May 4, 2015

2014-2015 PCI Big Beam Contest

Abdullah Alhaddad, Brian Bloom, Mingyang Chen, Catherine Irvine

Northern Arizona University

Sponsoring Producer Member:
Tpac Kiewit Western Company, Phoenix, AZ

Faculty Advisor:
Dr. Robin Tuchscherer

Department of Civil Engineering, College of Engineering, Forestry, and Natural Sciences

TABLE OF CONTENTS

List of Figures

List of Tables

List of Equations

1.0 Introduction

This document contains the design report for the 2014-2015 Prestressed/Precast Concrete Institute (PCI) Big Beam Capstone Engineering Project. This includes information on concrete mix and structural design processes, fabrication, testing, and final analysis.

1.1 Acknowledgements

The team would like to thank Dr. Robin Tuchscherer for his support and advice on this project, as well as Abdullah Kassab, our contact at Tpac Kiewit Western Co. (Tpac) [1], for taking the time to work with us to fabricate our beam. We would also like to thank all other employees at Tpac involved in the production and shipping of the beam for their hard work, and all members of Northern Arizona University (NAU) Facility Services

1.2 Project Details

The "Big Beam Contest" is held yearly by PCI for Civil Engineering undergraduate and graduate students to provide them with an opportunity to gain more knowledge about the precast/prestressed concrete industry. Students will design a beam under the competition rules that are provided for the year (see section 1.2.3). Each team must have an industry sponsor that will provide the materials, fabrication, and shipping for the project. Civil Engineering students participating in the contest are exposed to real experience in analyzing and testing prestressed/precast concrete beams through application of their education. [2]

The project will be located primarily at the NAU campus. Site visits to the Tpac facility in Phoenix will also be necessary. Design, analysis, and testing will occur at NAU, while fabrication of the beam will occur at the Tpac facility and the beam will alter be shipped to the NAU campus.

1.2.1 Purpose of Project

The purpose of the PCI Big Beam Contest is to design a prestressed concrete beam to span 17 feet that will be loaded according to one of the permitted load configurations shown in Figure 1 below.

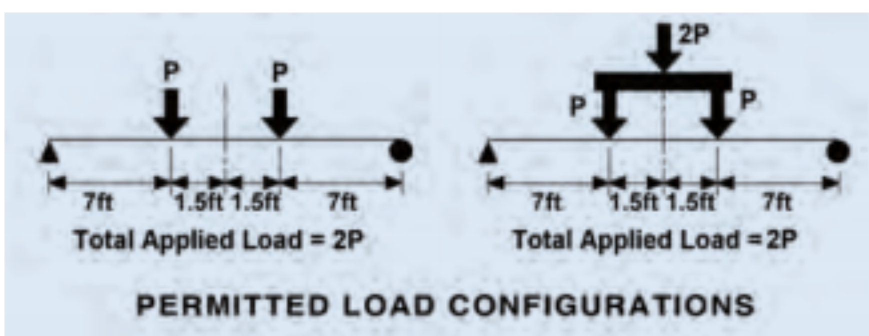


Figure 1: Permitted Load Configurations [3]

Each team must have a technical advisor in addition to the industry sponsor. Technical advisors will provide design assistance to the team. At the conclusion of the competition, prizes are awarded to the teams that perform best in the following areas:

- Lowest weight
- Lowest cost
- Highest deflection
- Cracking load greater than 20 kips
- Ultimate load between 32 and 40 kips
- Most accurate predictions
- Report quality
- Practicality
- Innovation
- Conformance with code

The team is required to submit a report with detailed documentation of the design process, fabrication, and testing. This will include drawings of the cross section and elevation of the beam, description of the concrete mix used, and calculations used for predictions and design. The team will also record and include a video of the testing for documentation. Design aspects of the beam must comply with the American Concrete Institute (ACI) and American Society for Testing and Materials (ASTM) standards.

1.2.2 Background Information [4]

Prestressed concrete beams are designed to overcome concrete's natural weakness in tension. Typically, a concrete's tensile strength is between 8 and 14 percent of its compressive strength. Due to this low tensile capacity, cracks due to flexure develop early in the life cycle of concrete structures. Prestressed concrete is designed to extend the flexural capacity of concrete before it cracks.

Prestressing pre-compresses the tension zone of a beam to counter the tension that will be produced under loading conditions. Beams are "precast" if they are fabricated at a certified facility prior to construction and later shipped to their intended location. This can be compared to cast-in-place concrete beams, which are constructed at their intended final location.

Figure 2 is a simplification of how prestressing works. The process begins with casting the concrete over a prestressing strand located in the tension zone (bottom flange) of the beam. A longitudinal force is placed on the strand to put it in tension. The strands are then cut, "releasing" the beam and forcing it to camber upward as seen in the figure. This puts the tension zone in compression prior to service loads, extending the amount of tension the concrete can withstand.

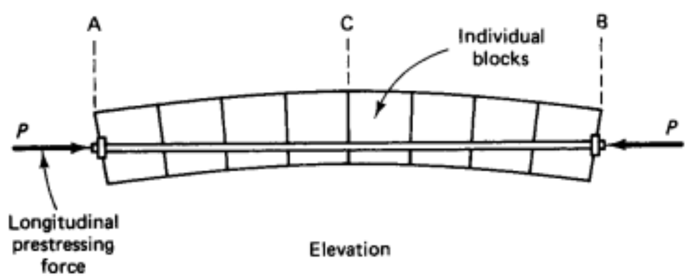


Figure 2: Prestressed Concrete Design

1.2.3 Contest Rules [3]

The contest has a series of rules that must be followed. If a team does not follow any of the rules, the team will be disqualified. Below is a summary of the 2014-2015 contest rules, a full version can be seen in Appendix 6.5.

- The beam must have a span of 17 feet, and cannot be longer than 19 feet overall.
- The beam may have any cross-sectional shape with a flat top surface
- The beam is designed for two factored live loads of 16 kips each, and cannot crack under the service live load of 10 kips each (20 kips total).
- The beam must be loaded as shown in Figure 3.1.1.
- Load must be reported as the total applied load (the sum of the two point loads).
- Ultimate deflection must be measured at Midspan.
- The beam must not use trusses, arches, and other non-flexural members, and must be made primarily of concrete (cement, course aggregates, fine aggregates, and water).
- Reinforcement must be pre-tensioned and/or post-tensioned. Non-prestressed top steel is allowed. All reinforcement must meet spacing and clear cover requirements.
- No experimental materials are to be used.
- All entries must meet ACI-318-11 [American Concrete Institute design code]

1.2.4 Stakeholders

Dr. Robin Tuchscherer:

Dr. Tuchscherer is from NAU and is the team's technical advisor. Throughout the process he provided technical advise on the design of a typical pre-stressed concrete structure, reviewed design calculations, and helped deal with any technical problems that occurred. Dr. Tuchscherer also provided the team with the resources and equipment needed to perform the testing and analysis.

