



LEHIGH
UNIVERSITY

PCI Big Beam Competition



Team Members:

Kate Springsteen

Taryn Ross

Peter Misiewicz

Ryan Bruce

Ryder Henry

Faculty Advisor:

Dr. Clay Naito

PCI Producing Sponsor:

Northeast Prestressed Products

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1. Acknowledgements

Lehigh University's Big Beam team would like to acknowledge and thank all the individuals who advised us along the way. With their help we were able to produce a successful entry and learn a lot.

We would like to first start out by thanking our faculty advisor, Dr. Clay Naito, for his dedication and mentorship during this process.

We also would like to express our gratitude towards everyone at Northeast Prestressed Products. They graciously donated their time and materials to this project.

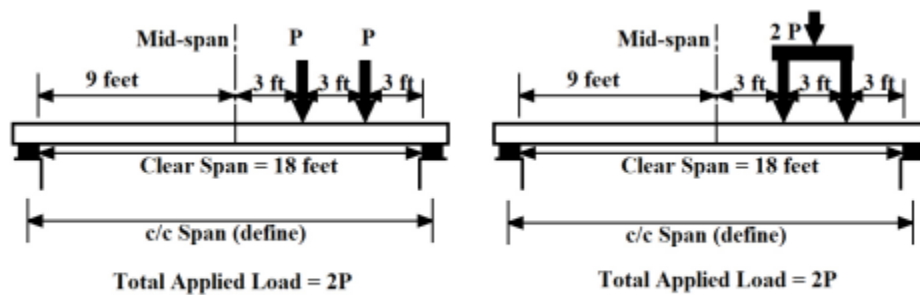
We would also like to thank the Lehigh University lab technicians, Aaron Moyer and Matthew Liero, for their time and support during the testing of our beam.

Lastly, we also would like to thank Precast/Prestressed Concrete Institute (PCI) for hosting this competition which provides us with this opportunity to display our knowledge.

2. Executive Summary

Every year Precast/Prestressed Concrete Institute (PCI) hosts a Big Beam Competition which allows students to display their knowledge by designing a prestressed concrete beam. This year with the help from Dr. Clay Naito and Northeast Prestressed Products students from Lehigh University took this opportunity and designed and tested a prestress beam.

The rules for the 2023-2024 PCI Big Beam Competition specify that the beam's clear span must be 18 feet and the beam must support two unsymmetrical point loads as shown in Figure 1 below. The beam must be able hold two point loads of 16 kips, totaling 32 kips, but must break before a total load of 40 kips. The beam also cannot crack before a total load of 20 kips.



PERMITTED LOAD CONFIGURATIONS

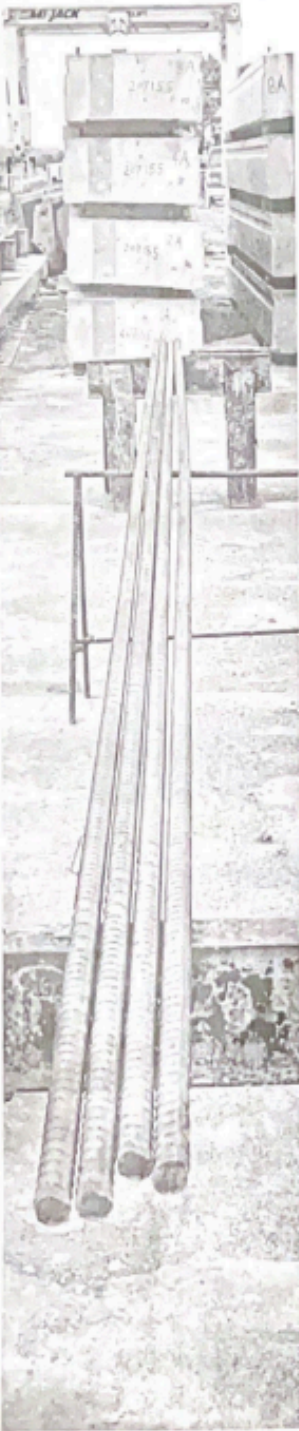
Figure 1: Big Beam Loading Rules

The team designed and fabricated a beam that followed these parameters. An I-shape member with ½" special strands was utilized. In addition to designing the beam the team also predicted the cracking load, ultimate load and ultimate deflection. Table 1 summarizes the team's the predicted values, actual values and percent difference.

Table 1: Pretest Predictions and Actual Test Summary

	Predicted Values	Actual Values	Percent Difference
Cracking Load	22.99 kips	22.48 kips	2.22%
Ultimate Load	39.84 kips	39.207 kips	16.06%
Ultimate Deflection	1.70 in	1.427 in	1.59%

3. Summary/ Judging Form



PCI BIG BEAM COMPETITION 2023-2024

CERTIFICATION

Northeast Prestressed Products
As a representative of (name of PCI producer member or sponsoring organization)
Lehigh University
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
Dawn Decker
Name (please print)
4/18/2024
Date
39.84 kips
Predicted maximum load
22.99 kips
Predicted cracking load
1.70 in. AT Max Moment Location (12ft. from left support)
Predicted deflection at midspan

THIS CERTIFICATION MUST BE PART OF THE FINAL REPORT.

