



SACRAMENTO STATE

HERKY'S BIG FREAKIN' BEAM

2021 PCI BIG BEAM REPORT



CE 164- Reinforced Concrete Design

7.12.2021

TEAM MEMBERS

**NAYEF AL-FAYIZ, JAVIER GAYTAN, VADIM GRITSAK,
NOUR HOJEIJ, GARRETT HOPE, SHAIRA SOLVIA, ANTON STA MARIA**

TECHNICAL ADVISOR

DR. ERIC MATSUMOTO

PCI PRODUCING ADVISOR

CLARK PACIFIC (WOODLAND, CA)

1.0 Acknowledgements

Herky's Big Freakin' Beam would like to recognize significant individuals for contributing to the completion of this Big Beam project for the term, Summer of 2021. First and foremost, we would like to recognize Clark Pacific and employees, Brian Bertain and Nathaniel Wilson as well for assisting and leading the fabrication of the beam. Herky's Big Freakin Beam would also like to show our appreciation for PCI Beam alumni Vitaliy Danchuk from the Spring 2019 team for introducing us to Concise Beam Analysis software. Navigating this project and calculations would not have been possible given the short amount of time without guidance from previous PCI Big Beam teams.

We would also like to thank the lab technicians: Mike Newton, Jeffrey Ortiz, Jared Weinburke and Jerremy Willis, who dedicated their time to make it possible for us to test the beam. They went above and beyond in assisting the team during the test-set up and providing the instrumentation needed to acquire all the data.

Last and most importantly, we would like to thank our advisor, Dr. Eric Matsumoto for his mentorship and guidance throughout this process in such a short amount of time. His expertise and dedication in this subject have inspired us to do well in this stressful but rewarding project experience.

2.0 Executive Summary

The Precast/Prestressed Concrete Institute organizes the annual Big Beam Competition for undergraduate and graduate students. Herky's Big Freakin' Beam is California State University Sacramento's team for the 2021 competition. The team consists of the Project Manager, Anton Sta. Maria, Nayef Al-Fayoz, Javier Gaytan, Garrett Hope, Vadim Gritsak, Nour Hojeij, and Shaira Soliva. The team's faculty advisor is Dr. Eric Matsumoto, and Clark Pacific was the team sponsor. This team focused on improving past team beams in order to win the Big Beam Competition.

The team's beam design is an I-beam with three prestressing strands in the bottom. Four steel reinforcing bars were placed at the top flange to satisfy code requirements and ductility. For cost efficiency, stirrups were placed with eight inch spacing from the left of midspan and four inch spacing right of midspan. The team learned and utilized excel spreadsheets and Concise *Beam* software. An important challenge of this year's competition was the scheduling due to COVID-19 restrictions. The team went through extensive campus procedures to be able to fabricate at Clark Pacific and test the beam on campus in person.

Table of Contents

<i>1.0 Acknowledgements</i>	<i>i</i>
<i>2.0 Executive Summary</i>	<i>ii</i>
<i>3.0 Test Summary</i>	<i>1</i>
<i>4.0 Member Certification</i>	<i>2</i>
<i>5.0 Concrete Mix</i>	<i>3</i>
<i>6.0 Beam Design</i>	<i>3</i>
6.1 Preliminary Considerations.....	3
6.2 Flexure	4
6.3 Shear	4
6.4 Prestress Losses	5
<i>7.0 Beam Fabrication</i>	<i>6</i>
7.1 Building Formwork.....	6
7.2 Pretensioning	6
7.3 Placement of Steel Reinforcement.....	6
7.4 Placing the Concrete	6
<i>8.0 Testing</i>	<i>8</i>
8.1 Cylinder Testing.....	8
8.2 Testing Procedures	8
8.3 Summer 21 CE-164 Testing Recommendations	Error! Bookmark not defined.
<i>9.0 Results and Analysis</i>	<i>12</i>
9.1 Stages of Flexural Response	Error! Bookmark not defined.
9.2 Shear Stirrups	Error! Bookmark not defined.
9.3 Compression Rebar	Error! Bookmark not defined.
9.4 Summary of Recommended Improvements	Error! Bookmark not defined.
<i>10.0 Personal Statements</i>	<i>14</i>
<i>11.0 References</i>	<i>17</i>
<i>12.0 Appendices</i>	<i>18</i>
Appendix 1. Figure A.1. CAD Drawings	19

Appendix 2. Cost Analysis	22
Appendix 3. Structural Design Calculations - Summer 21	24
Appendix 4. Concise Beam Analysis.....	31
Appendix 5. Test Log	33
Appendix 6. Concrete Mix Analysis.....	34
Appendix 7. Strand Specifications	36

3.0 Test Summary

PCI BIG BEAM COMPETITION 2020-2021

07/02/2021

Date

California State University, Sacramento

1

04/30/2021

Student Team (school name)

Team Number

Date of Casting

Basic Information

1. Age of beam at testing (days) 55 days

2. Compressive cylinder tests*

Number tested 1

Size of cylinders 4"x8"

Average (psi) 9,143

3. Concrete properties

Unit weight of concrete (lb/ft³) 147.8

Slump (in.) 25.19

Air content (%) 3.2

Tensile strength (psi) 777.6

Pick one: ☒ Split cylinder ☐ MOR beam

4. Pretest calculations

a. Applied load (total) to cause cracking (kip) 20.92

b. Maximum applied point load at midspan (kip) 32.50

c. Maximum anticipated deflection due to applied load only (in.) 3.027

Pretest calculations MUST be completed before testing.

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

Judging Criteria

Teams MUST fill in these values.

1. Actual maximum applied load (kip) 32.46

2. Measured cracking load (kip)[†] 21.18

3. Cost (dollars) 409.97

4. Weight (lb) 1,797

5. Largest measured deflection (in.) 2.584

6. Most accurate calculations

a. Absolute value of (maximum applied load – calculated applied load)/calculated applied load 0.0012

b. Absolute value of (maximum measured deflection – calculated deflection)/calculated deflection 0.1463

c. Absolute value of (measured cracking load – calculated cracking load)/calculated cracking load 0.0124

Total of three absolute values (a + b + c) = 0.1599

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

Test summary forms must be included with the final report, due July 15, 2021.

Sponsored by:



4.0 Member Certification



PCI BIG BEAM COMPETITION 2020-2021

CERTIFICATION

Clark Pacific

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

Sacramento State

Sponsoring (name of school and team number)

I certify that:

- The 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

Brian Bertain, Assistant Project Manager, Clark Pacific

Name (please print)

07/09/2021

Date

32.50k

Predicted Maximum Load

20.92k

Predicted Cracking Load

3.027

Predicted Deflection at Midspan

THIS CERTIFICATION MUST BE PART OF THE FINAL REPORT

Sponsored by:

5.0 Concrete Mix

With the guidance of Bob De Ruiter, a mix specialist at Clark Pacific, Spring 2021's Team utilized a mix design with a strength of $f'_c = 8500$ psi (28 day break) and $f'_c = 9,260$ psi (56 day break). Based on the judging criteria, this decision was made to ensure the compressive strength of the mixture was not over 10 ksi. The concrete mix is a self-consolidating concrete containing the following admixtures: viscosity modifiers while avoiding segregation, water reducers, and a slump retention admixture. The purpose of the admixtures is to increase flowability of the concrete and compressive strength of the concrete. Provided by Clark Pacific, a full list of the concrete constituents and suppliers is listed in the Appendix.

6.0 Beam Design

6.1 Preliminary Considerations

The parameters used for the structural design were ensured to be in accordance with the rules set forth by the PCI Big Beam Competition handbook based on careful review by engineering students and professional advisors involved. The handbook specified a simply supported beam with a span of 20 ft subjected to a four-point flexural test with asymmetrical loading. The two applied point loads are 3 ft apart with one load being 11 ft from one support, and the other load being 6 ft from the opposite support as shown in Figure 1.

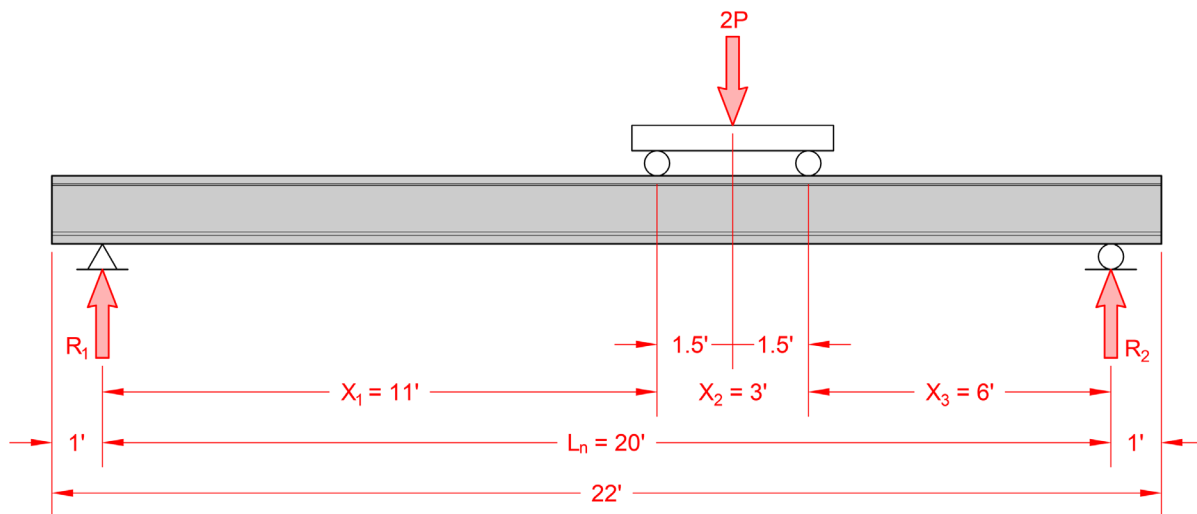


Figure 1. Beam Loading Configuration.

Since the guidelines have not significantly changed from last year's PCI big beam competition, this year's preliminary designs focused on improving the inherited design from the previous teams participating, including 2019's The Reinforcements and Beam Me Up.

Early considerations for improvement included searching for the beam materials including aggregates, chemical admixtures, concrete, cement, reinforcing steel, and prestressed strands which must be commercially available, affordable, and complicit with ASTM requirements. This research also developed into an extensive dive into ASTM and ACI 318-19 codes. Changes from previous beam design have been carefully analyzed and revised as deemed appropriate based on calculated results using excel spreadsheets to ensure a competitive pre-stressed beam design. The following is a summary of improvements from the inherited design.

- Increased cover at the top flange from 5/8" minimum to 1" reducing ductility
- Change from 2" O.C. Welded-Wire Reinforcement (WWR) to #3 Gr. 60 stirrups.
- Increased number of compressive reinforcements from (3) #3 to (4) #3 Gr. 60 rebar.
- Increased number of prestressing strands from (2) 0.6" dia. to (3) 0.5" dia. Gr. 270 strand.