Tpac:

Tpac Kiewit Western Co (Tpac) is a concrete manufacturer located in Phoenix, Arizona. They are a "recognized leader in the design, manufacture, and erection of precast/prestressed architectural building systems." [1] Tpac offered professional and practical advice for prestressed concrete. As the fabricator for the beam, the final design was constrained by available resources, and what was feasible with their current equipment.

PCI Committee:

The PCI Committee regulates the contest and will be the judges for this project. PCI is a trade organization that has a seat on the code committee to represent all precast companies. It was founded in 1954 and now provides technical resources, certification, continuing education, and research in the precast/prestressed concrete field. [2]

NAU Department of Civil Engineering, Construction Management, and Environment Engineering:

The NAU Department of Civil Engineering, Construction Management, and Environmental Engineering (CECMEE) is the final stakeholder in the project. As students of the CECMEE department, the work done by the team throughout the semester reflects on the department itself.

2.0 Summary/Judging Form

BIG BEAM CONTEST 2015

28 April 2015
Date

Northern Arizona University — Student Team (school name)
N/A — Team Number
18 Mar 2015 — Date of Casting

Basic information

1. Age of beam at testing (days): 28

2. Compressive cylinder tests*
   - Number tested: 3
   - Size of cylinders: 4x8"
   - Average: 8330 psi

3. Unit weight of concrete (pcf): 126.2
   - Slump (in.): (spread) 24.5
   - Air content (%): 3
   - Tensile strength (psi): 530
   - Circle one: Split cylinder MOR beam

4. Pretest Calculations
   - a. Applied point load at midspan to cause cracking (kip): 22.1
   - b. Maximum applied point load at midspan (kip): 32.3
   - c. Maximum anticipated deflection due to applied load only (in.): 2.5

Pretest calculations MUST be completed before testing.

*International entries may substitute the appropriate compressive strength test for their country.

Test summary forms must be included with the final report, due June 16, 2015

Judging Criteria

Teams MUST fill in these values.

a. Actual maximum applied load (kip): 43.5

b. Measured cracking load (kip)[1]: 21.2

c. Cost (dollars): 132.29

d. Weight (lb): 1452

e. Largest measured deflection (in.): 4.01

f. Most accurate calculations

(a) Absolute value of (maximum applied load – calculated applied load) / calculated applied load: 0.347

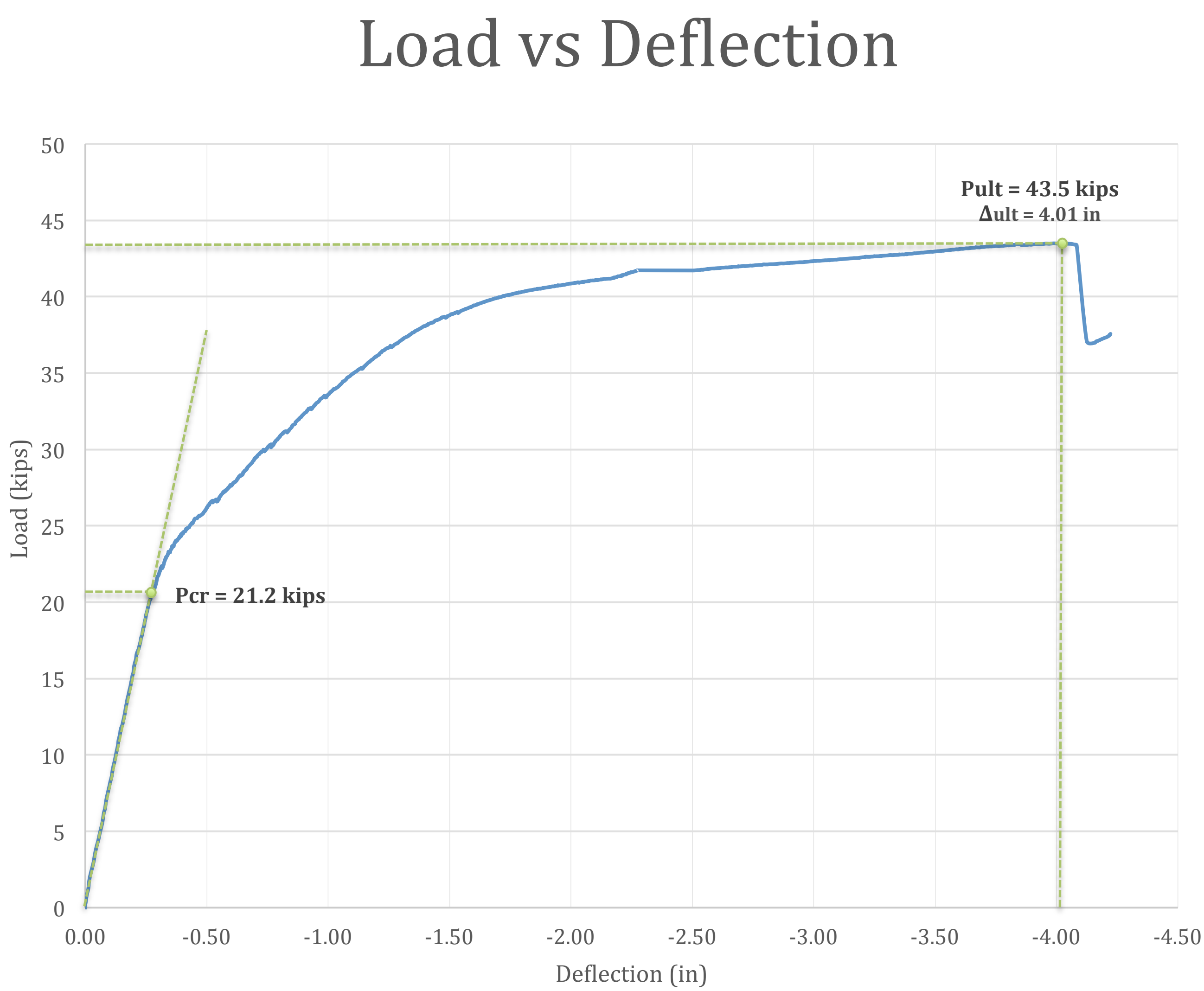
(b) Absolute value of (maximum measured deflection – calculated deflection) / calculated deflection: 0.616

(c) Absolute value of (measured cracking load – calculated cracking load) / calculated cracking load: 0.041