Sponsored by:

ASPIRE **ALP**
SUPPLY

PCI BIG BEAM COMPETITION 2023-2024

4/29/2024

Date

Lehigh University

1

April 10, 2024

Student Team (school name)

Team Number

Date of Casting

Basic Information

1. Age of beam at testing (days) 8
2. Compressive cylinder tests*
 - Number tested 3
 - Size of cylinders 4x8
 - Average (psi) 7752
3. Concrete properties
 - Unit weight of concrete (lb/ft³) 143.75
 - Slump or spread (in.) 23.0
 - Air content (%) 7.0
 - Tensile strength (psi) 805.5
 - Circle one: ☐ Split cylinder ☒ MOR beam
4. Pretest calculations
 - a. Applied load (total) to cause cracking (kip) 22.99
 - b. Maximum applied point load at midspan (kip) 39.84
 - c. Maximum anticipated deflection due to applied load only (in.) 1.70

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. Center to center span (ft) 18.0
 2. Actual maximum applied load (kip) 39.207
 3. Measured cracking load (kip)[†] 22.48
 4. Cost (dollars) \$59.91
 5. Weight (lb) 1281lb
 6. Largest measured deflection (in.) 1.427
 7. Most accurate calculations:
 - a. Absolute value of (maximum applied load – calculated applied load)/calculated applied load 1.59%
 - b. Absolute value of (maximum measured deflection – calculated deflection)/calculated deflection 16.06%
 - c. Absolute value of (measured cracking load – calculated cracking load)/calculated cracking load 2.22%
- Total of three absolute values (a + b + c) = 19.87%**

[†] 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 digital report, due June 14, 2024.

Sponsored by:



4. Load/Midspan deflection Graph

Figure 2 below shows the Load vs Midspan deflection graph. The load consisted of the force applied by the universal machine and the weight of the loading fixtures. Figure 3 shows the load versus displacement graph. The max load, cracking point and ultimate displacement is noted. The max load corresponds to the maximum load resisted. The ultimate displacement occurs after this point as the beam is able to continue to resist the applied loads with a marginal decrease in capacity. The ultimate displacement is taken as the point where a significant decrease in strength is observed. The cracking displacement was determined by a change in the slope of the curve. The intercept of the shifted elastic curve and the load displacement response was used to determine this point.

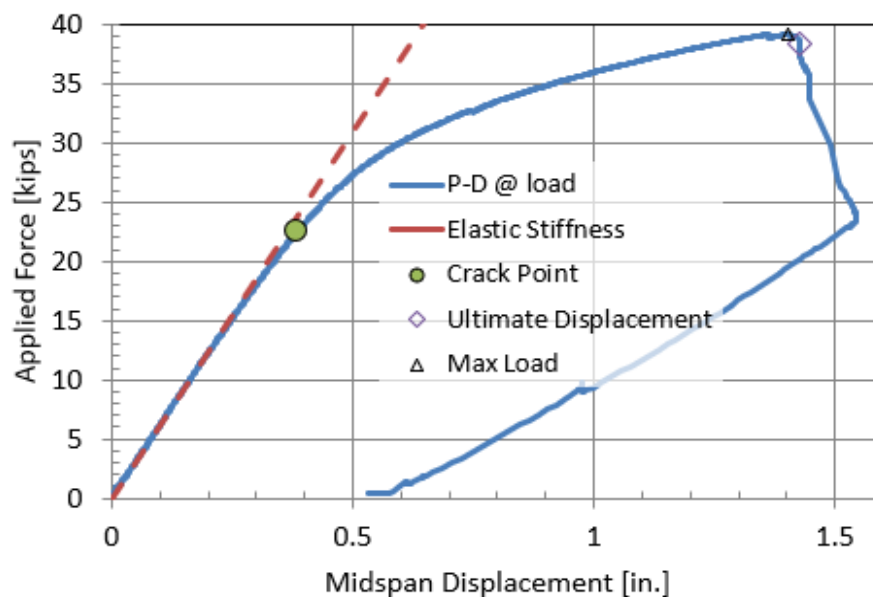


Figure 2: Load vs Midspan Displacement Graph

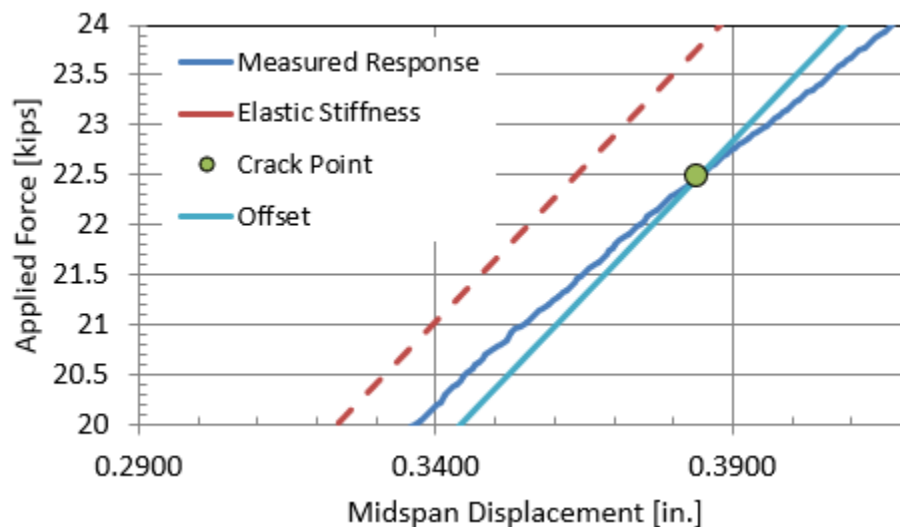


Figure 3: Load vs Midspan Displacement at Initial Cracking Graph

NOTES:

CONCRETE PROPERTIES: CONCRETE RELEASE COMPRESSIVE STRENGTH = 6800 PSI

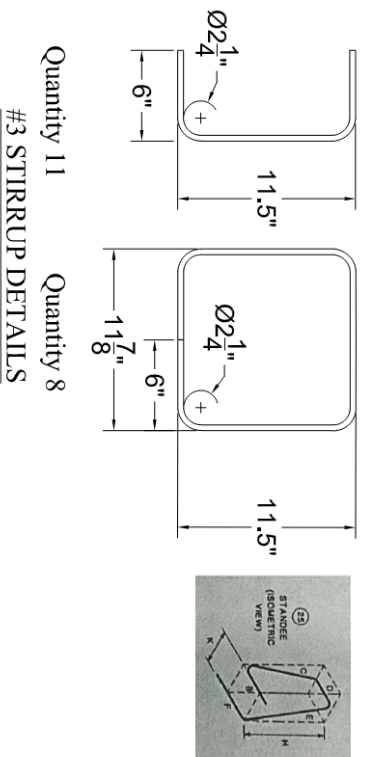
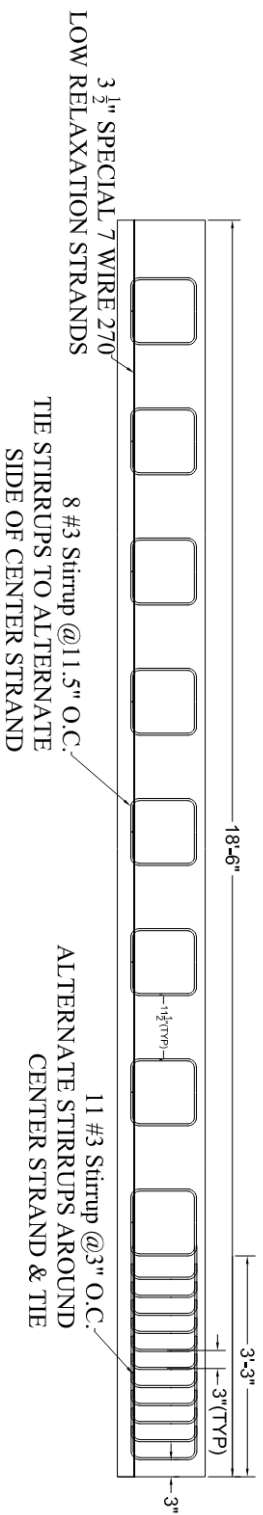
CONCRETE 28 DAY COMPRESSIVE STRENGTH = 8000 PSI

STRAND PROPERTIES: $\frac{1}{2}$ " SPECIAL 7 WIRE GRADE 270 LOW RELAXATION STRANDS

JACKING STRESS = 0.75FPU = 202.5 ksi

TOTAL JACKING FORCE = 101.45 kip

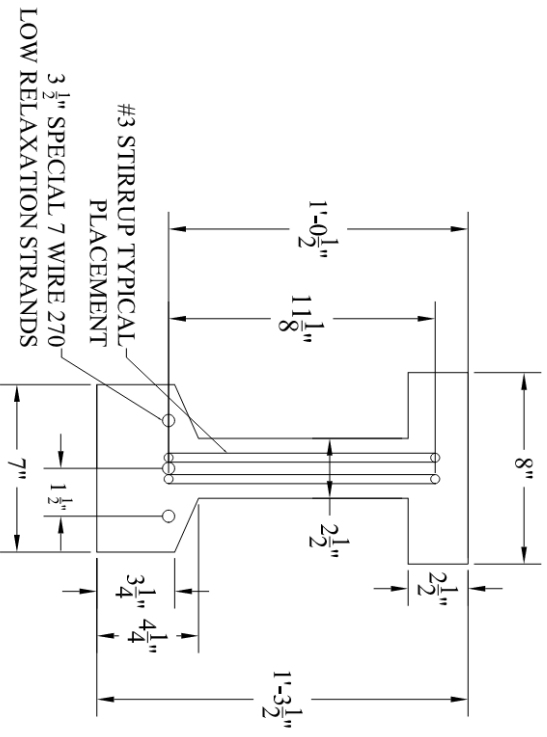
JACKING FORCE PER STRAND = 33.82 kip



Quantity 11

#3 STIRRUP DETAILS

Quantity 8



#3 STIRRUP TYPICAL PLACEMENT

3 $\frac{1}{2}$ " SPECIAL 7 WIRE 270 LOW RELAXATION STRANDS

5. Drawings

6. Materials

Mix Design

The concrete for this design was generously provided by Northeast Prestressed Products LLC. The plant provided concrete with a 28-day compressive strength of 8 ksi to meet our structural design calculations. Due to the small scale of the big beam, when compared to typical beams in the industry, it was important that the mix was self-consolidating and had high workability to fully fill out the formwork. Viscosity modifying (VMA 362) and air entraining (Master Glenium 7710 High Range Water Reducing) admixtures were used to achieve these goals. Additionally, due to scheduling limitations between the pour date and testing date, it was necessary that the mix obtain high early strength using Type III cement. Since this is common in precast plant operations, it was easy for this to be met. Table 2 summarizes the key components of the mix and the complete documentation from Northeast Prestressed Products LLC is included in the Appendix.

Table 2: Concrete mix material proportions

Material	Sand (lbs/yd³)	Coarse Aggregates (lbs/yd³)	Type III Cement (lbs/yd³)	Slag (lbs/yd³)	Water (lbs/yd³)	Microsilica (lbs/yd³)	Air (oz/yd³)
	1270	1535	567	254	288	25	2.0
Admixture Type	Viscosity Modifying (fl. oz/yd³)	Air Entraining (fl. oz/yd³)					
	14.0	86.0					

A spread test was performed at the plant before the concrete mix was approved to be sent and placed in the formwork. The spread test produced a 23-inch spread which was within the target range of 20-26-inches. Additionally, a J-ring test was conducted to resemble the concrete spreading between reinforcing bars, and a 22-inch spread was observed and deemed acceptable. Figure 4 includes the results of both of these spread tests. The air content was determined to be 7.0% and the actual unit weight (density) of the mix was 143.75 pcf.