6.2 Flexure

Flexural design had several important considerations, beginning with the beam geometry, calculating a balanced flange area to help ensure the beam would respond within the desired design intent, while minimizing the cost of materials. The beam should withstand a service load of 20 kips without cracking and should be able to carry a factored live load of atleast 32 kips. One recommendation made by Clark Pacific was to reduce the size of the primary Gr 270 strands from (2) 0.6" dia. to (3) 0.5" dia. The intended purpose was to reduce spalling at the ends of the beam, to avoid potential loss of bond after the strands have been released. This was an important decision as it helped improve the likelihood of achieving the predicted failure mode.

6.3 Shear

From reviewing the 2019 test results, evidence shows that the beam failed in an undesirable shear failure mode. This is an unsafe design in practice. Therefore, one of the more important revisions from the previous year's design focused on calculating the necessary shear reinforcement. Initial considerations were to improve on the welded wire design, however logistical constraints created complications in the timeline, given that a 10-week lead time was required for W8 2" O.C. welded-wire reinforcement (WWR). The alternative design choice, although slightly heavier, was to use 1 legged #3 Gr.60 stirrups. This change also gave opportunity to design a more accurate shear reinforcement design, given that the beam was unsymmetrically loaded, and shear stresses vary along the span of the beam. As seen in Figure 2 below, a total of 16 #3 Gr.60 stirrups were placed at an 8" spacing from the left 6" end of the

beam, and 32 stirrups with 4" spacing starting 6" from the right end of the beam.

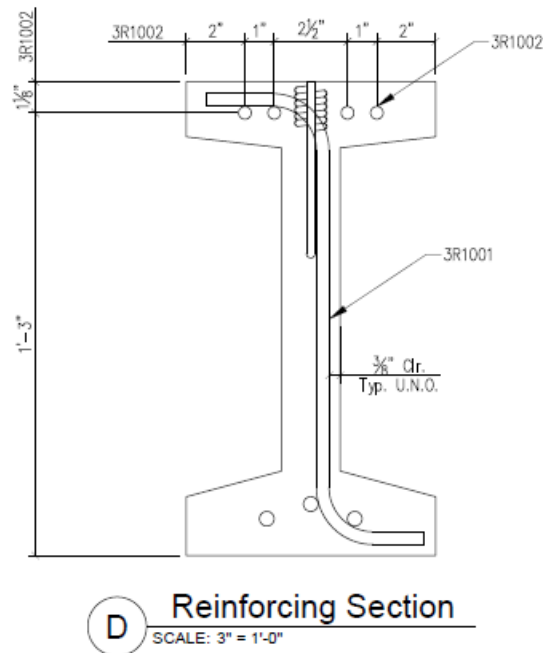


Figure 2. Cross Section.

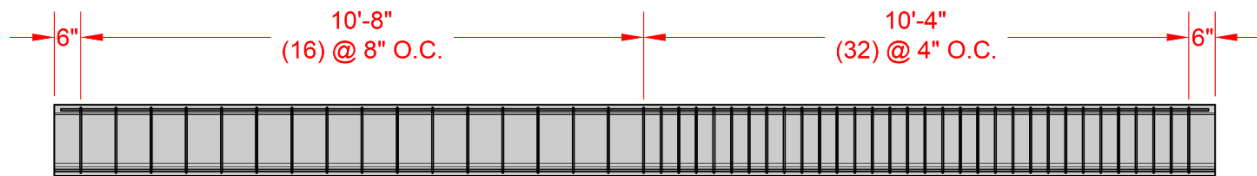


Figure 3. Shear Reinforcement Configuration.

6.4 Prestress Losses

Prestressed losses were determined using the AASHTO-LRFD Refined method which accounted for creep, shrinkage, and relaxation. Additionally, the calculated loss was checked for similarity using alternative ACI 318-19 and PCI equations. The effective force P_{se} was determined to be 76.26 kips, which was then used to predict the load at cracking, $P_{cr} = 20.92$ kips and $P_u = 32.50$ kips. From a design perspective, a few iterations were made to reduce the losses in the prestressed strands from the previous year's design. First was the increase the length of the beam overhanging ends to 12", which would provide better bond and development of the strands. Also, a 5" long 3" dia. corrugated steel duct was placed at both ends of the beam encompassing the three strands to confine the strands and restrict any potential crack propagation at the end beam as recommended by Clark Pacific.

7.0 Beam Fabrication

7.1 Building the Form Work

With the help of Clark Pacific, the beam forms were cut to our design prior to arrival. By fastening the wood forms to the steel casting bays the beam form was properly secured. Then they were covered with oil to prevent concrete from adhering after the pouring process. Bulkheads were also fastened at both ends of the form. The next step in the process was to place the reinforcements, which was possible after the formwork was quality checked per our given design and final approval.

7.2 Tensioning with Prestressed Strands

The chosen depth for the two outer strands was 1.25 inches from the bottom of the beam, and the center strand was placed at 1.75 inches from the bottom creating a triangular pattern in the section. By placing the tendons in such a configuration, bond strength between the tensioned strands and the concrete was enhanced, improving beam performance. Symmetry was also an important factor in placing the prestressed strands, as an *asymmetrical* pattern produces out of plane behavior.

7.3 Placement of the Steel Reinforcing Bars

The team's beam design included four longitudinal steel bars in the top region of the beam's cross-section. This amount resulted from multiple considerations of beam stress at transfer, ductility, and compressive strength, and ultimately led to using four #3 compressive longitudinal bars. Four bars were used for the design because after analyzing the beam, it was evident that they were needed for symmetry.

When tying the steel rebar, Clark Pacific provided automatic wire tools that fastened the longitudinal steel bars to the transverse stirrup bars. The stirrup essentially holds up the longitudinal bars throughout the length of the beam. As concrete is cast into the forms, the compressive bars are not kept in the proper location without being tied to the transverse stirrups. Plastic spacers were also used to hold the bars up in places where the longitudinal compressive bars were limp. By the end of the pouring, it was evident that the drawing dimensions provided before the pour had slight discrepancies with the fabrication results. However, with the additional tolerances accounted for the placement of the rebar and the coverage that the concrete provides, there was reassurance that the intended design was still achieved during fabrication.

7.4 Placing the Concrete

After the rebar was placed, the concrete was finally ready to be poured onto the steel. It was poured from a concrete mixer truck and directly into the formwork that was previously created. During the pouring process, the team would vibrate the sludged concrete as it was being poured

in order to prevent any trapped air bubbles that would be present within the viscous concrete. Utilizing the SCC mix minimized the need for vibration. After the formwork was fully filled, the team used trowels to smooth the surface of the concrete and finalize the look for the beam before being allowed to settle and be covered before the curing process.

8.0 Testing

8.1 Cylinder Testing

Prior to the actual beam testing, cylinder testing was performed using the cylinders fabricated by Clark Pacific, after it has been cured for 55 days. The team tested 3 cylinders: 1 standard compression test and 2 split cylinder test to obtain our compressive and tensile strengths. The values are used to acquire the modulus of rupture for tensile strength determination and peak cracking. Based on previous studies, modulus of rupture was calculated from tensile strength by a 1.3 factor.



Figure 3. Compression and Split Cylinders

8.2 Testing Procedures

On the day of the test, the lab technicians prepared the structured lab for beam testing. Since the beam was delivered from Clark Pacific last semester with no proper guidance in how the beam should be oriented due to the placement of the stirrups throughout the beam. The lab technicians took out the Caldwell Lifting Beam to properly orientate the beam in the way that the side which there are more stirrups to counteract shear failure to which the load is applied.

When the beam was properly placed, initial beam condition was marked and recorded. Pre-existing cracks were marked in green markers and pictures were taken for comparison. It was observed that most of the pre-existing cracks were located on the top flanges due to the camber on the beam after prestressing. The team and the technicians set up 5 dial gauges, 1 for each loading points, 1 for the mid span and the other 2 for each support. In addition, 3 LVDT's were also set up at the midspan, and the two load points. On top of that, cameras were set up at every angle of the beam. In the actual testing, a test configuration of two unsymmetrical point loads that are 3 ft apart, were implemented. 5.5in x 8in steel bearing plates were placed on 6x4 wood blocks. The two dial gages at the wood supports were recommended to record any compression at the supports, which was deducted from the net deflection afterwards. A horizontal laser level was aligned along the web, and marked with a line to indicate starting level, which would also serve as a visual for deflection during the testing period. After verifying the test-setup with the competition requirements, the testing began. The beam was loaded under displacement control at a rate of 0.2 inches per minute. The team monitored and documented the behavior of the

beam especially the initial cracking, during which displacement was held at 21 kips, as the team members marked any visible cracking. Testing once again proceeded up until 29 kips, where an additional pause was made to re-adjust the 2" LVDT's because of limitation on stroke. After the final gage adjustment, the team stepped away to a safe distance to continue the testing until ultimate failure.