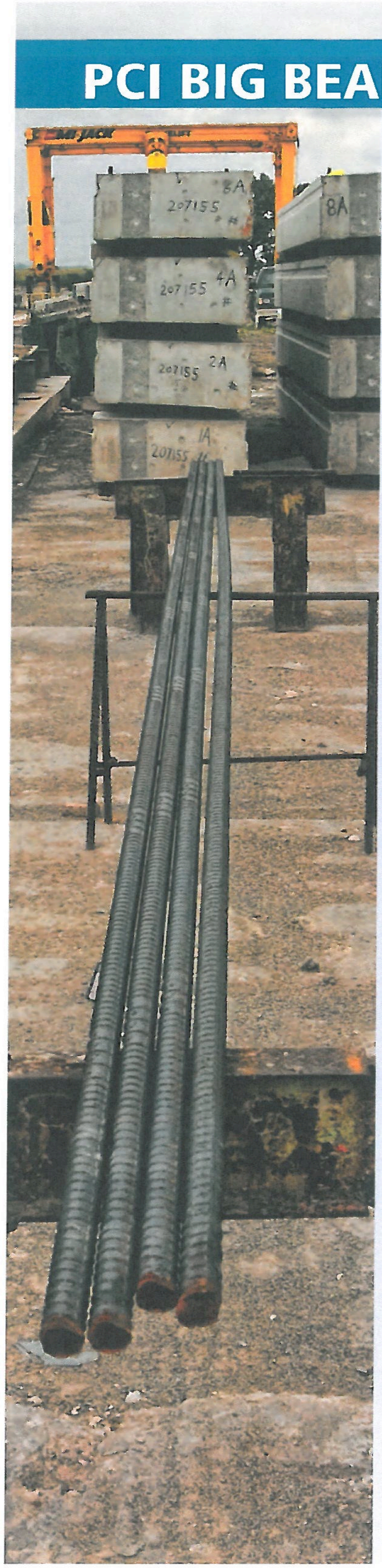
Total of three absolute values (a + b + c) = 1.004

[1]Measured cracking load is found from the "bend-over" point in the load/deflection curve. Provide load/deflection curve in report.

Sponsored by PCI and Sika


Load vs Deflection
Pult = 43.5 kips
Δult = 4.01 in
Pcr = 21.2 kips
Load (kips)
50
45
40
35
30
25
20
15
10
5
0
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
Deflection (in)

3.0 Certification Of Calculations Performed Prior to Testing



PCI BIG BEAM COMPETITION – 2015

CERTIFICATION

Tpac, A Division of Kiewit Western Co.

As a representative of (name of Producer Member or sponsoring organization)

Northern Arizona University

Sponsoring (name of school and team number)

I certify that:

- The big beam submitted by this team was fabricated and tested within the contest period.
- The calculations of predicted cracking load, maximum load, and deflection were done prior to testing of the beam.
- The students were chiefly responsible for the design.
- The students participated in the fabrication to the extent that was prudent and safe.
- The submitted test results are, to the best of my knowledge, correct, and the video submitted is of the actual test.

Certified by:

Signature

Abdullah Y. Kassab

Name (please print)

April 24th, 2015

Date

THIS CERTIFICATION MUST BE PART OF THE FINAL REPORT

Sponsored by PCI and Sika

4.0 Drawings

Figure 3 and Figure 4 show the cross-section and beam elevation, respectively, for the final design created in AutoCad [5]. Table 1 is the final Bill of Materials sent to Tpac. The full shop drawing is in Appendix B-4**.**

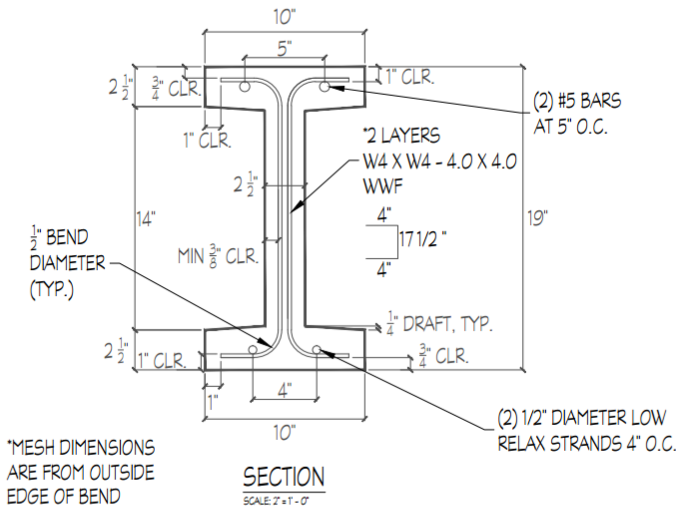


Figure 3: Final Cross-Section (Not to Scale)

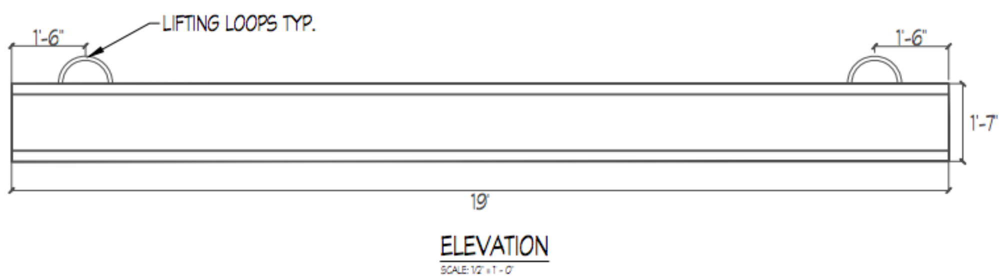


Figure 4: Beam Elevation (Not to Scale)

Table 1: Bill of Materials

Material	Quantity	Units	Comments/Criteria
½" Diameter Strand Jacking Force=31 kips	38	ft	ASTM A416 (270 ksi) [6]
#5 bar	38	ft	ASTM A615 (60 ksi) [7]
W4 x W4 - 4.0 x 4.0 WWF (Welded Wire Fabric)	0.0269	ft^2	ASTM A1064 (65 ksi) [8]
LW-5 concrete	0.42	yd^2	f'ci = 5000 psi, f'c (28 day) = 8000 psi
4 x 8 cylinders	6	ea.	ASTM C31 [9]
	Total Beam Weight		**<u>1428 lb.</u>**

5.0 Concrete Mix Design

5.1 Characteristics

The concrete mix used for this project was a lightweight, self-consolidating concrete (SCC) mix design provided by Tpac. Table 2 lists the characteristics of the mix design along with typical content of each.

Table 2: Concrete Mix Characteristics

Characteristic	Content
Type II AZ Portland Cement	197 lb./ft^3
Course Aggregate: ½" Expanded Shale	102 lb./ft^3
Fine Aggregates: WCS Maricopa	163 lb./ft^3
Pozzolan Class F Fly Ash	137 lb./ft^3
Dry Unit Weight @ 28 day	122 lb./ft^3
Water	63 lb./ft^3
Air Content	3%
Max W/C Ratio	0.346
Fines to Total Aggregate Ratio	0.62
Chemical Admixtures	*
Spread	27"

**Proportions of chemical admixtures are proprietary and include Water Reducer, Air Entrainer, and Concrete Rheology Admixture for SCC*

5.2 Discussion of Mix Design Choice

The team had three choices for mix design; a lightweight concrete mix (Table 2), a normal weight concrete mix design, or to make a new concrete mix. The team wanted a mix that would be extremely reliable and had plenty of data to back it up. Because Tpac had used the two mix designs they provided already, they had large amounts of data that showed their reliability, therefore the team chose not to make their own concrete mix and use one of the two provided.