Figure 4: Spread Tests

The plant also provided the results of cylinder tests performed before the beam was delivered to Lehigh University. Additional concrete cylinders and two 6"x6"x18" test specimens were cast. Prior to testing, the modulus of elasticity, compressive strength and modulus of rupture were determined from experimental tests on these specimens. This testing will be further discussed later in the report. Preliminary calculations were adjusted per these updated properties.

Rebar Specifications

The only additional reinforcement provided in this design was shear reinforcement. The shear reinforcement was tied around the prestressing strands to support their layout. All rebar used in the beam were Grade 60 Steel #3 bars. The spacing of the shear reinforcement varied along the length of the beam and will be discussed further in the *Design* section of this report.

Prestressing Strands Specification

$\frac{1}{2}$ Special 7-wire low relaxation 270 ksi strands were used as the prestressing strands in this design. The strands were jacked to a stress that was 75% that of the ultimate stress. The strands had a uniform eccentricity along the entire length and were located 12.5in from the top of the beam.

7. Design

To design this beam the team followed the guidelines set by PCI. The team decided to use an unsymmetrical I-shape cross section due to the shape's efficiency, constructability and strength capacity. When designing this beam there were two design components: the flexural strength and the shear strength.

Flexural Service & Strength Checks

The first step in designing this beam was to design the beam for flexure. This included designing for both strength and service considerations. To design for flexure the team had to consider the

criteria set forth by PCI. The criteria is as follows: The beam must hold a total load of 32 kips, the beam cannot crack before a total load of 20 kips and the beam must break before a total load of 40 kips. This means that the beam's nominal strength capacity, M_n , must not exceed the moment caused by 40 kips of load, and the cracking moment for service, M_{cr} , must be greater than the moment caused by 20 kips of load.

Before the team dove into the design some parameters were set by the prestressing plant. The first parameter was that $\frac{1}{2}$ " special strands were to be used and those strands were to be straight. Next the predicted compressive strength of the concrete was given as 8000 psi and the predicted compression strength at transfer was given as 6800 psi.

With these parameters set and goals in mind the team designed the beam through many iterations. Adjustments to the beam's geometry and number of strands were made until an accurate design was found that satisfied both strength and serviceability requirements. For each iteration the losses due to elastic shortening, relaxation creep and shrinkage were calculated. These loss calculations helped predict the initial and effective prestressing forces which were then used in the ACI allowable stress checks calculations. These stresses were then compared to the codes to ensure the design was in compliance with ACI. Then both the ACI Simplified Method and Strain Compatibility Method was used to predict the beam strength. For the final design the Strain Compatibility Method was used as it is a more accurate prediction. In addition to strength the cracking moment was also found using the effective prestressing force found in the losses calculations.

As the team was iterating through the design the main desire other than staying within the guideline of the competition and passing all the stress checks was to have the strands aligned horizontally rather than vertically. This was a desire as it would result in a more accurate prediction of the ultimate load because all strands would be at the same strain for a given flexural demand. To achieve this desire the eccentricity of the strands had to be large enough that the strands would be in the bottom flange and the width of the bottom flange had to be large enough to fit the strands and have an adequate clear cover.

Shear Strength

In addition to the flexural strength the shear strength of the beam was calculated and designed. To calculate the shear strength of the beam the Simple Shear Method was used. In this method the shear strength of the concrete section is determined and compared to the shear demand to see if additional shear reinforcement is needed. Shear reinforcement is designed to prevent the failure mechanisms of shear after cracking has already occurred. No. 3 stirrups tied alternately around the center strand were used in this design to ensure symmetry. The shear reinforcement is designed as 11 No. 3 stirrups 3 inches on center for the first 3 feet from the support, and then 8

stirrups spaced 11.5 inches on center for the remainder of the beam. Figure 5 below shows the cross section of this beam with the detailed shear reinforcement.

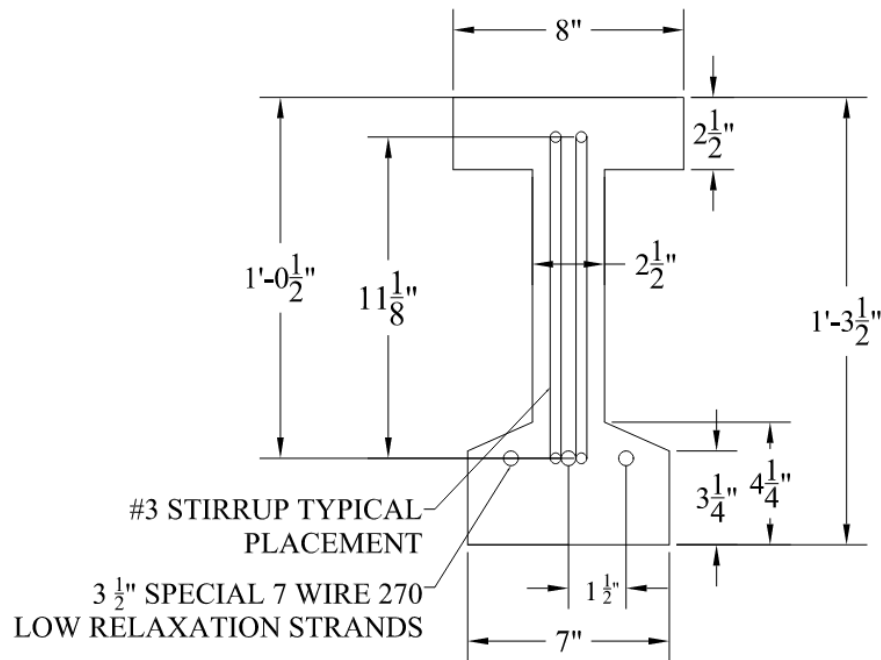


Figure 5: Cross Section of Beam

Development Length

Another aspect that must be considered when designing the beam is the development length. Calculating development length is important because the strands must have adequate length to be able to reach their full design strength.