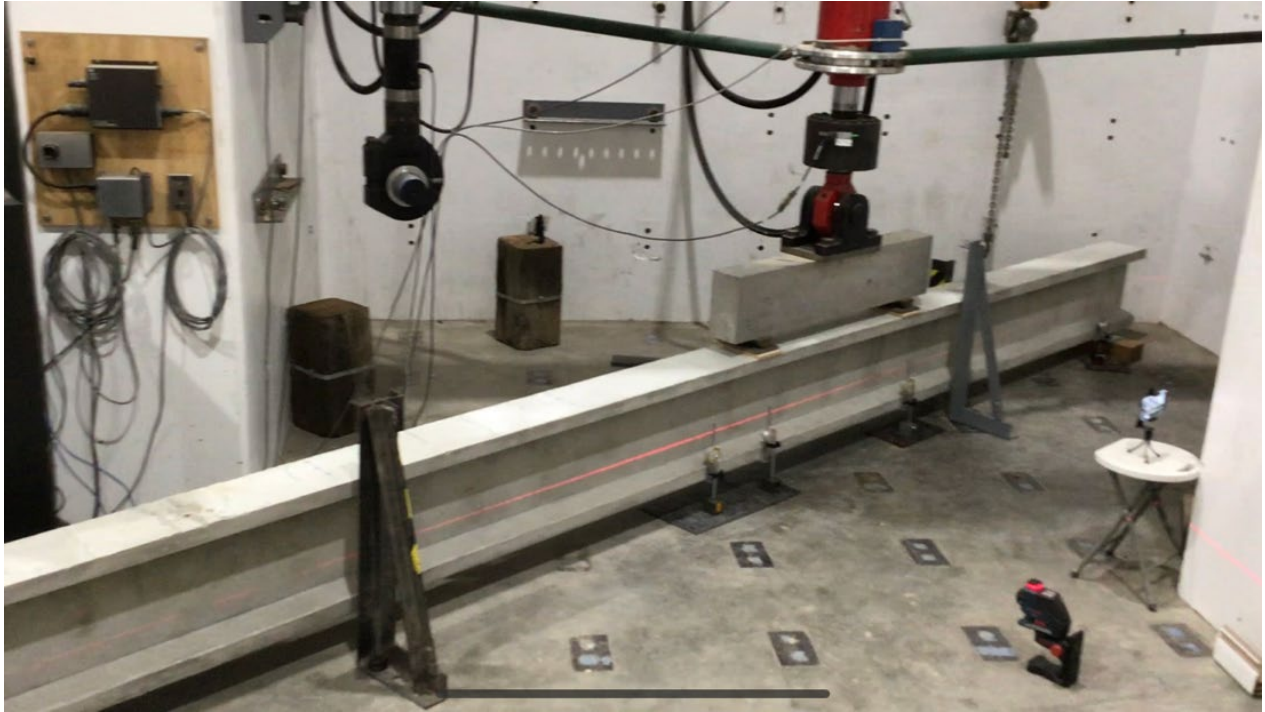


Figure 4. Overall Test Set-Up and Spreader Beam

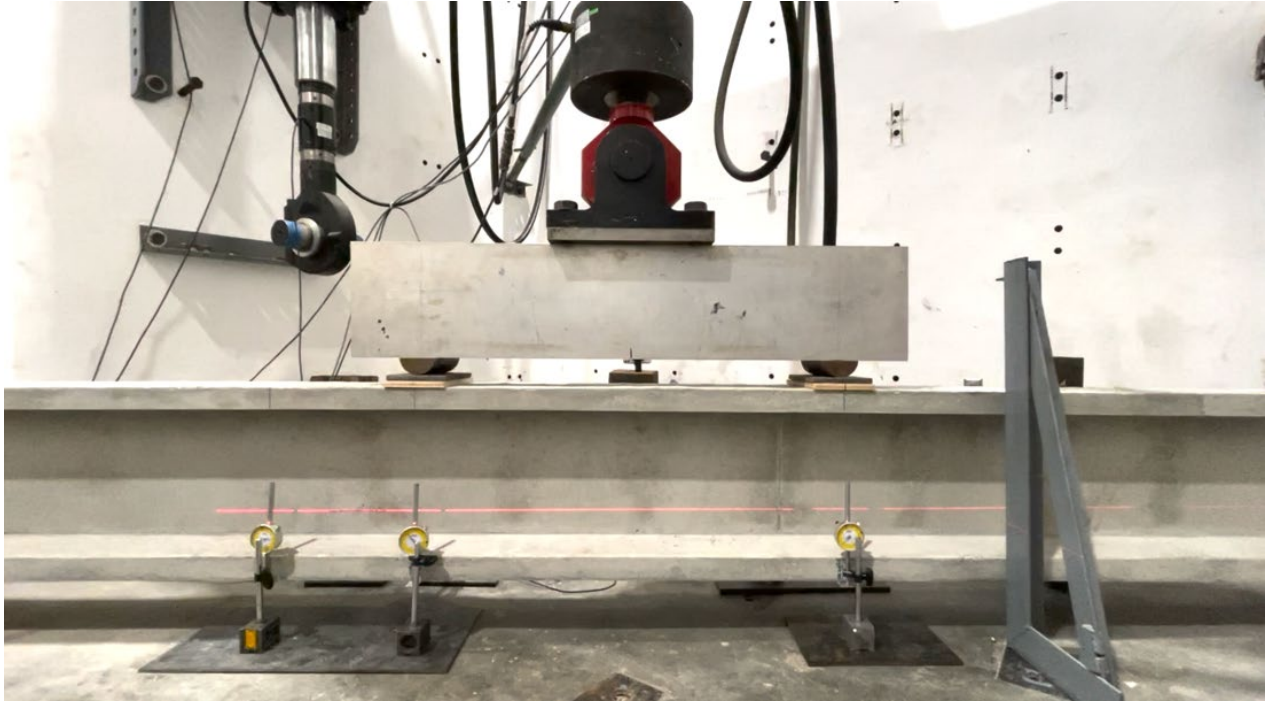


Figure 5. *Unloaded Set up*

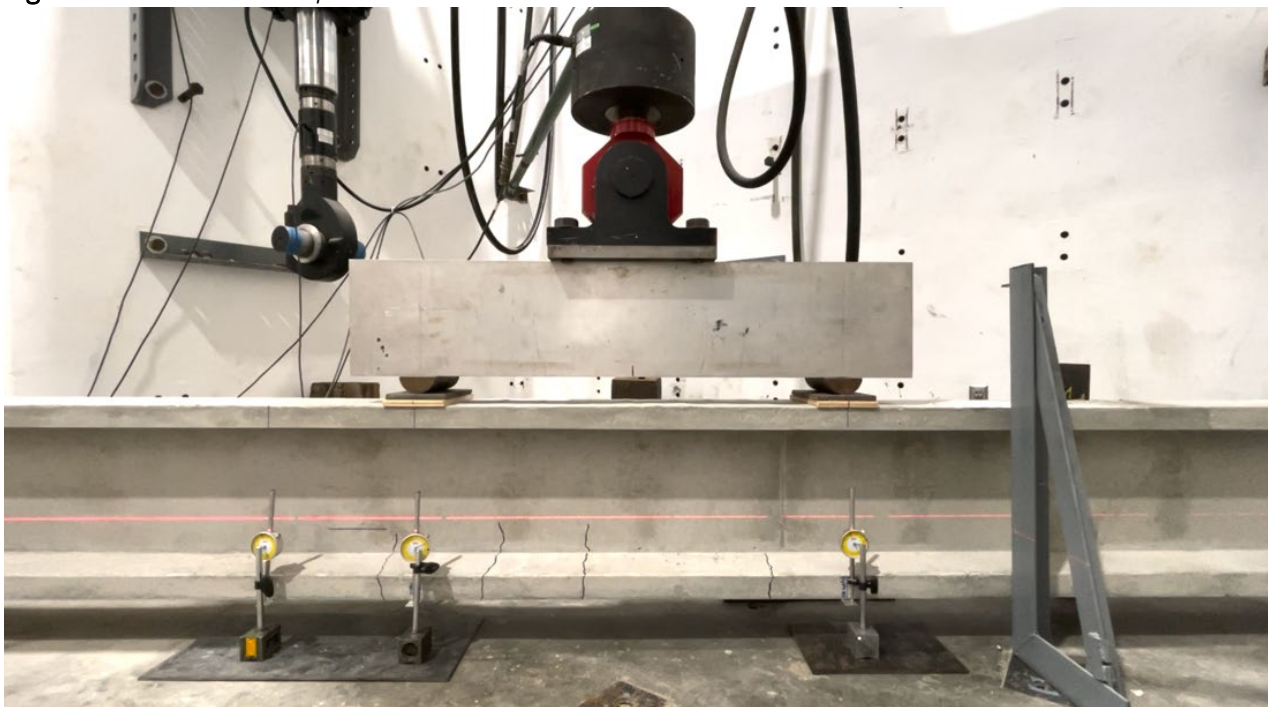


Figure 6. Flexural Cracks Immediately after Cracking Loads

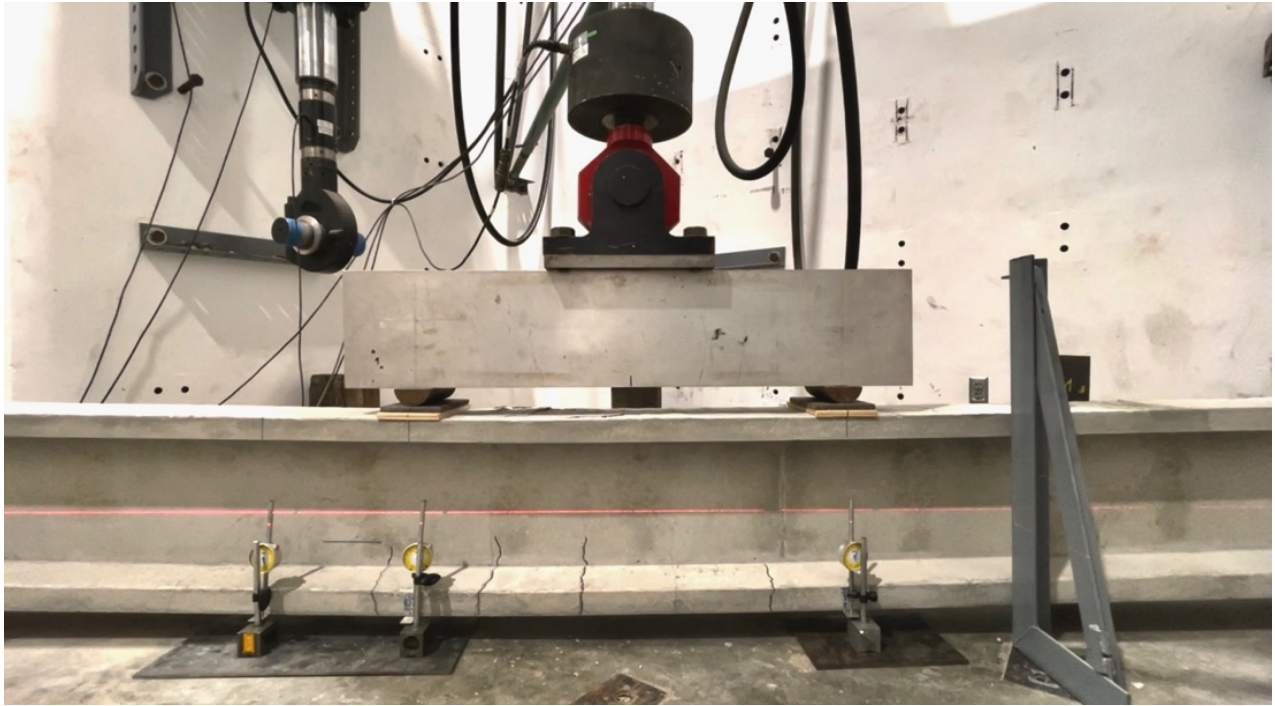


Figure 7. Beam at Peak Load

9.0 Results and Analysis

The beam initially cracked at 21.18 kips and ultimately failed at 32.46 kips. The beam displayed flexural cracking at initial as expected and as the loads reached ultimate allowing a ductile flexure failure. displayed shear flexure cracks demonstrating the stirrups were effective. The compression rebar also buckled where the stirrups were not covering, which also caused some spalling at the top of the beam. The percent error of the pretest predictions from the actual values of the initial cracking, peak deflection and ultimate load were 1.23%, 14.63%, and 0.123% respectively. The large error in the deflection prediction is due to errors in the use of equations. Table 1 below shows the comparison of Predicted vs. Actual values for the beam testing.