The second decision was between lightweight and normal weight concrete. Lightweight concrete was ultimately chosen because it allowed us to reduce the weight of the beam without ultimately sacrificing any strength [10]. Also, research also has shown that lightweight concrete tends to have higher ultimate strain than normal weight concrete [11]. Higher strains produce higher curvature, which produces higher deflection. So this choice allowed us to reduce the weight while also potentially increasing the ultimate deflection.

5.3 Mix Design Performance

The design performed better than expected in most of the design areas. Figure 5 shows the stress-strain curves for the three cylinders tested. The average of the three points labeled were taken to determined average stress and strain shown above. Table 3 shows the design values versus the measured values.

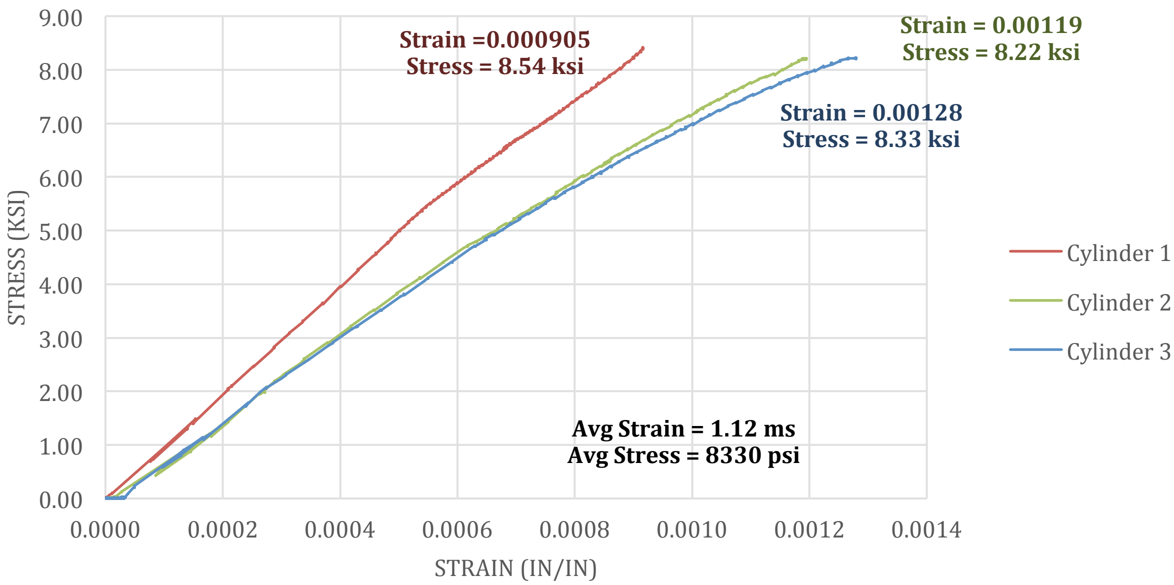


Figure 5: Stress/Strain Curves

Table 3: Design Values vs Measured Values

Characteristic	Design	Measured	% Difference
Compressive Strength at Release (f_{cr})	5000 psi	5530 psi	-10
Compressive Strength at 28-days (f'_c)	8000 psi	8330 psi	-4
Ultimate Strain at 28-days (ε_c)	2 ms	1.12 ms	-11
Unit Weight (γ_c)	122 pcf	126.1 pcf	-3
Modulus of Elasticity (E_c)	5098 ksi	6852 ksi	-29

These values were measured by testing six 4x8" concrete cylinders, three per ASTM C496 (tensile strength) and three per ASTM C39 (axial compression, average displacement).

The peak stress and corresponding strain values were determined as the largest point (stress) in the data before it began to drop, and the peak strain was the strain at that point. The averages of the three tests were used in the calculations for final predictions (section 7.3).

6.0 Structural Design

Based on the project requirements [3], the team began by analyzing potential designs in Mathcad [12] based on the following three design criteria: 1) stress at release meets code requirements, 2) cracking load greater than 20 kips, and 3) an ultimate load between 32 and 40 kips. The team determined to design three beam alternatives characterized by "lowest weight," "lowest cost," and "highest deflection." The final designs are shown in
Figure 6.

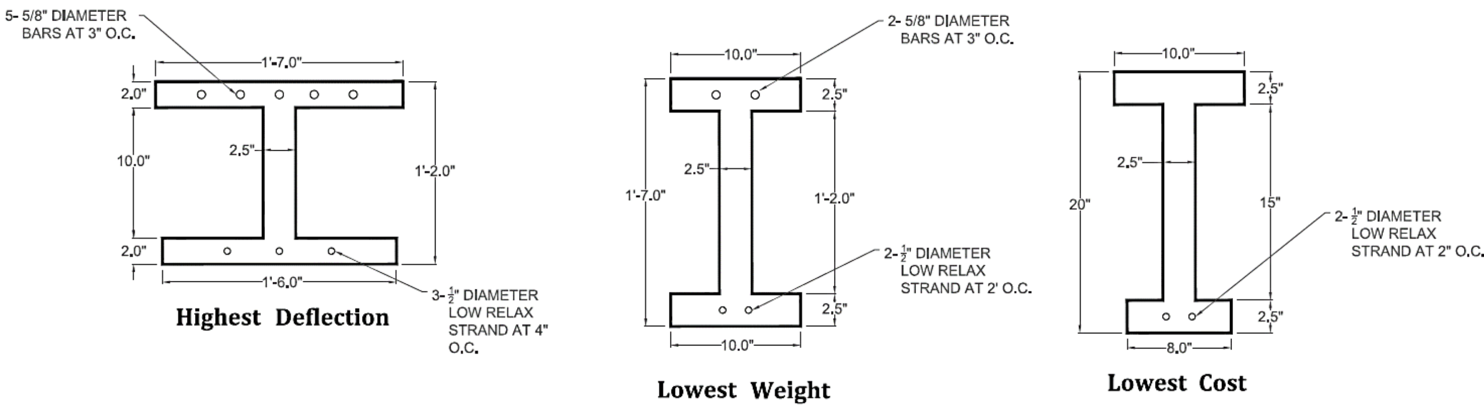


Figure 6: Three Design Alternatives

- *Highest Deflection*: To increase the deflection, the team focused on decreasing the depth of the beam while increasing the amount of compression steel to potentially allow for more deflection before ultimate failure. Lightweight concrete was used in this design, because (as discussed in section 5.2) it is expected to have a higher deflection.
- *Lowest Weight:* This was the lightest feasible beam that met cracking and ultimate load requirements. Lightweight concrete was the only concrete mix alternative considered for this design. Use of prestressing and compression steel was not considered to be a factor, as ultimately most of the weight is due to concrete. The design overall was controlled by the minimum size of the cross-section and the number of reinforcement steel needed. This resulted in a slender and deep beam, an efficient design for flexure. The bottom and top flanges were the same size because it increased the cracking load to meet the minimum load requirement.
- *Lowest Cost:* This design attempted to maximize flexural ability while minimizing all other options that general increase the cost. This led to a slightly deeper beam than the lowest weight design. Normal-weight concrete was the mix alternative considered, as it is cheaper by the contest rules [3] than lightweight. Additionally, no compression steel was considered for the design, only the necessary amount of prestressed steel. The bottom flange was smaller than the top flange because it already met the cracking load requirement, and it reduced the total cost by using less concrete.