As mentioned previously this beam was fabricated at Northeast Prestressed Products, a bridge beam producer in Pennsylvania. As a result the team was limited to 1/2 in. special strands. The big beam requirements specified two load points at 3 feet and 6 feet from the support. The maximum moment location was located at the second load point 6 ft from the support. The team utilized a 6 in. bearing plate so the maximum moment is located 75 in. from the end of the beam. The estimated development length of this beam was 80.96 in. This is shorter than the 75 in. length available on the beam. Based on bond testing conducted by Professor Naito for NPP the length needed to fully develop the tensile strength of the strands is less than 35 in. as noted in Naito et al. (2015). To ensure that bond slip was not an issue the end slip was checked at the nominal flexural strength (estimated applied load of 39.96 kips). No slip was observed at that point.

8. Fabrication

To fabricate the beam the team traveled to Northeast Prestressed Products, a bridge beam producer in Pennsylvania. Fabrication took place on Wednesday April 10th, 2024. NPP had prepared for fabrication by pretensioning the strands, creating wood formwork, and bending and cutting the shear reinforcement. Once the team arrived the first task was to verify that the formwork was constructed to the right dimensions. The next step was to install the shear reinforcement. Members of the team installed the shear reinforcement by tying the reinforcement to the middle strand. Figure 6 shows the shear reinforcement in the formwork. The last step was to close the formwork.

Once the form work was closed the concrete mix was craned over from the mixing plant and was poured. The concrete was then poured little by little into the form and evened out as much as possible. As it is poured, the concrete vibrator works out as many of the air pockets as possible. In addition to fabricating the beam, concrete cylinders and modulus of rupture beams were also fabricated to be tested later.



Figure 6: Shear Reinforcement

Cost

Once the beam was fabricated and as-built dimensions were obtained, the cost of the beam was calculated. PCI provided typical costs for the varying materials and those were used to determine the overall cost. The cost of this beam was determined to be \$59.91. Table 3 shows the breakdown of materials and their costs.

Table 3: Cost Breakdown

Material	Quantity	Unit Cost	Total
Concrete (ft ³)	8.91	\$100	\$33.22
Prestressing Strands	55.5 ft	\$0.32/ft	\$17.76
Rebar	19.85 lb	\$0.45/lb	\$8.93

Material Testing

As mentioned before, cylinders and beams were also fabricated at NPP. These cylinders and beams were tested at Lehigh to determine the true values of the concrete mix. The cylinders were used to determine the compressive strength and modulus of elasticity while the beams were used to determine the modulus of rupture. Table 4 shows the values from these tests. Additionally, the plant provided mill certifications for the prestressing strands. These provided us with an updated ultimate strength of 278.36 ksi and yield strength of 258.51 ksi which were used to refine our calculations.

Table 4: Concrete Measured Properties

	Measured Values
Modulus of Elasticity	4400 ksi
Modulus of Rupture	805.5 ksi
Average Compressive Strength	7023

9. Predictions

Once the beam was fabricated and the true properties of the concrete mix and prestressing strands were known, members of the team predicted the cracking load, ultimate load and ultimate deflection. Figure 7 shows the cross-section of the final beam from which as-built dimensions were taken from.



Figure 7: Prestressed beam cross-section

To calculate the ultimate load the Strain Compatibility method was used and to find the ultimate deflection the curvature was calculated. The curvature was calculated at three points. At release, at cracking, and at nominal. Using these curvatures and their corresponding moments, the real curvature of the beam was calculated. This was then multiplied by the virtual moment diagram and integrated over the length to obtain the deflection. Table 5 shows the predicted values.

Table 5: Predicted values

	Predicted Values
Cracking Load	22.99 kips
Ultimate Load	39.84 kips
Ultimate Deflection	1.70 in

10. Testing

Northeast Prestressed Products delivered the beam to Lehigh University's and testing took place on Thursday, April 18th. The Five Million Pound Baldwin Universal Test Machine in Fritz Laboratory was used to perform the testing. Per the requirements of the Big Beam competition, the beam was supported on rollers 18 feet apart. A spreader beam, weighing 457 lbs, was used to distribute the force from the machine to the desired load points, 3-feet and 6-feet from the end support. Two linear variable differential transformers (LVDT) were attached to the bottom of the beam under the 6-foot point load, where maximum moment was expected, to measure the deflection of the beam during the testing. A load cell was used to measure the applied load. Figure 8 shows the test setup.