Table 1. *Prediction vs. Actual Loads and Deflection*

Response	Pretest Predictions	Actual	Percent Error (from Predicted)
Concrete Cracking (kips)	20.92	21.18	1.23%
Peak Load Deflection (in)	3.027	2.584	14.63%
Ultimate Load (kips)	32.50	32.46	0.123%

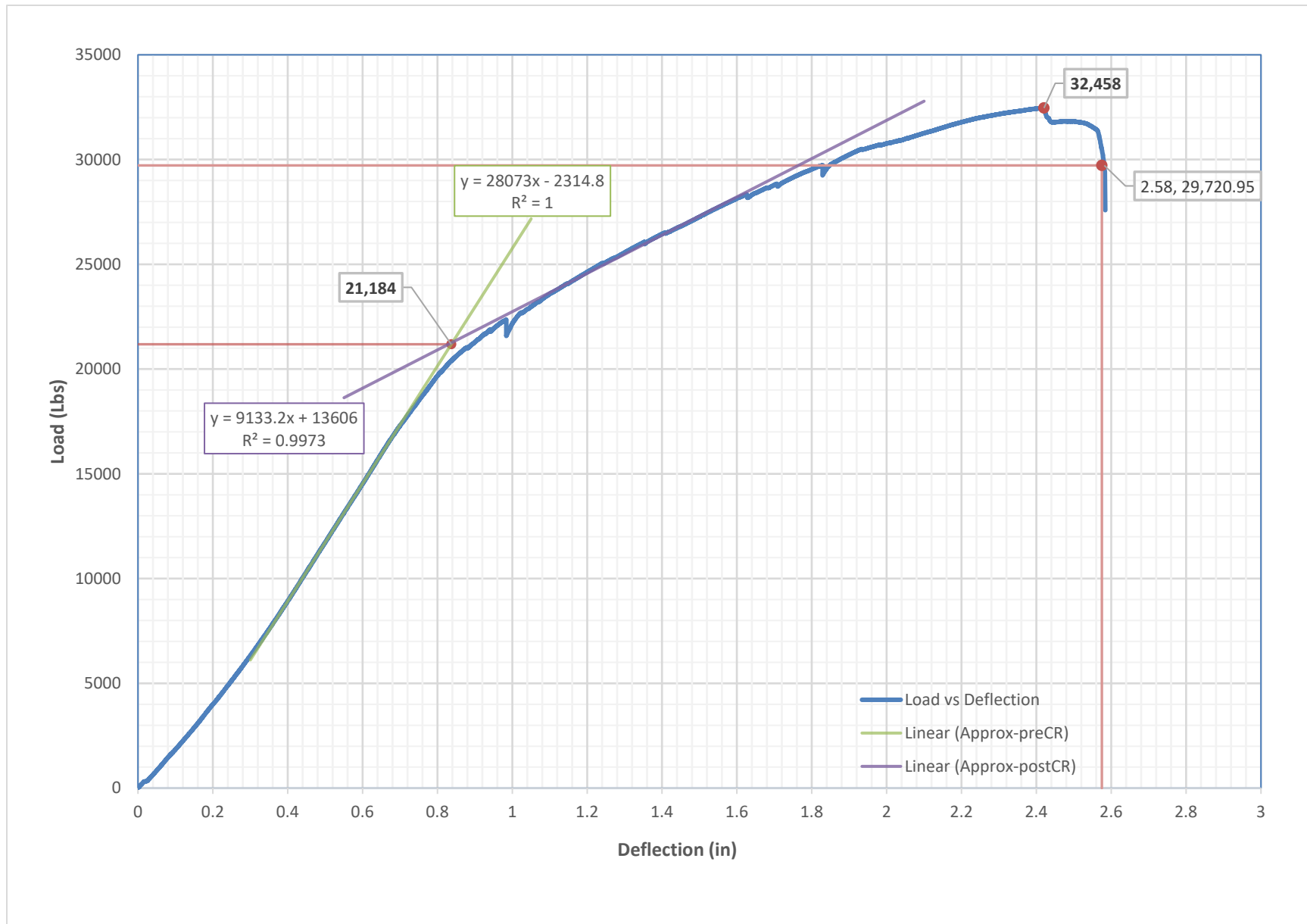


Figure 8. Load Deflection Plot

10.0 Personal Statements

Anton Sta. Maria - The PCI Big Beam competition has provided an extraordinary opportunity to not only work on a long-term project where theories learned are applied, but to also work with industry and gain perspective on the various elements of engineering in practice. The amount of organization, communication, commitment, and vigorous thought required to adequately function on a project has astonished, enlightened, and inspired confidence in my pursuit of a successful career as a Civil Engineer.

Anton Sta. Maria
1100 Crystal Springs Dr
Vacaville, CA 95688

Shaira Soliva - The PCI Big Beam Project was a very stressful and rewarding experience a student could have in a school setting. It really tested my problem-solving skills and challenged my persistence and dedication given that we were only given 6 weeks during summer to work on this project without having any experience or background with precast/prestressed concrete beam prior to this class. The lack of knowledge combined with busy schedule was very tough, however the working with a team that have the same goals and determination along with proper guidance from industry professionals was a great learning experience.

Shaira Soliva
9110 Lucchesi Dr.
Sacramento, CA 95829

Vadim Gritsak – Participating in the PCI Big Beam competition was a unique glimpse into the practical real world of engineering. The opportunity to relate design from learned theory, fabricate with professional individuals, and finally test the beam was an invaluable and memorable experience that solidified appreciation for engineering applications. One of the most important takeaway lessons that I have learned was how critical communication between team members can be the difference between success and failure. Being open minded to new ideas and questioning uncertain details openly helped overcome challenges and prevent errors through constant communication with the team.

Vadim Gritsak
8040 Country Trail Dr
Orangevale, CA 95662

Nour Hojeij - As expected, having six weeks to participate in the PCI Big Beam Project was intense but nonetheless very advantageous. Through my experience I was able to apply the conceptual and tactical principles learned in the course to further my understanding of reinforced concrete. Working on this project not only benefited my comprehension of the subject but also allowed me to recognize the importance of time management and communication with my team and industry professionals. I look forward to the applying the skills and knowledge acquired from this project as I prepare to step into my professional engineering career.

Nour Hojeij
7750 Elena Marie Dr.
Sacramento, CA 95831



Figure 15. *Herky's Big Freakin' Beam Team* - Nour Hojeij, Shaira Soliva, Vadim Gritsak, Anton Sta. Maria.

11.0 References

Building Code Requirements For Structural Concrete (ACI 318-14). American Concrete Institute, ACI, 2014.

Darwin, David et al. Design Of Concrete Structures. Mcgraw-Hill Education, 2016.

Swartz, Brian D. et al. "AASHTO LRFD Bridge Design Specifications Provisions For Loss Of Prestress". PCI Journal, vol 57, no. 4, 2012, pp. 108-132. Precast/Prestressed Concrete Institute.

Matsumoto, Eric. CE 164 Reinforced Concrete Design. XanEdu Publishing, 2021. (fall 2019 report)

PC Strand. Sumiden Wire. (2017) <https://www.sumidenwire.com/products/pc-strand/>

12.0 Appendices

Appendix 1. Figure A.1. CAD Drawings 19

Appendix 2. Cost Analysis 22

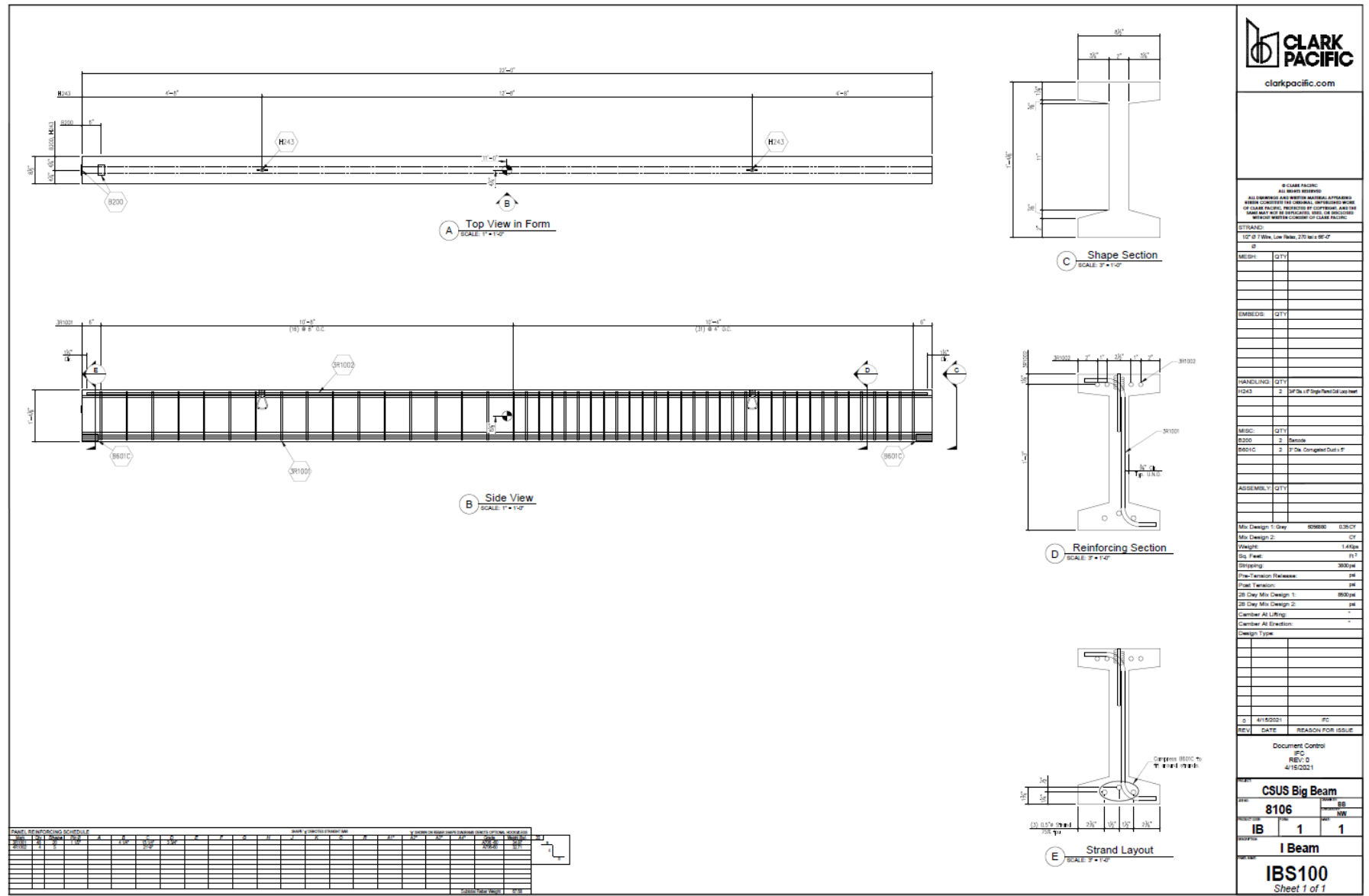
Appendix 3. Structural Design Calculations - Summer 21 24