6.1 Initial Design Values

A summary of the results from the MathCad [12] analysis can be seen in Table 4 below (calculations are in Appendix B-1). These values are approximations, and are not the final predicted values for any of the designs. The deflections shown are *not* accurate but approximated assuming linear-elastic behavior. The resulting values were solely used as a basis for qualitative comparison between designs. The method for predicting the actual deflection is described in Section 7.3.

Table 4: Initial Design Values

	Mc (k-ft)	Pc (kips)	Mu (k-ft)	Pu (kips)	Deflection (in)	Cost ($)	Weight (lb.)
Lowest Weight	77.7	22.1	116	32.3	1.87	63	1257
Lowest Cost	84.2	24.1	120	33.5	1.60	42	1430
Highest Deflection	86.9	24.7	125	34.9	5.22	96	1735

6.2 Decision Matrix

A decision matrix (Table 5) was created to compare the three designs. The scoring is based on the competition's for scoring of the beam [3], and is rounded to the nearest whole number.

Table 5: Decision Matrix

Design	Weight (lb)	Score	Cost ($)	Score	Deflection (in)	Score	Total
Lowest Weight	1257	10	63	6	1.87	1	***17***
Lowest Cost	1430	6	42	10	1.59	0	***16***
Highest Deflection	1735^	0	96	0	5.20	10	***10***

Based on this method, the "Lowest Weight" option was the best design. Shear reinforcement was designed and calculations were performed as another check for the suitability of the design, and can be seen in Appendix B-1**.** Final predicted values are shown in Table 6, with a summary of the process in Section 7.3.

Table 6: Predicted Values

Cracking Load	Ultimate Load	Ultimate Deflection
22.1 kips	32.3 kips	2.5 in

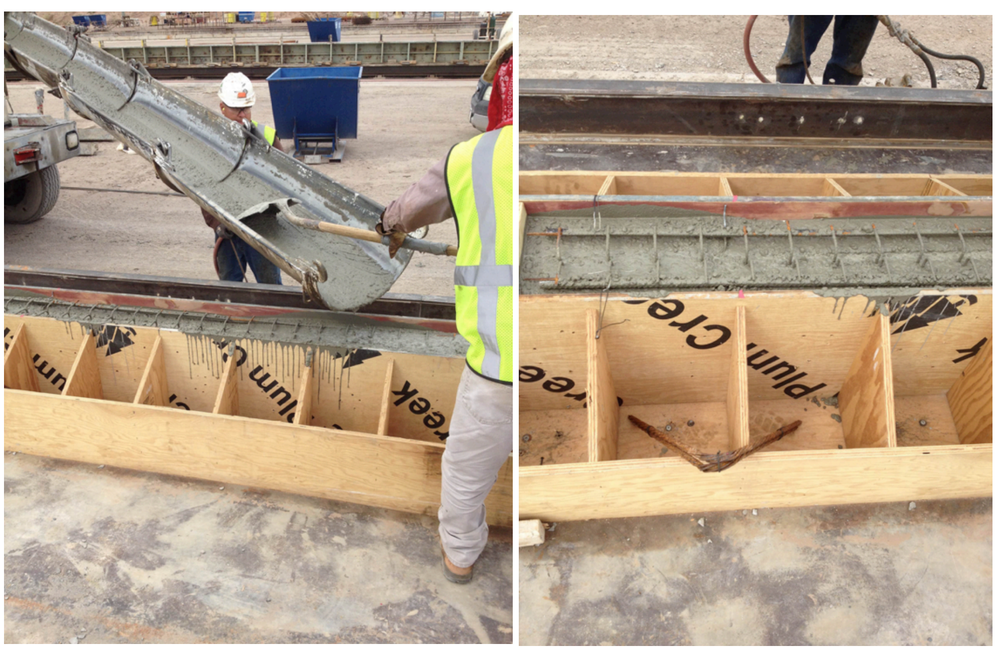
7.0 Beam Fabrication & Testing

7.1 Fabrication

The beam was fabricated on 18 March 2015 at Tpac in Phoenix, Arizona, and shipped 5 days later on 23 March to NAU in Flagstaff, Arizona. One team member attended the fabrication and checked all measurements prior to placing the concrete, as seen in Figure 7. Figure 8 includes pictures showing the fabrication process. The concrete was placed in increments while it was vibrated in between in order to allow the concrete to fill all available space.

(a) Checking Formwork (b) Checking Measurements

Figure 7: Formwork



(a) Placing Concrete (b) Vibrating Concrete

Figure 8: Fabrication

7.2 Test Setup

While waiting for the beam to be at 28-days to test, the team set up the testing equipment, as demonstrated in Figure 9 and Figure 10.

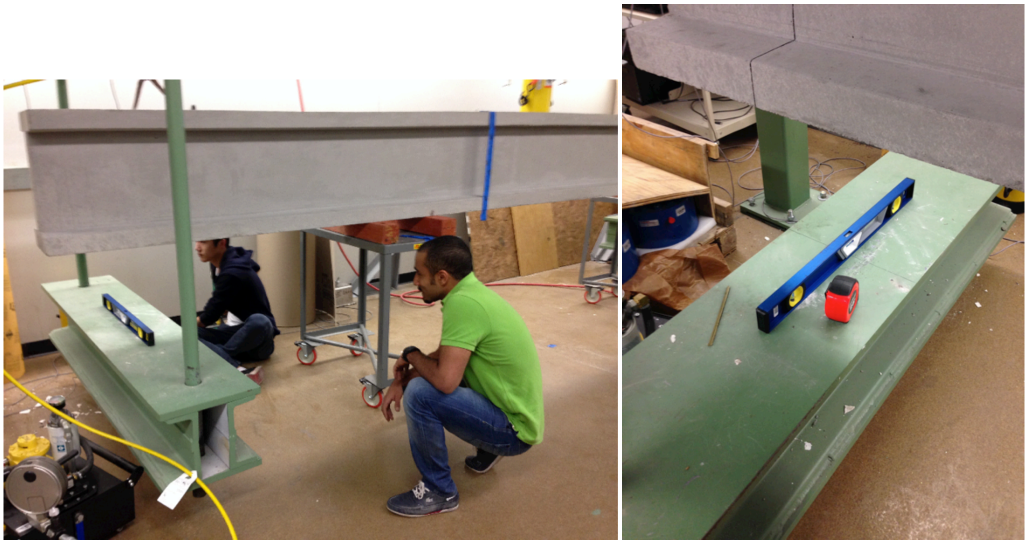


Figure 9: Lowering and Leveling Supports

Figure 10: Dropping Beam onto Supports

Figure 11 shows an AutoCAD [5] drawing of the test setup and Figure 12 shows the beam in the setup prior to testing.