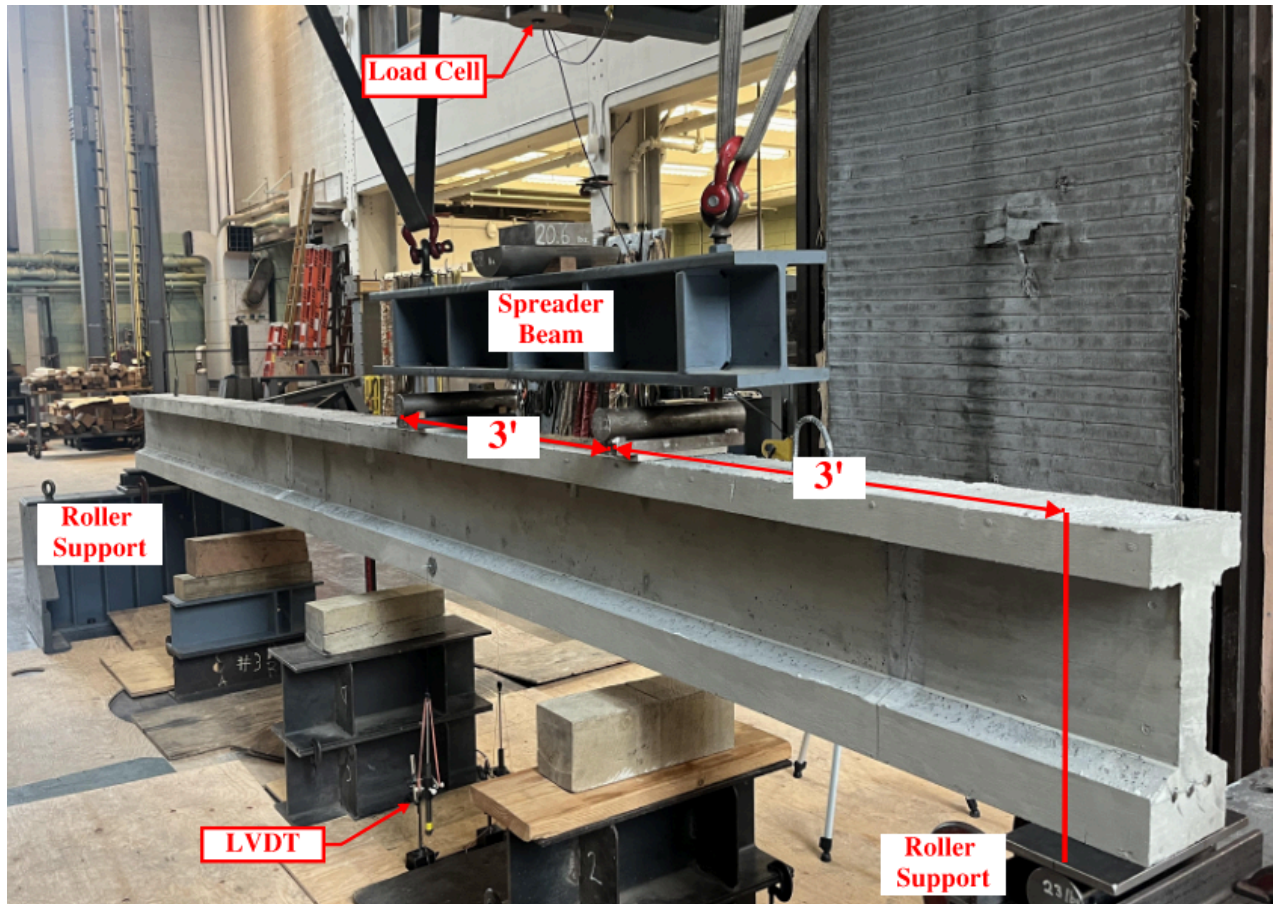


Figure 8: Testing setup

During the loading of the beam, observations were made at various times and cracking was marked on the beam when observed. The load at the first sign of cracking was documented as well as the load at ultimate failure. The type of failure observed, the cracking load and the ultimate load will be discussed in the next section of this report. A camera was also used to record the entirety of the test so that it could be watched back more closely after the fact. At the end of testing the data from the LVDT's and the load cell were downloaded for further analysis.

11. Results

This beam met the competition requirements laid out by PCI. The beam initially cracked at 22.48 kips and ultimately failed at 39.207 kips. The beam ultimately experienced a shear flexural failure. Flexural cracks formed at the expected location of maximum moment which occurred at 6' feet from the support as shown in Figure 9. As the load increased additional flexural cracks formed under the other point load 3' feet from the support and shear cracks also began to form. The load continued to increase and the cracks grew in size until a flexural crack combined with shear crack and failure ensued as shown in Figure 10. After failure a bond slip was observed as

shown in Figure 11. This bond slip can be attributed to the additional force created by the shear failure.