Appendix 4. Concise Beam Analysis..... 31

Appendix 5. Test Log 33

Appendix 6. Concrete Mix Analysis 34

Appendix 7. Strand Specifications..... 36



Appendix 1. Figure A.1. CAD Drawings

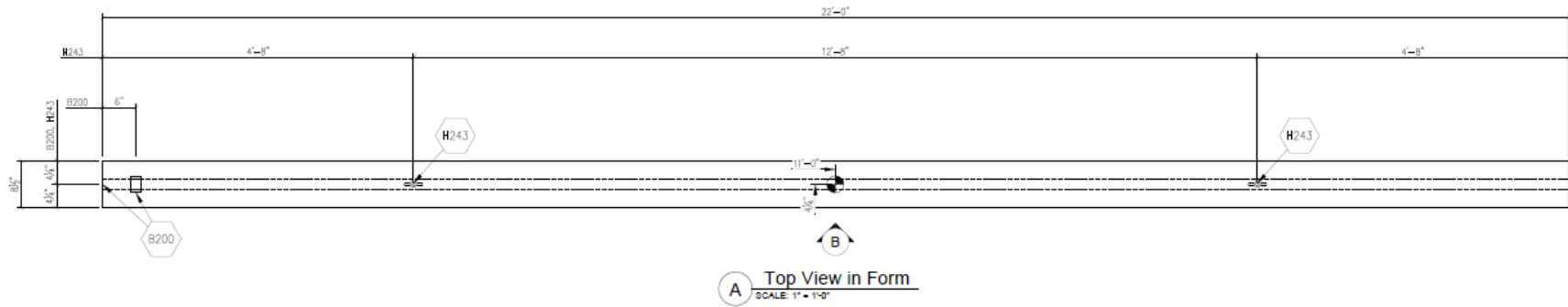


Figure A.2 Top view In Form

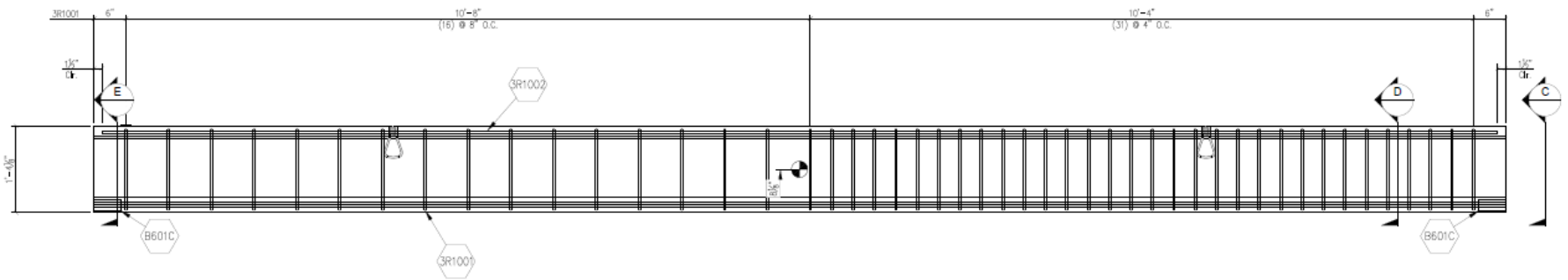


Figure A.3: Front Elevation View

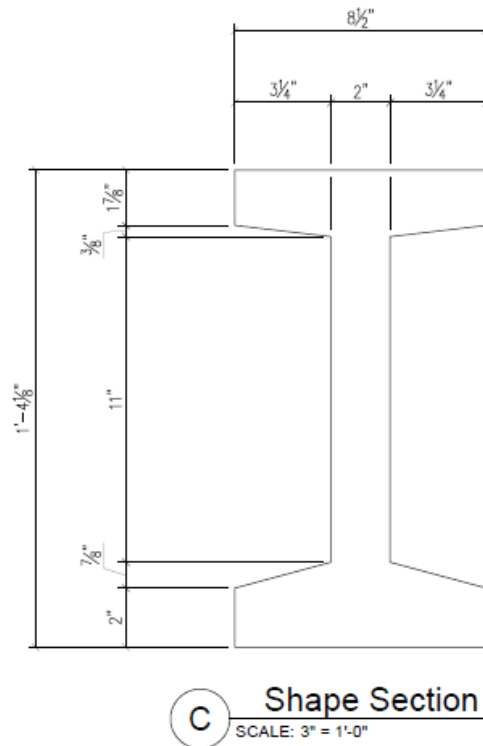


Figure A.4: *Shape Section*

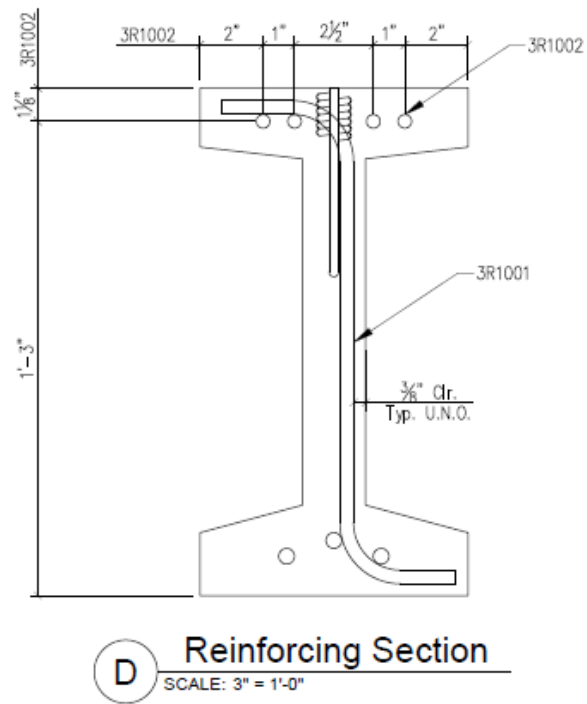


Figure A.5: Reinforcing Section

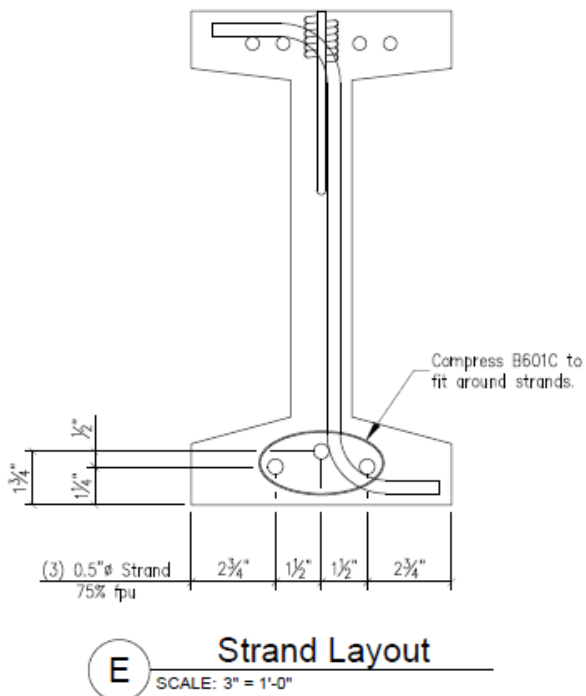


Figure A.6: *Strand Layout*

Appendix 2. Cost Analysis

High-Strength Concrete (I-Beam)			22-May
Geometry	h(in)	w(in)	Area (in ²)
top flange	1.88	8.50	15.94
web	11.00	2.00	22
bottom flange	2	8.50	17
top taper	0.38	3.25	1.97
bottom taper	0.88	3.25	4.59
		total (in ²) =	61.5
Length (ft) =	22		
Length (in) =	264		
		total (in ³) =	16236
		total (ft ³) =	9.40
		total (yd ³) =	1.04
		cost (@\$120/yd ³) =	\$125.28
		Steel (Strands)	
		cost/ft @0.6 in dia	\$0.30
		strand length (ft)	22
		number of strands	3
		total strand cost	\$19.80
		Longitudinal Rebar	
		cost/lb	\$0.45
		rebar weight (lb/ft)	0.376
		rebar length	22
		number of rebar	4
		total rebar cost	\$14.89
		Stirrup #3	
		cost/lb	\$0.45
		weight (lb/ft)	0.376
		length (ft)	960.02
		total WWR	\$162.44
		Formwork	
		cost/sqft	\$1.25
		sqft	70.05
		Total Cost	\$87.56
		Total Cost	\$409.97

	Weight (lb)	
	Concrete	1388.70
	Strands	34.32
	Rebar	13.36
	#3 Stirrups	360.98
	Total	1797.4

	I-Beam (Normal Strength Concrete)
Concrete (cuyd)	0.74 @ \$120/cuyd
Cost	\$125.28
Prestressing Strands	3 strands @\$0.30/ft
Cost	\$19.80
Rebar and Stirrup	\$177.32
Formwork (sqft)	70.05
Cost	\$87.56
Total Cost	\$409.97

Appendix 3. Structural Design Calculations - Summer 21

Geometry of Beam Calc's:

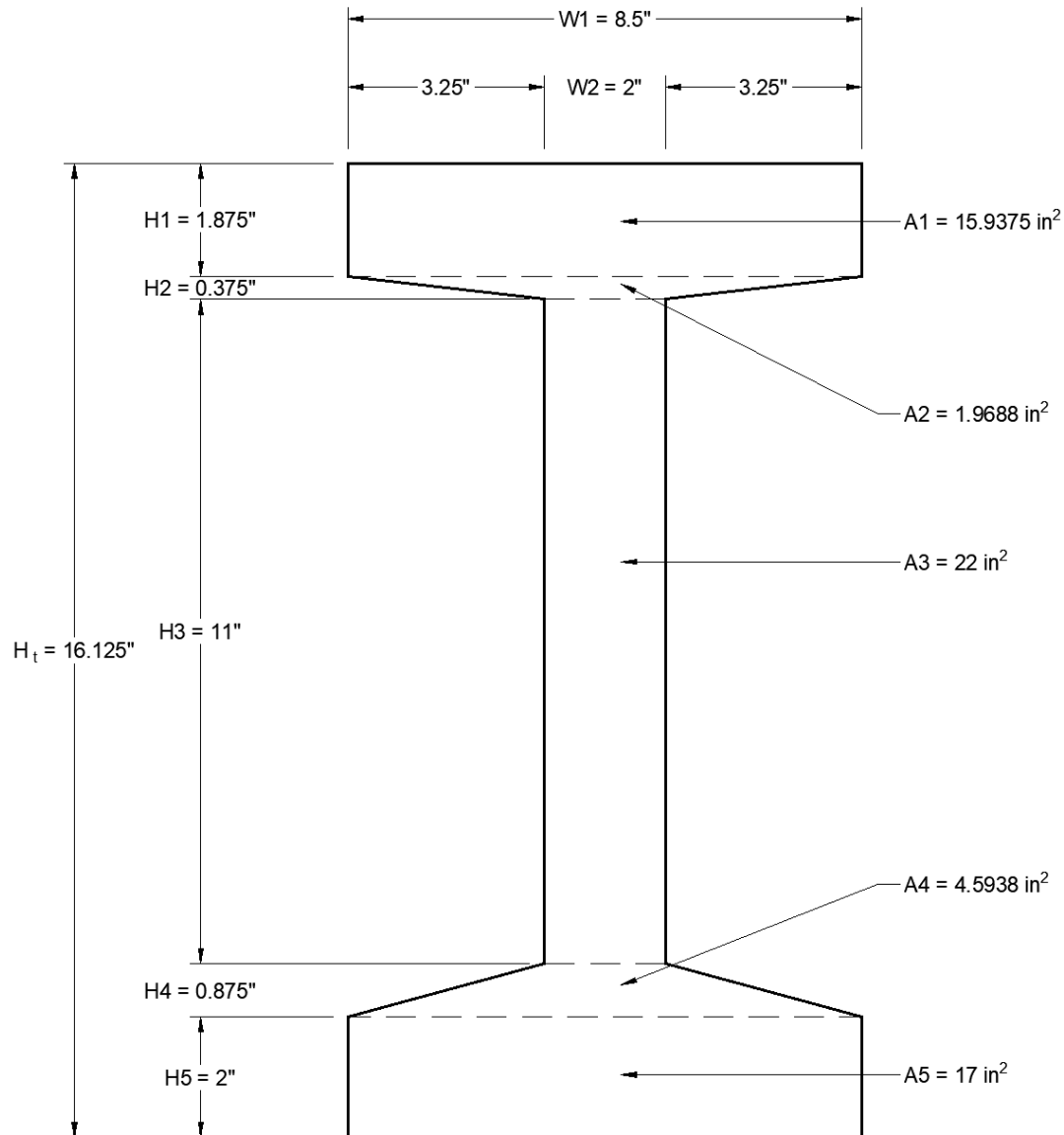


Figure A.7. Beam cross section area references.

