain curves, we can graphically see the moment the beam fails. Stress and strain data is used to find the failure loading conditions.

Table 4 Results of the Final Beam Testing

Cracking Load (Kips)	NA (Test yet to be performed)
Failure Load (Kips	NA (Test yet to be performed)

(Given that we have not completed the test, The information above explains how the data will be analyzed, including the graphs generated from the testing of the load/mid-span deflection graph with the peak load and cracking load (from the bend over point). This section will also contain pictures of the testing process.)

4.0 Summary of Engineering Costs

The following section explains the engineering roles, cost of services, and total hours performed on the project.

4.1 Engineering Roles

For the competition, the team decided to have four engineering roles to design the optimal design. The four engineering roles included the senior engineer, structural engineer, lab technician, and an engineer in training. The role of the senior engineer included reviewing the overall competition rules, deciding the overall concrete mix that will be used for the manufacturing, decided the overall cross sectional design that will be used, and overlooked the testing and project management. The role of the structural engineer included programming the Mathcad software that was used in running multiple cross sections. The structural engineer also assisted the senior engineer in the testing process and project management. The mix design and concrete testing was done by the lab technician. The engineer in training assisted all of the other roles in areas that needed assistance.

4.2 Updated Hours of Work

The number of hours of work that were performed on this project have been inserted into *Table 4* and the predicted hours for the project can be seen in *Table 5*. The number of hours for the Beam Design has increased due to complications in the Mathcad programming. The time of the lab technician did decrease due to completion of the mix design happening in the first semester. The team has a total of 232 hours in the budget to complete the project on time.

Table 5 Current Hours of Work

Task	Senior Engineer	Structural Engineer	Lab Technic	EIT	Total Hours
Task 1 - Competiton Understanding	7	6	0	2	15
Task 2 - Beam Design	23	124	100	85	332
Task 3 - Tpac Manufacturing	8	6	0	28	42
Task 4 - PCI Big Beam Final Testing	0	0	0	0	0
Task 5 - Delilverables	25	10	7	50	92
Task 6 - Project Management	20	20	20	10	70
Total	83	166	127	175	551

Table 6 Predicted Hours of Work

Task vs Staff position (estimated hours)					
Task	Senior Engineer	Structural Engineer	Lab Technician	EIT	Total Hours
Task 1 - Competiton Understanding	7	6	8	6	27
Task 2 - Beam Design	51	68	137	72	328
Task 3 - Tpac Manufacturing	8	6	0	28	42
Task 4 - PCI Big Beam Final Testing	20	25	12	29	86
Task 5 - Delilverables	32	15	14	74	135
Task 6 - Project Management	40	40	30	25	135
Total	158	160	201	234	753

4.3 Cost of Engineering

The current cost of engineering services can be seen in Table 6 and the predicted cost of engineering costs can be seen in Table 7. The team is currently under budget for the project by $17,343.33.

Table 7 Current cost of engineering services

Classification	Billing Rate ($/hr)	Hours	Total Cost $
Senior Engineer	151.25	90	13612.5
Structural Engineer	126.225	130	16409.25
Lab Technician	90.75	57	5172.75
EIT	56.32	127	7152.64
TOTAL			$42,347.14

Table 8 Predicted cost of engineering services

Classification	Billing Rate ($/hr)	Hours	Total Cost $
Senior Engineer	126	158	19830.571
Structural Engineer	101	160	16165.5909
Lab Technician	57	201	11519.2986
EIT	52	234	12175.0067
			$59,690.47

4.4 Scheduling

Initially, a schedule was created to map out the progression of our project over the two semesters of Capstone. From the Gantt chart created in the first semester, we should be about half way into the manufacturing and fabrication process. Currently we are just starting the manufacturing and fabrication process, though we are still on schedule. This is due to us initially giving Tpac ample time to get all production done, nearly three months. Since it took longer in the design phase, that extra buffer of time came in handy allowing the team to remain on schedule. The two figures below show the Gantt chart from the first semester, Figure 4, and the updated Gantt chart for this semester, Figure 5.