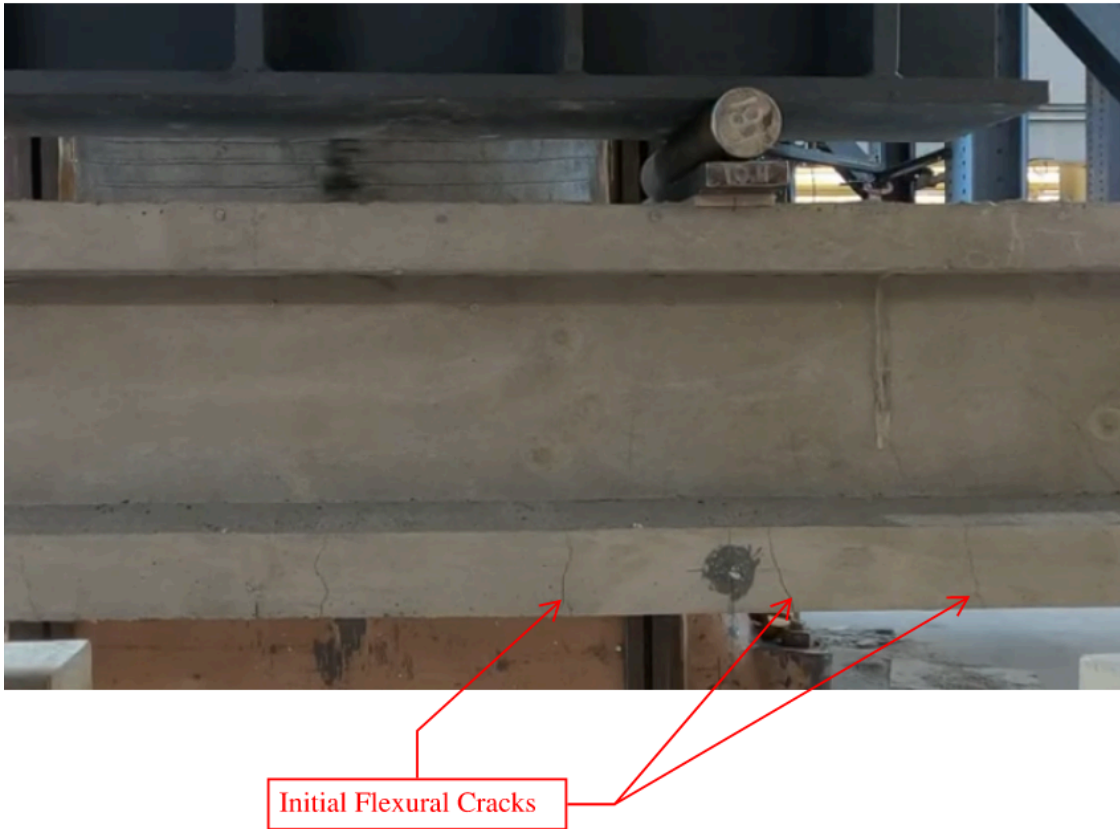


Figure 9: Initial Flexural Cracks

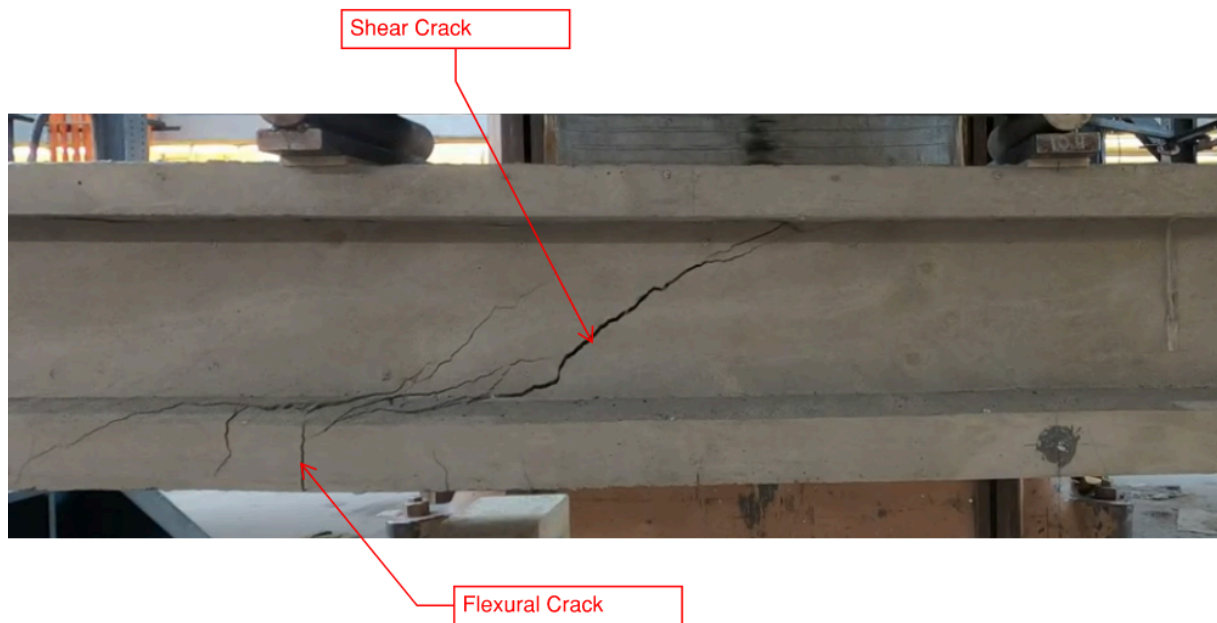


Figure 10: Beam at Flexural Shear Failure



Figure 11: Strand bond slip

Table 6 displays the load at which the beam cracked, the ultimate load the and the ultimate deflection. The team's predicted values are also shown and in the end had a total percent difference of 19.87%.

Table 6: Predictions and Test Summary

	Predicted Values	Actual Values	Percent Difference
Cracking Load	22.99 kips	22.48 kips	2.22%
Ultimate Load	39.84 kips	39.207 kips	16.06%
Ultimate Deflection	1.70 in	1.427 in	1.59%
Total			19.87%

These values were pulled from the Load vs Midspan Displacement Graph which is shown in Figure 12 below.

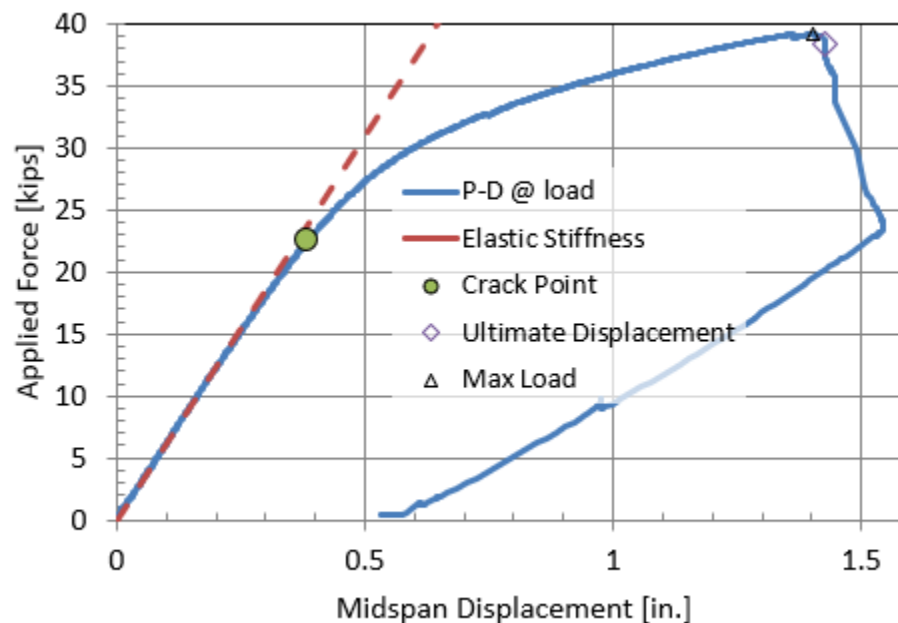


Figure 12: Load vs Midspan Displacement Graph

To more accurately determine where cracking occurred a more condense graph was used which is shown in Figure 13.