Heights:

$$h_T = h_1 + h_2 + h_3 + h_4 + h_5 = (1.875 + 0.375 + 11 + 0.875 + 2) \text{ in} \quad \mathbf{h_T = 16.125 \text{ in}}$$

Areas: (rectangular and trapezoidal)

$$A_1 = h_1 w_1 = (1.875 \text{ in})(8.5 \text{ in}) = 15.9375 \text{ in}^2 \quad A_1 = 15.94 \text{ in}^2$$

$$A_2 = \frac{h_2(w_1+w_2)}{2} = \frac{(0.375in)(8.5in+2in)}{2} = 1.96875 in^2$$

$$A_2 = 1.969 in^2$$

$$A_3 = h_3w_2 = (11in)(2in) = 22 in^2$$

$$A_3 = 22.00 in^2$$

$$A_4 = \frac{h_4(w_1+w_2)}{2} = \frac{(0.875in)(8.5in+2in)}{2} = 4.59375 in^2$$

$$A_4 = 4.594 in^2$$

$$A_5 = h_5w_1 = (2in)(8.5in) = 17 in^2$$

$$A_5 = 17.00 in^2$$

$$A_T = (15.9375 + 1.96875 + 22 + 4.59375 + 17) = 61.5 in^2$$

$$A_T = \mathbf{61.5 in^2}$$

Centroid: (from bottom)

$$y_1 = h_T - 0.5h_1 = 16.125in - 0.5(1.875in) = 15.1875in$$

$$y_1 = 15.19in$$

$$y_2 = h_T - h_1 - \frac{h_2(2w_2+w_1)}{3(w_2+w_1)}$$

$$= 16.125in - 1.875in - \frac{0.375in(2 \cdot 2in + 8.5in)}{3(2in + 8.5in)} = 14.1012 in$$

$$y_2 = 14.10in$$

$$y_3 = h_5 + h_4 + 0.5h_3 = 2in + 0.875in + 0.5(11in) = 8.375 in$$

$$y_3 = 8.375 in$$

$$y_4 = h_5 + \frac{h_4(2w_2+w_1)}{3(w_2+w_1)} = 2in + \frac{0.875in(2 \cdot 2in + 8.5in)}{3(2in + 8.5in)} = 2.34722 in$$

$$y_4 = 2.347 in$$

$$y_5 = \frac{h_5}{2} = \frac{2in}{2} = 1in$$

$$y_5 = 1.000 in$$

$$y_b = \frac{\sum Ay}{\sum A} = \frac{(15.94in^2 \cdot 15.19in) + (1.969in^2 \cdot 14.10in) + (22in^2 \cdot 8.375in) + (4.594in^2 \cdot 2.347in) + (17in^2 \cdot 1in)}{61.5 in^2}$$

$$y_b = \mathbf{7.835 in}$$

Moment of Inertia: ($I_{cx} + Ad^2$)

$$I_{cx_1} = \frac{w_1h_1^3}{12} = \frac{(8.5in)(1.875in)^3}{12} = 4.66919in^4$$

$$I_{cx_1} = 4.669in^4$$

$$I_{cx_2} = \frac{h_2^3(w_2^2 + 4w_2w_1 + w_1^2)}{36(w_1+w_2)} = \frac{0.375in((2in)^2 + 4(2in)(8.5in) + (8.5in)^2)}{36(8.5in+2in)} = 0.02012in^4$$

$$I_{cx_2} = 0.0201in^4$$

$$I_{cx_3} = \frac{w_2h_3^3}{12} = \frac{(2in)(11in)^3}{12} = 221.833in^4$$

$$I_{cx_3} = 221.8 in^4$$

$$I_{cx_4} = \frac{h_4^3(w_2^2 + 4w_2w_1 + w_1^2)}{36(w_1+w_2)} = \frac{0.875in((2in)^2 + 4(2in)(8.5in) + (8.5in)^2)}{36(8.5in+2in)} = 0.25565in^4$$

$$I_{cx_4} = 0.256in^4$$

$$I_{cx_5} = \frac{w_1h_5^3}{12} = \frac{(8.5in)(2in)^3}{12} = 5.6667in^4$$

$$I_{cx_5} = 5.667 in^4$$

$$I_{cx} = (4.66919 + 0.02012 + 221.83333 + 0.02556 + 5.66667)in^4 = 232.445in^4$$

$$I_{cx} = \mathbf{232.4 in^4}$$

$$\begin{aligned}
 Ad_1^2 &= A_1(y_b - y_1)^2 = (15.94in^2)(7.835in - 15.19in)^2 = 861.82in^4 & Ad_1^2 &= 861.8in^4 \\
 Ad_2^2 &= A_2(y_b - y_2)^2 = (1.969in^2)(7.835in - 14.101in)^2 = 77.313in^4 & Ad_2^2 &= 77.31in^4 \\
 Ad_3^2 &= A_3(y_b - y_3)^2 = (22in^2)(7.835in - 8.375in)^2 = 6.4152in^4 & Ad_3^2 &= 6.415in^4 \\
 Ad_4^2 &= A_4(y_b - y_4)^2 = (4.594in^2)(7.835in - 2.347in)^2 = 138.363in^4 & Ad_4^2 &= 138.4in^4 \\
 Ad_5^2 &= A_5(y_b - y_5)^2 = (17in^2)(7.835in - 1in)^2 = 794.193in^4 & Ad_5^2 &= 794.2in^4 \\
 Ad^2 &= (861.82 + 77.313 + 6.4152 + 138.363 + 794.193)in^4 = 1878.104in^4 \\
 & & \mathbf{Ad^2} &= \mathbf{1879in^4}
 \end{aligned}$$

$$I_g = I_{cx} + Ad^2 = 232.445in^4 + 1879.104in^4 = 2110.549in^4 \quad \mathbf{I_g = 2111in^4}$$

f'c for 4"x8" Cylinder Tests, at 38-day strength.

$$\begin{aligned}
 A_{cyl} &= \frac{\pi(4in)^2}{4} = 12.5664in^2 & A_{cyl} &= 12.57in^2 \\
 P_{max_{T1}} &= 111,300lbs, \& P_{max_{T2}} &= 111,900lbs & P_{max_{avg}} &= 111,600lbs \\
 f'c_{(38)} &= \frac{P_{max_{avg}}}{A_{cyl}} = \frac{111,600lbs}{12.5664in^2} = 8880.8458psi & f'c_{(38)} &= 8880.85psi \\
 f'c_{(28)} &= \frac{4+0.85t}{t} f'c_{(t)} = \frac{4+0.85(38day)}{(38day)} (8880.85psi) = 8483.5448psi & \mathbf{f'c_{(28)}} &= \mathbf{8.483ksi}
 \end{aligned}$$

Starting stress and camber condition:

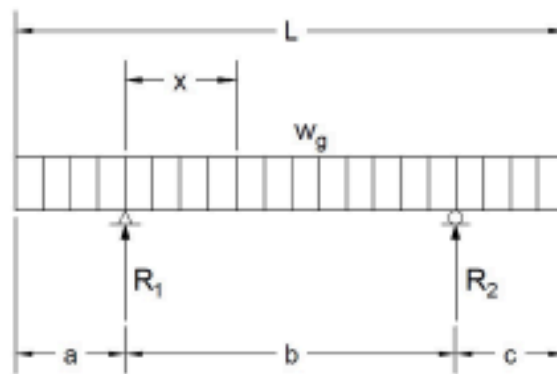
$$\begin{aligned}
 \Delta_{ps} &= -\frac{P_t e_i L^2}{8E_{ci} I_{trf}} = \frac{-(92.95kip)(6.97in)(264in)^2}{8(3566.64ksi)(2332.8in^4)} = -0.6784in & \Delta_{ps} &= -0.6784in \\
 \Delta_{sw} &= \frac{5w_g L^4}{384E_{ci} I_{trf}} = \frac{5(0.005k/in)(264)^4}{384(3566.64ksi)(2332.8in^4)} = 0.0380in & \Delta_{sw} &= 0.0380in \\
 \Delta_{net} &= \Delta_{ps} + \Delta_{sw} = -0.6784in + 0.0380in = -0.6404in & \Delta_{net} &= -0.6404in
 \end{aligned}$$

Prestress Strand Properties

Ultimate Tensile Stress of Strand	$f_{pu} := 279.38 \text{ ksi}$
Yield Stress of Strand	$f_{py} := 251.44 \text{ ksi}$
Jacking stress of Strand	$f_{pj} := 0.75 \cdot f_{pu} = 209.54 \text{ ksi}$
Jacking Force of Strand	$P_j := f_{pj} \cdot A_p = 96.18 \text{ kip}$
Eccentricity	$e := y_{bot} - y_{ps} = 6.418 \text{ in}$

Immediate Prestress Losses

Unit Weight of Concrete per Foot	$w_g := \gamma_c \cdot A_g = 0.063 \frac{\text{kip}}{\text{ft}}$
Overhang Past Supports	$a := 1\text{-ft} \quad c := a$



Support Reaction Based on Diagram	$R_1 := \frac{[w_g \cdot L \cdot (L - 2 \cdot c)]}{2 \cdot L_s} = 0.694 \text{ kip}$
Moment due to Gravity at Midspan	$M_g := R_1 \cdot \left(\frac{R_1}{2 \cdot w_g} - a \right) = 3.125 \text{ kip-ft}$
Elastic Shortening (ES) at transfer	$\Delta f_{pES} := \frac{\left[A_p \cdot f_{pj} \cdot \left(I_g + e^2 \cdot A_g \right) - e \cdot M_g \cdot A_g \right]}{A_p \cdot \left(I_g + e^2 \cdot A_g \right) + \frac{A_g \cdot I_g \cdot E_{ci}}{E_p}}$
	$\Delta f_{pES} = 23.58 \text{ ksi}$
Stress in Strands after Immediate Losses	$f_{pi} := f_{pj} - \Delta f_{pES} = 185.96 \text{ ksi}$
Effective Prestress Force (initial)	$P_i := f_{pi} \cdot A_p = 85.36 \text{ kip}$