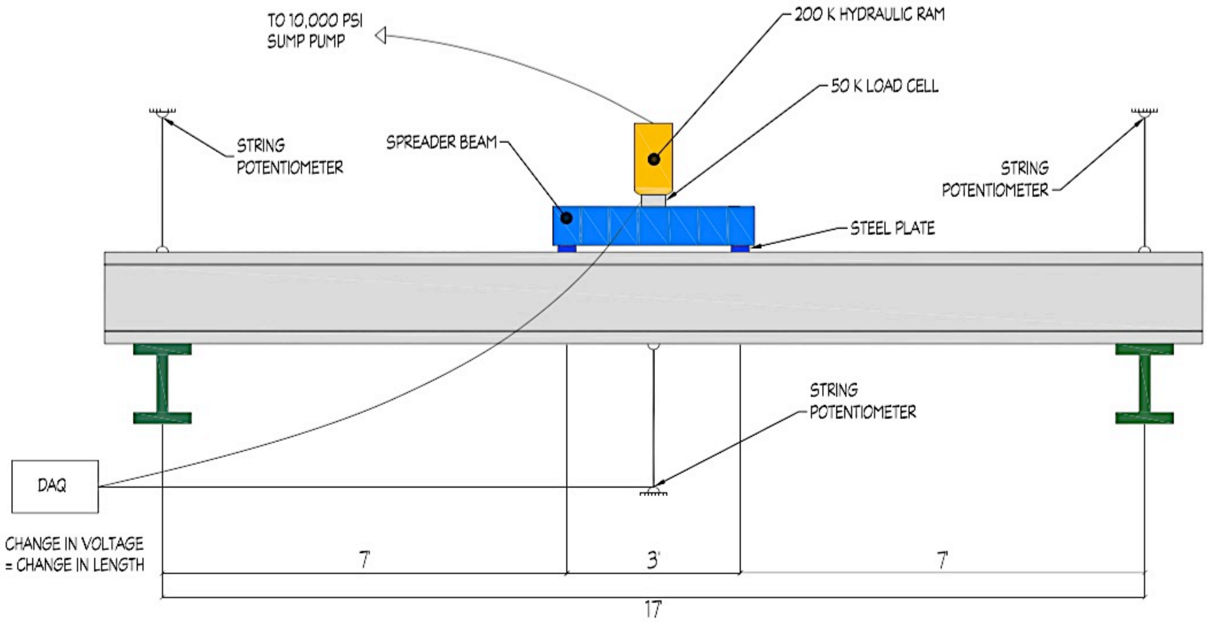


Figure 11: Test Setup & Frame

The load is applied by a hydraulic ram onto a spreader beam, which distributes the load to two steel plates 1.5 feet on each side from the center. The load is measured by a load cell directly beneath the hydraulic ram. Displacement is measured by three string potentiometers, one at each support and the third in the center. The total displacement is calculated as shown in Equation 1.

$$\Delta_{ult} = \Delta_{centerline} - \frac{\Delta_{left} + \Delta_{right}}{2}$$

Equation 1: Total Deflection

The load cell and string potentiometers are hooked up to Data Acquisition (DAQ) hardware, where the data is collected in terms of voltages and converted to loads and displacements.

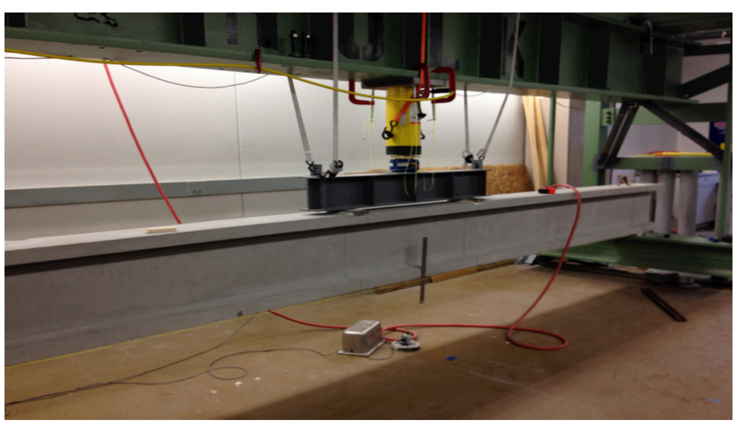


Figure 12: Setup Complete

7.3 Final Predictions

After the beam setup, predictions were made using the cylinder tests (section 4) and Response2000 [13]. Response2000 shows the moment-curvature section response for the beam design, using concrete mix values as reported in Section 4. The moment-curvature graph (Figure 13) given in response shows the moment at cracking (where the graph becomes nonlinear) and the ultimate moment (where the graph ends). These values were used to calculate the cracking load and ultimate load.

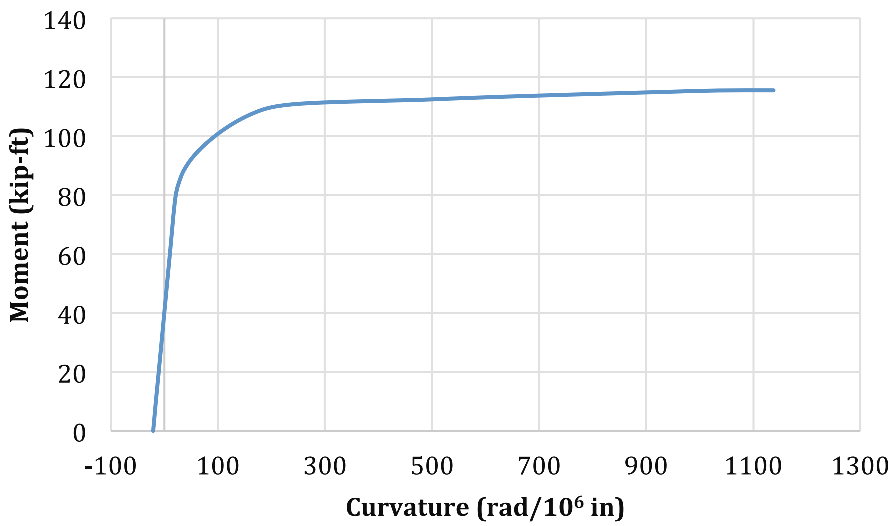


Figure 13: Moment-Curvature Graph from Response2000

Microsoft Excel [14] was used to calculate ultimate deflection by integrating the moment-curvature response by the Method of Virtual Work (Equation 2). Full calculations for cylinder tests, load predictions, and deflection predictions are available in Appendix B.

$$\Delta = \int_0^L \frac{Mm}{EI} dx$$

Equation 2: Virtual Work Method

7.4 Testing

The test lasted approximately 3.5 minutes in total (see Appendix C for video of test). The ultimate failure was caused by one of the prestressing strands breaking (Figure 14) at a total load of 43.5 kips. This also resulting in some crushing at the top of the beam (Figure 15).