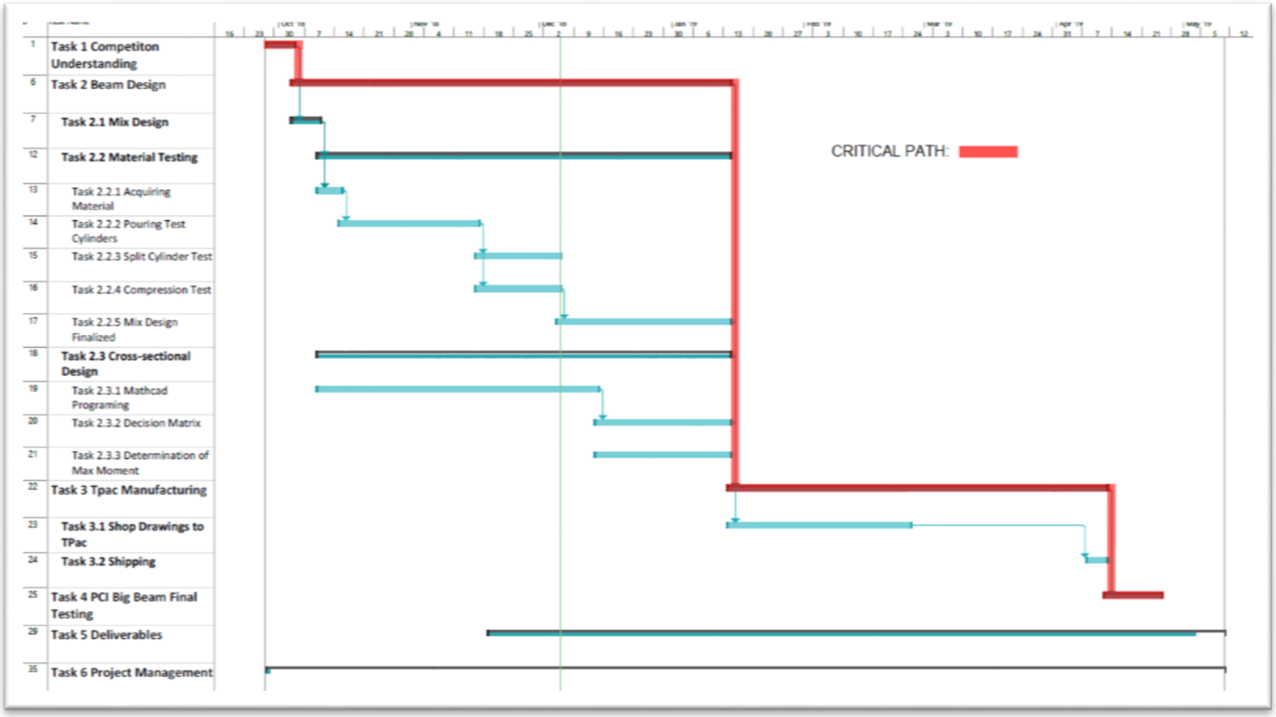


Figure 4 Initial Gantt Chart

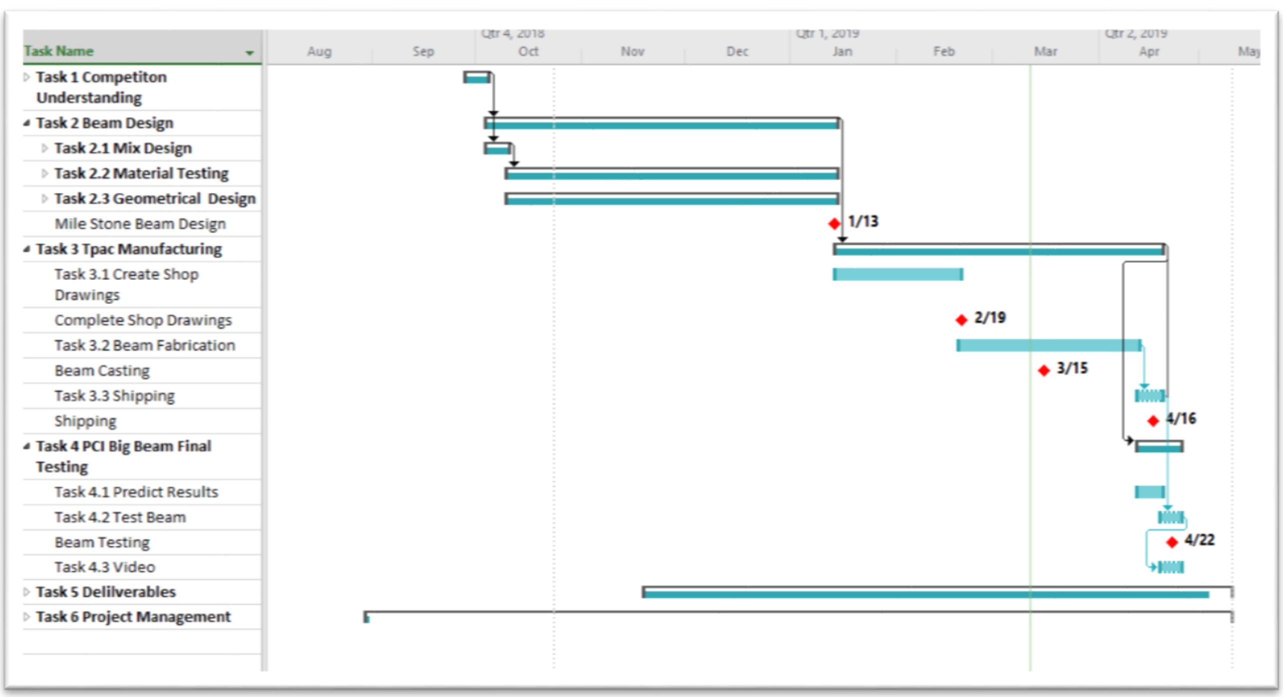


Figure 5 Updated Gantt Chart

5.0 Conclusion

Through the course of this design project, the team went through the design process for a topic that has not been taught in NAU's engineering courses. This meant that all information had to be taught or learned from the PCI handbook. The extent of the project involves more than just designing a beam, but engineering a beam to meet the criteria set forth by the Precast Concrete Institute. The calculations from the Mathcad programming allowed the team to make predictions on when the beam will crack and fail with the induced live loads.