Long Term Time Dependent Losses

Perimeter of Cross Section

$$P = 60.02 \text{ in}$$

V/S (Area to Perimeter Ratio)

$$V_s := \frac{A_g}{P \cdot \text{in}} = 0.976$$

Time at which Beam was Loaded

$$T_f := 11 \text{ days}$$

Time of Transfer (Strands Cut)

$$T_{\text{transfer}} := 2 \text{ days}$$

Determination of Time Dependent Coefficients

$$K_{vs} := 1.45 - 0.13 \cdot V_s = 1.323 \quad K_f := \frac{5}{\left(1 + \frac{f_{ci}}{\text{ksi}}\right)} = 1.042$$

$$K_{td} := \frac{(T_f - T_{\text{transfer}})}{61 - 4 \cdot \left(\frac{f_{ci}}{\text{ksi}}\right) + (T_f - T_{\text{transfer}})} = 0.164$$

$$K_{hs} := 2 - 0.014 \cdot \text{Humidity} = 1.02$$

$$\text{Time Dependent Shrinkage Factor } (\epsilon_{bid}) \quad \epsilon_{bid} := 0.00048 \cdot K_{vs} \cdot K_{hs} \cdot K_f \cdot K_{td} = 1.108 \times 10^{-4}$$

$$\psi_{fi} := 1.9 \cdot K_{vs} \cdot K_{hs} \cdot K_f \cdot K_{td} \cdot T_{\text{transfer}}^{-0.118} = 0.831$$

Transformed Section Coefficient

$$K_{id} := \frac{1}{1 + \frac{E_p \cdot A_p}{E_{ci} \cdot A_g} \cdot \left(1 + \frac{A_g \cdot e_f^2}{I_{trf}}\right) \cdot (1 + 0.7 \cdot \psi_{fi})}$$

$$K_{id} = 0.827$$

Stress at Strand Centroid (f_{cgp})

$$f_{cgp} := -P_i \cdot \left(\frac{1}{A_g} + \frac{e^2}{I_g}\right) + \frac{M_g \cdot e}{I_g} = -2.94 \text{ ksi}$$

Shrinkage (SH)

$$\Delta SH := \epsilon_{bid} \cdot K_{id} \cdot E_p = 2.621 \text{ ksi}$$

Creep (CR)

$$\Delta CR := \frac{E_p}{E_{ci}} \cdot f_{cgp} \cdot \psi_{fi} \cdot K_{id} = -16.193 \text{ ksi}$$

Relaxation (RE)

$$\Delta RE := 1 \text{ ksi} \quad \text{Assumed to be 1 ksi due to such short duration between facrication and testing}$$

Total Losses (TL)

$$\Delta TL := \Delta f_{pES} + \Delta SH + |\Delta CR| + \Delta RE = 43.39 \text{ ksi}$$

$$f_{se} := f_{pj} - \Delta TL = 166.15 \text{ ksi}$$

$$P_{se} := f_{se} \cdot A_p = 76.26 \text{ kip}$$

Cracking Moment/Load

Maximum Average Load Applied to Split Cylinder

$$P_{ct} := 39.09 \text{ kip}$$

Cylinder Geometry

$$\text{Height} := 8 \text{ in} \quad \text{Diameter} := 4 \text{ in}$$

Tensile Stress Accroding to Split Cylinder Test

$$f_{ct} := \frac{2 \cdot P_{ct}}{\pi \cdot \text{Diameter} \cdot \text{Height}} = 777.57 \text{ psi}$$

Modulus of Rupture Conversion

$$f_r := 1.3 \cdot f_{ct} = 1010.84 \text{ psi}$$

Moment Due to Live and Dead Load

$$M_{cr.tot} := f_r \cdot S_b + P_{se} \cdot \left(\frac{S_b}{A_{trf}} + e_f \right)$$

$$M_{cr.tot} = 89.43 \text{ kip-ft}$$

Moment Due to Live Load Only

$$M_{cr} := M_{cr.tot} - M_g = 86.29 \text{ kip-ft}$$

Load at which Cracking Occurs

$$P_{cr} := M_{cr} \cdot MtoP = 20.92 \text{ kip}$$

Ultimate Moment/Load

$$K = 2 \left(1.04 - \frac{f_{py}}{f_{pu}} \right) = 0.28$$

$$\beta_1 = 0.65 \quad \text{per ACI 318-19 22.2.2.4.3}$$

$$c = \frac{(A_{ps} \cdot f_{pu} - A'_s \cdot f_y) - (0.85 \cdot f'_c \cdot (b_t - b_w) \cdot \beta_1 \cdot t_f)}{(0.85 \cdot f'_c \cdot b_w \cdot \beta_1) + K \cdot A_{ps} \cdot \left(\frac{f_{pu}}{d} \right)} = 3.784 \text{ in}$$

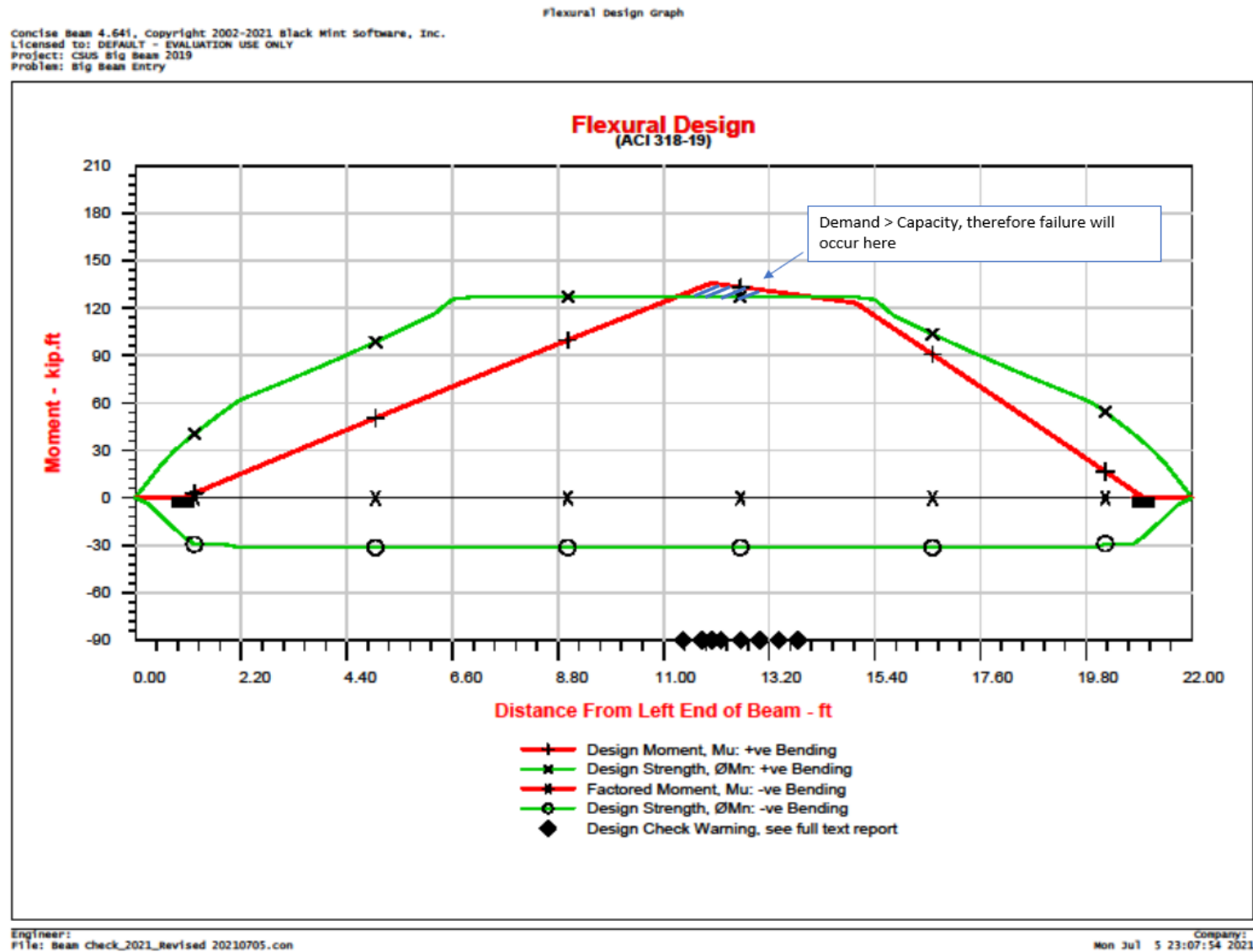
$$F_{ps} = f_{pu} \cdot \left(1 - k \frac{c}{d} \right) = 259.25 \text{ ksi}$$

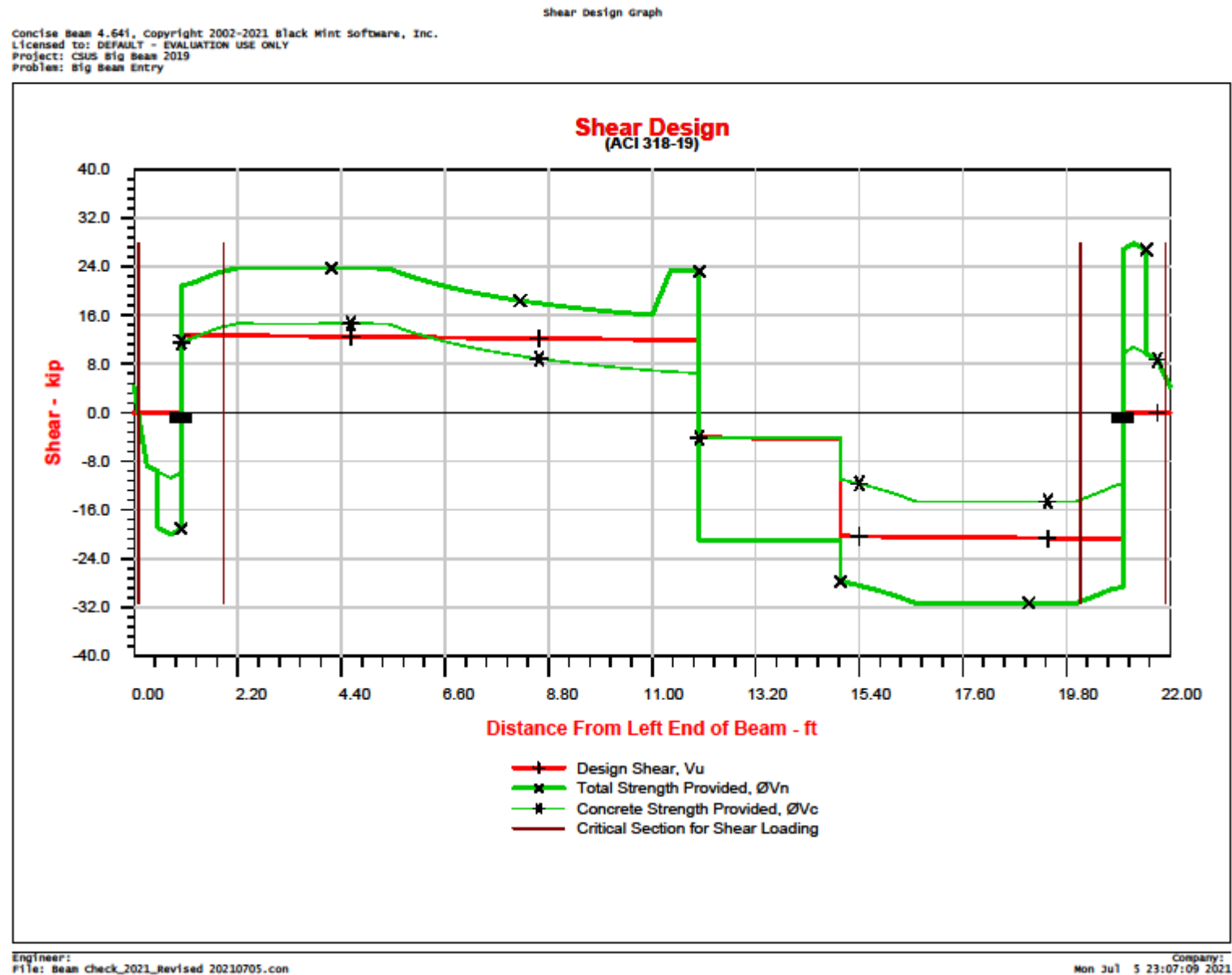
$$a = \frac{A_{ps} \cdot f_{ps} - A'_s \cdot f_y}{0.85 \cdot f'_c \cdot b_f} = 1.511 \text{ in}$$