Figure 14: Ultimate Failure (Strand/Crack)

Figure 15: Crushing / Visual Indication of Deflection

7.5 Analysis of Test Data

After the test was complete, the team took the data and compared it to the predicted values, as shown in Table 7.

Table 7: Predicted Values vs Actual Results

	Predicted	Actual	%Difference
Cracking Load	22.1 kips	21.2 kips	4
Ultimate Load	32.3 kips	43.5 kips	-30
Ultimate Deflection	2.5 in	4 in	-46

The ultimate load resulted in a 30% difference, and was above the 42 kip limit. This was likely caused by several factors. The first factor was the mesh used in the beam had steel running horizontally along the length of the beam – as shown in Figure 16 – rather than just vertically and this was not factored into the design. This extra steel potentially added more tensile capacity to the bottom flange.

Figure 16: Strand and Mesh

The calculations were re-run accounting for these errors and reached a new moment of 140.6 kip-ft corresponding to a new ultimate load of 39.4 kips. These assumed errors accounted for 7000 pounds of the extra load the beam held. Had the team accounted for the flexural resistance provided by mesh, the error on the predicted ultimate would have been reduced from 30% to 10%. The cross-section including the mesh (as modeled in Response2000 [13]) is shown in Figure 17 and the updated Moment-Curvature graph is shown in Figure 18.

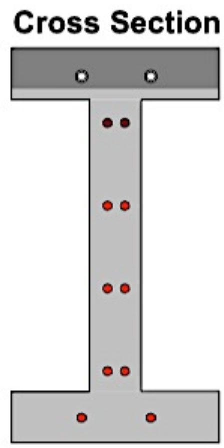


Figure 17: Cross-Section Showing Approximated Mesh Locations

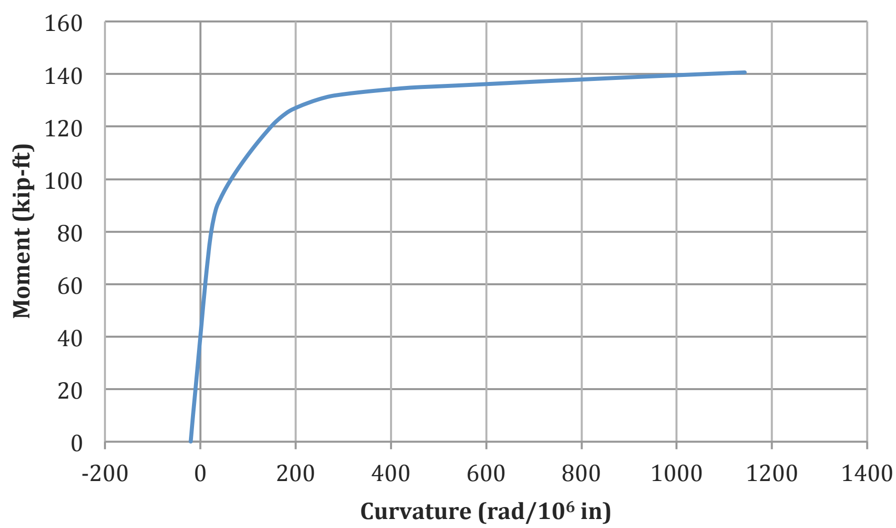


Figure 18: Moment-Curvature Graph Including Mesh

8.0 Summary of Project Costs and Schedule

8.1 Cost of Implementing the Design

Table 8 shows the cost of implementing the design based on the costs provided in the contest rules [3]. The cost represented here is purely fabrication cost, and does include design or other costs incurred. For full project cost, see section 8.3.

Table 8: Summary of Beam Costs

Classification	Hours/Quantity	Billing Rate ($/hr)	Cost
Lightweight Concrete	0.42 cu. yd	$110/cu. yd	$46
½" Prestressing Strand	38 ft	$0.30/ft	$11
Compression Steel	40 lb	$0.45/lb	$18
Mesh	0.027 lb	$0.50/lb	$1
Formwork	46 sq. ft	$1.25/sq. ft	$57
		TOTAL	$133

8.2 Cost of Engineering Design

Table 9 shows the total design cost for the project. This number includes personnel costs and any travel expenses.

Table 9: Final Cost of Engineering Design

	Classification	Hours/Quantity	Billing Rate ($/hr)	Cost
I. Personnel	Senior Engineer	156	110	$17,160
	Information Engineer	156	86	$13,416
	Design Engineer	156	100	$15,600
	Engineering Analyst	156	100	$15,600
	TOTAL HOURS	*624*	*SUBTOTAL*	*$61,776*
II. Travel	Trips to Phoenix @ 286 mi/trip	3	$0.56/mi	$481
TOTAL DESIGN COST: $62,267				

Table 10 is a comparison of the predicted versus the actual cost. The implementation cost was predicted to be significantly higher than the actual cost, because at the time of proposal submission, the value was based off assumed commercial values, rather than values provided in the contest rules. The engineering design cost is slightly lower due to the fewer number of hours needed to complete the project, also shown.

Table 10: Comparison of Predicted vs Actual Cost

	Predicted	Actual
Implementation Cost	$5000	$133
Engineering Design Cost	$70,088	$61,776
Total Hours	752	624

8.3 Project Schedule

Table 11 shows the actual project schedule versus the proposed project schedule. Green highlights represent on-time tasks while yellow highlights represent late tasks. Grey highlights are tasks that were not originally included in the project schedule. Most of the project was completed on time, but halfway through the second semester, an error in design was discovered. Due to this error, the team had to design and submit new designs and come up with a new decision matrix, even though all this had already been completed for an older (but incorrect) design. In spite of this, however, the project was still completed on time.