(Discuss more about the predicted values to the actual values from the testing for the cracking and failure loads. This will be done after the testing is completed. Team feels this will be a large part of the conclusion.)

6.0 References

[1] P. C. Institute, "PCI," 2018. [Online].

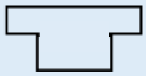
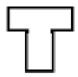
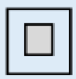
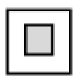
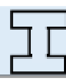
[2] "2018-2019 PCI Competition".

[3] E. Bentz, "Response 2000," University of Toronto, 2010. [Online].

7.0 Appendix

7.1 Apendix 1 - Cross Section Decision Matrix

Table 9 Decision Matrix

Section	Shape	Weight (lb)	Gross Area (in^2)	Cost	Formwork
Shallow T-Beam		3960	198	$284.33	Difficult
T-Beam		2640	132	$262.66	Difficult
LW Hollow Box		1940	114	$257.13	Moderate
NW Hollow Box		1960	98	$204.03	Moderate
I-Beam		3400	177	$328.24	Difficult

7.2 Appendix 2 - Manufacturing Cost

Table 10 Manufacturing Cost

Manufacturing Cost			
	Cost	Quantity	Total
Concrete (yd^3)	$100/yd^3$	0.478	$52.20
Prestressed Strand (ft)	0.30/ft	80	$24.00
A615 Steel	0.45/lb	56	$25.20
Forming (ft^2)	$1.25/ft^2$	82.1	$102.63
		Total	$204.03

7.3 Appendix 3 – Shop Drawings

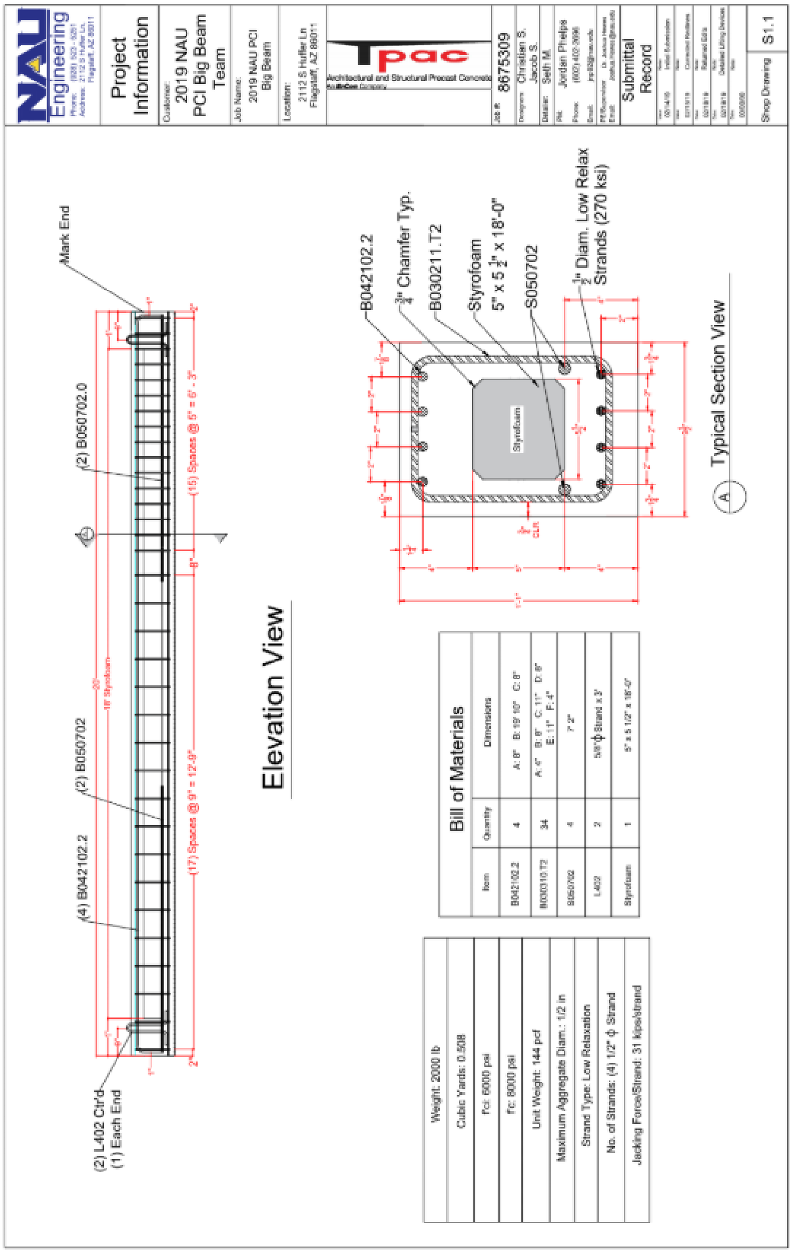


Figure 6 Approved Shop Drawing