$$M_n = \frac{A'_s \cdot f_y \cdot (d_{ps} - d') + (A_{ps} \cdot f_{ps} - A'_s \cdot f_y) \left(d_{ps} - \frac{a}{2} \right)}{12} = 137.22 \text{ kip} \cdot \text{ft}$$

$$M_n = M_n - M_g = 134.08 \text{ kip} \cdot \text{ft}$$

Appendix 4. Concise Beam Analysis





Appendix 5. Test Log

	<u>TEST LOG</u> 0.2 in/min LOADING RATE Test Begins: <u>2:32</u> ENDS: <u>2:42</u> - Video gages every 2kips - 10kips $\Delta \approx 0.5$ in - Cracking @ - Pave at 22k • Cracks are 4 Front, 4 on back • Load drop to 21.34k while holding for crack marks • More cracks concentrated towards Left Point Load • Laser turned off - START @ 21.5k - Hold 25.5k $\rightarrow$ Loud Noise (ps strand?) $\rightarrow$ No more gage recordings - 29.3k holding load $\Delta = 1.9$ in resetting LVDT & gages (Limit to 2") - 29.0k start again - Flakes fall $\rightarrow$ Core Crum 30.8k - Diagonal shear forming 31.2k - 32k hear Cracking 32k - 24 in - 33k $\rightarrow$ Loud BURST $\rightarrow$ Concrete from 6-8' away - Top Rebar buckled.	CE-164-Exp. 1 6-23-21
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Appendix 6. Concrete Mix Analysis



Mix Design Report

Client :		Date : 04/09/2021	
Project/Contract :			
Placement : Bucket/Truck			
Usage : Precast			
Mix Design No. : 6056880		Description : 6,000 psi SCC 50% II/V 50% III 25% Slag	

Compressive Strength	6 000 psi at 28 Days	Submittal No.	
Aggregate Size	3/8" X #8	Plant	Woodland Struct
Air %	Non Air Entrained	Volume	27.00 ft ³
w/cm Ratio	0.34	U.W. at 3.0 % of air	145.8 lb/ft ³
Flow		Flow with SuperP	22.00 to 28.00 in

Constituents and Suppliers	Quantity (yd ³)	Sp. Gr. SSD	Volume
Cement - 13319 - Cal Portland type III - Type III - Cal Portland	300 lb	3.150	1.53 ft ³
Cement - 13331 - Cal Portland Type II/V - Type II/V - Cal Portland	300 lb	3.150	1.53 ft ³
Cement - TBD - Slag Cement - Blast Furnace Slag - Lehigh - Hanson, Cupertino	200 lb	2.870	1.12 ft ³
Water - H-20 - Well Water - Well - Well Water	36.0 Gal	1.000	4.81 ft ³
Stone - 13090 - 3/8" X #8 - Natural gravel - Granite, Capay	1619 lb	2.647	9.80 ft ³
Sand - 13053 - #4 - Natural sand - Granite, Capay	1218 lb	2.637	7.40 ft ³
Admixture - 13323 - ViscoCrete 4100 - High range water reducer - Sika, Santa Fe Springs	64.00 oz/yd ³	1.080	0.07 ft ³ /
Admixture - 13112 - Plastocrete 161 - Water reducer - Sika, Santa Fe Springs	32.00 oz/yd ³	1.140	0.03 ft ³ /
Admixture - 13314 - ViscoFlow 2020 - Slump Retention - Sika, Santa Fe Springs	16.00 oz/yd ³	1.040	0.01 ft ³ /
Admixture - 13128 - 4R - Viscosity modifier - Sika, Santa Fe Springs	16.00 oz/yd ³	1.020	0.02 ft ³ /
Air Volume			0.81 ft ³
Total	3937 lb		27.00 ft³

Optional Products :
2 - Rapid 1; 3 - SikaSet NC; 7 - Perfin 305; 12 - Sika Visco Flew 2020; 11 - Sikatard 440 Hydration Control

Remarks :

Prepared by : ~Bob De Ruiter, Concrete Operations Manager	Approved by :
Date : 02/07/2020	~Monica Cervantes, Corporate Quality
Woodland Struct	Date : 02/07/2020

BC0349

CLARK PACIFIC		QUALITY CONTROL DEPT		CONCRETE Statistical report											
Plant :		Woodland Struct		City:		Compressive Strength : 6 000 psi to 28 Days									
Mix Design No.:		6056880 (2)		Mix Design Creation Date:		02/07/2020									
STRENGTH AND RESULT															
Sample No.	Date sampled	Contract	Compressive Strength: AASHTO T-22					Air Before %	Air After %	Slump Field in	Slump Plant in	Temp. °F	U.W. lb/ft³	Qty No. yd³	Truck No.
			Age and psi												
			7 Days	28 Days	56 Days										
169100	04/03/2020	6094	7 600	9 437	10 490				1.8			26.00	70.0	145.8	
169399	05/08/2020	6094	7 330	9 130	9 010				1.5			26.50	71.0	148.0	
169410	05/11/2020	6094	7 480	8 650	9 680				3.0			26.00	62.0	147.2	
169420	05/12/2020	6094	7 960	9 880	10 160				1.3			27.77	69.0	148.6	
169431	05/13/2020	6094	7 460	9 065	9 390				2.4			25.00	68.0	147.2	
169444	05/14/2020	6094	6 940	8 417	8 840				2.5			25.50	68.0	147.0	
169512	05/22/2020	6094	7 120	8 327	8 770				2.5			25.00	80.0	147.2	
169757	06/26/2020	6094	7 640	7 830	8 230				3.0			23.00	80.0	145.6	
169936	07/24/2020	6094	7 830	8 715	9 320				2.4			24.50	76.0	145.4	
169989	07/31/2020	6094	6 730	7 897	8 170				2.4			26.00	69.0	144.8	
170056	08/10/2020	6122	6 580	7 820	8 190				1.6			25.00	54.0	146.2	
170087	08/12/2020	6122	6 820	8 353	8 690				2.1			24.00	57.0	146.6	
170106	08/14/2020	6122	6 990	7 773	7 830				1.8			24.50	90.0	146.1	
170127	08/18/2020	6122	6 460	8 540	9 110				1.6			26.00	90.0	146.6	
170157	08/24/2020	6122	6 110	8 000	8 600				1.2			25.00	54.0	147.3	
170183	08/26/2020	6122	6 080	7 860	8 630				0.5			26.00	51.0	147.7	
170210	08/28/2020	6122	7 550	8 303	9 010				1.0			25.50	78.0	146.7	
170234	09/01/2020	6122	6 810	8 333	9 000				1.0			23.50	80.0	145.9	
SUMMARY RESULT INTERPRETATION															
Lot Average:			7 223	8 735	9 261				3.2			25.15	78.0	146.0	
Minimum Value:			6 080	7 773	7 830				0.5			17.00	62.0	125.0	
Maximum Value:			8 510	9 880	10 840				70.0			28.00	93.0	149.0	
Range:			2 430	2 107	3 010				69.5			11.00	31.0	24.0	
Standard deviation:			450	498	632				9.60			1.95	6.0	3.0	
Reported by:			Date : / /			Verified by:									

BC037

Appendix 7. Strand Specifications



Sumiden Wire

SPECIFICATIONS FOR PRESTRESSING STRAND – TECHNICAL DATA

ASTM A416 – SEVEN-WIRE UNCOATED LOW RELAXATION STRAND							
Grade	Nominal Strand Diameter in [mm]	Strand Tolerance in [mm]	Minimum Breaking Strength Lbs [kgs]	Min. Yield Strength at 1% Extension Lbs [kgs]	Minimum Elongation at 24" Gauge	Nominal Area In ² [mm ²]	Nominal Weight Lbs/1000 ft Kg/1000 m
250K	3/8" [9.5]	0.3910/0.3590 [9.93/9.13]	20,000 [9,072]	18,000 [8,165]	3.5%	0.080 [51.61]	272 [405]
	7/16" [11.1]	0.4535/0.4215 [11.51/10.71]	27,000 [12,247]	24,300 [11,022]		0.108 [69.68]	367 [548]
	1/2" [12.7]	0.5160/0.4840 [13.1/12.3]	36,000 [16,329]	32,400 [14,696]		0.144 [92.9]	490 [730]
270K	3/8" [9.5]	0.4010/0.3690 [10.18/9.38]	23,000 [10,433]	20,700 [9,389]	3.5%	0.085 [55.03]	290 [432]
	7/16" [11.1]	0.4635/0.4315 [11.76/10.96]	31,000 [14,061]	27,900 [12,655]		0.115 [74.19]	390 [582]
	1/2" [12.7]	0.5260/0.4940 [13.35/12.55]	41,300 [18,733]	37,170 [16,860]		0.153 [98.71]	520 [775]
	0.52" (1/2" HBS) [13.2]	0.5460/0.5140 [13.86/13.06]	45,000 [20,412]	40,500 [18,368]		0.165 [106.45]	563 [874]
	9/16" [14.3]	0.5885/0.5565 [14.94/14.14]	51,700 [23,451]	46,530 [21,102]		0.192 [123.87]	650 [967]
	0.6" [15.2]	0.6260/0.5940 [15.89/15.09]	58,600 [26,581]	52,740 [23,922]		0.217 [140.00]	740 [1,102]

RELAXATION PROPERTIES	
Initial Stress	Maximum Relaxation after 1000 Hours
70% G.U.T.S.	2.5%
80% G.U.T.S.	3.5%