Table 11: Project Schedule

Task Name	Actual Start	Actual Finish	Predicted Start	Predicted Finish
Project Understanding & Research	**Mon 8/25/14**	**Mon 11/17/14**	**Mon 8/25/14**	**Mon 11/17/14**
- Understand Technical Requirements	Mon 8/25/14	Fri 9/19/14	Mon 8/25/14	Fri 9/19/14
- Understand Competition Rules	Thu 9/25/14	Fri 10/3/14	Thu 9/25/14	Fri 10/3/14
- Tpac Plant Visit	Mon 11/17/14	Mon 11/17/14	Mon 11/17/14	Mon 11/17/14
Technical Details and Design	**Mon 9/22/14**	**Mon 11/24/14**	**Mon 9/22/14**	**Mon 11/24/14**
- Learn basics of pre-stressed design	Mon 10/6/14	Mon 10/20/14	Mon 10/6/14	Mon 10/20/14
- Initial Designs	Tue 10/21/14	Mon 11/24/14	Tue 10/21/14	Mon 11/24/14
Calculations in Mathcad	**Tue 10/7/14**	**Mon 11/10/14**	**Tue 10/7/14**	**Mon 11/10/15**
- Learn to use and setup Mathcad	Tue 10/7/14	Mon 11/3/14	Tue 10/7/14	Mon 11/3/14
- Calculations	Mon 11/3/14	Mon 11/10/14	Mon 11/3/14	Mon 11/10/14
Final Design	**Mon 11/10/14**	**Mon 3/16/15**	**Mon 11/10/14**	**Mon 2/9/15**
- Decision Matrix	Tue 11/25/14	Sat 3/14/15	Tue 11/25/14	Sat 12/6/14
- Shop Drawings	Mon 1/19/15	Mon 3/16/15	Mon 1/19/15	Mon 2/9/15
Predictions in Response2000	**Mon 2/9/15**	**Wed 4/15/15**	**Mon 2/9/15**	**Mon 3/9/15**
- Predictions	Mon 2/9/15	Wed 4/15/15	Mon 2/9/15	Sun 3/8/15
- Cylinder Tests	Wed 4/15/15	Wed 4/15/15	Mon 3/9/15	Mon 3/9/15
Testing and Analysis	**Wed 3/18/15**	**Thu 4/23/15**	**Mon 3/9/15**	**Fri 3/13/15**
- Fabrication	Wed 3/18/15	Wed 3/18/15	N/A	N/A
- Shipping	Mon 3/23/15	Mon 3/23/15	N/A	N/A
- Test setup	Mon 3/23/15	Wed 4/15/15	Mon 3/9/15	Mon 3/9/15
- Testing	Thu 4/16/15	Thu 4/16/15	Tue 3/10/15	Tue 3/10/15
- Analysis	Thu 4/16/15	Thu 4/23/15	Wed 3/11/15	Fri 3/13/15
Project Management	**Wed 11/5/14**	**Tue 5/5/15**	**Wed 11/5/14**	**Thu 4/23/16**
- Application Form	Thu 3/5/15	Thu 3/5/15	Thu 3/5/15	Thu 3/5/15
- Website	Wed 11/5/14	Tue 5/5/15	Wed 11/5/14	Fri 3/20/165
- Final Report	Thu 4/23/15	Tue 5/5/15	Thu 4/23/15	Thu 4/23/15
- Final Presentation	Thu 4/23/15	Thu 4/23/15	Thu 4/23/15	Thu 4/23/15
Evaluate Broader Impacts of Design	**Mon 8/25/14**	**Tue 5/5/15**	**Mon 8/25/14**	**Thu 4/23/15**
- Evaluate Impacts	Mon 8/25/14	Tue 5/5/15	Mon 8/25/14	Thu 4/23/15

9.0 Team Member Statements

Abdullah Alhaddad:

From the PCI Big Beam Project 2015, I have learned many useful things that would help me in my future career. This project made me exposed to acknowledge more about concrete and specially precast/pre-stressed concrete. Furthermore, I applied what I have learned from my civil engineering's classes in this project as a reality project. And, this contest helped me to accomplish the tasks on time and perfect as much as I can. Finally, this type of project would help students who are interested in concrete, to be professional in their future career lives.

Brian Bloom:

Participating in the Big Beam Project challenged me to combine several concepts learned in previous courses. These concepts include engineering design and analysis, beam flexure theory and pre-stressed concrete design. As the project progressed, I was required to combine several of these concepts in order to produce a desired result. The Big Beam competition has also enabled me to gain experience working with a technical advisor and a team of engineers. This project has truly helped me understand the entire perspective when dealing with concrete beam design.

Mingyang Chen:

The most valuable knowledge I gain from this contest is how pre-stressed concrete make structure better. First, pre-stressed concrete is more suitable for precast construction. Our beam is an I-girders type precast beam. It's easy to construct with formwork. The quality control also be easier compare to the reinforced concrete. Second, pre-stressing extends life of structure due to its higher stiffness, shear capacity, which improves serviceability. Last but not least, pre-stressed concrete is low cost alternative for architecture design. It has more aesthetic appeal due to slender sections and more economical sections.

Catherine Irvine:

Throughout the contest these last two semesters, I have learned the importance of learning outside of class and applying that knowledge. I was challenged to take what I knew already and the analytical skills I had been taught and apply it to a new concept. I found that the design process is not as clear and simple as an analytical calculation learned in class, and that there is no "right answer," but there is the design process and design decisions. These decisions must be made as a result of understanding the process, and not just guessing or doing what has been done in the past. The Big Beam Contest has taught me to see beyond equations and actually think, while gaining experience in design rather than simple analysis.

9.1 Team Recommendations

For future contests, we would recommend adding a requirement to the rules that the beam must be released in 72 hours or less to reflect real constraints of the industry while keeping all teams on the same playing field

Appendix

Appendix A: References

Appendix B: Design Calculations / Documents

Appendix B-1: MathCad Document

Appendix B-2: Response2000 Printout

Appendix B-3: Excel Deflection Calculations By Virtual Work Method

Appendix B-4: Shop Drawing

Appendix B-5: Cylinder Test Calculations in Excel*

*only part of data & formulas shown (full graphs shown)

Appendix B-6: Final Load / Deflection Data in Excel

Appendix C: DVD of Test

Appendix A: References

[1] Tpac. (n.d.). Retrieved November 2, 2014, from http://www.tpacaz.com/
[2] PCI. (n.d.). Retrieved September 17, 2014, from http://www.pci.org/
[3] PCI. *Big Beam Contest 2015: Official Rules for the PCI Engineering Design Competition*. 2014. PDF file.
[4] Nawy, Edward G. *Prestressed Concrete: A Fundamental Approach*. 5th ed. Upper Saddle River, N.J.: Prentice Hall, 2010. Print.
[5] AutoCad (2015) [Computer Software]. San Rafael, CA: Autodesk.
[6] ASTM A416 / A416M-12a, Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete, ASTM International, West Conshohocken, PA, 2012, www.astm.org
[7] ASTM A615 / A615M-14, Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement, ASTM International, West Conshohocken, PA, 2014, www.astm.org
[8] ASTM A1064 / A1064M-14, Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete, ASTM International, West Conshohocken, PA, 2014, www.astm.org
[9] ASTM C31 / C31M-12, Standard Practice for Making and Curing Concrete Test Specimens in the Field, ASTM International, West Conshohocken, PA, 2012, www.astm.org
[10] "Properties of Lightweight Concrete." *The Constructor Civil Engineering Home.* 1 Jan. 2014. Web. 1 Mar. 2015 http://theconstructor.org/concrete/properties-light-weight-concrete/5890/
[11] Zareh, Mohammad. "Comparative study of lightweight and normal weight concrete in flexure" (1971). Dissertations and Thesis. Paper 1483.
[12] Mathcad (Version 3.1) [Computer Software]. Needham, MA: PTC.
[13] Response2000 (Version 1.0) [Computer Software]. Toronto, CA: Evan Bentz.
[14] Excel (2013) [Computer Software]. Redmond, WA: Microsoft.

Appendix B: Design Calculations

Appendix B-1: MathCad Document

Appendix B-2: Response2000 Printout

Appendix B-3: Excel Deflection Calculations

Appendix B-4: Shop Drawing

Appendix B-5: Cylinder Test Calculations in Excel

Appendix B-6: Final Load / Deflection Data in Excel

Appendix C: DVD of Test

See included flashdrive