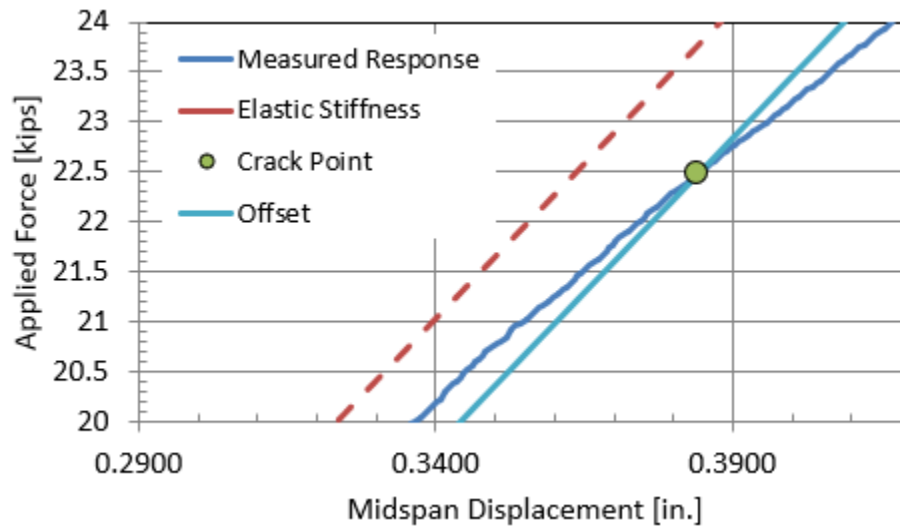


Figure 13: Load vs Midspan Displacement at Initial Cracking Graph

12. Lessons Learned

The students from Lehigh University had a great time participating in this competition and learned a lot. Below each student explained specifically what they learned.

Kate Springsteen:

This competition was a great way to expand and test our knowledge outside of the classroom. As a visual learner it is really valuable to be able to connect something we learned in class to a true beam. Because of this competition I have a deeper understanding of the design of a prestress beam. I also learned a lot about fabrication, which is an important aspect to keep in mind when designing anything. Any design we build must be able to be fabricated. This was something we quickly learned when calculating the shear reinforcement. In all, this was a great learning experience.

Kate Springsteen
609 Upham Place,
Vienna, VA, 22180

Emails:
Lehigh- kas623@lehigh.edu
Personal- KateASpringsteen@gmail.com

Taryn Ross:

The hands-on experience provided through the PCI Big Beam competition added so much to my understanding of the topic. In most college courses I haven't been able to see the application of the calculations and design processes I've learned, but through this experience I've been able to see and be a part of the process firsthand. I enjoyed working through the design, problem

solving, hands on tying the rebar during fabrication, measuring our beam and testing it. From start to finish I was able to learn a lot and gain a greater appreciation for the industry through this competition. Seeing a design through to its final installation is important as a structural engineer and I am glad I had this opportunity before starting my post graduate job.

Taryn Ross
671 Donald Dr. N.
Bridgewater, NJ, 08807

Emails:
Lehigh- tlr222@lehigh.edu
Personal- tarynLross@gmail.com

Peter Misiewicz:

The PCI Big Beam competition gave our team a way to tangibly see and experience not only the process of design, but also fabrication and testing. This holistic approach presented new and interesting obstacles that proved to be a great learning experience. For example the shear reinforcement was determined to be spaced 3" O.C with proper development length. This passed our mathematical checks, however the practical aspect of fabrication had to be considered when preparing shop drawings. While tying our stirrups we ensured that they alternated the center strand to ensure cross sectional symmetry. Furthermore, seeing the fabrication process, and editing our calculations with updated values for material strengths and cross section, brought to light the inconsistencies in manufacturing. The PS strands were spaced correctly however placed slightly off center (approx 1/4 in) which resulted in a visible eastern camber. Some hairline cracks could be observed on the compression face of the beam, possibly due to release at too low of a concrete compressive strength. There is also much to learn from the mechanism of failure. The beam initially started failing with flexural cracks at the point load closest to the north end which then progressed into a shear crack between the two point loads. This means that our beam passes nominal bending strength at the point of max moment but fails when the moment increases to a point where the PS reinforcement does not have enough development length to achieve this capacity. This resulted in a flexural crack at that first point load and then subsequent failure with the shear crack. The PCI Big Beam Competition enhanced our knowledge of design by providing an opportunity to see our classwork physically in person.

Peter Misiewicz
1870 Hart St. #2L
Ridgewood NY 11385

Emails:
Lehigh- pjm224@lehigh.edu
Personal-pjmisiewicz@gmail.com

Ryder Henry:

It was fascinating to see how the designs that we had been carrying out all semester long were taken to the plant and fabricated. Whether it is strength values or even dimensions, it made it very clear why there are such significant factors of safety (the phi factor of 0.75 in the shear design after our tying job makes sense).

Ryder Henry
8 Hanson Road
Darien, CT 06820

Emails:
Lehigh- jr324@lehigh.edu
Personal- jrhenry600@gmail.com

Ryan Bruce:

I believe the best part about engineering is taking what you learn in the classroom and applying it in real world applications. In internships I've had in the past, I've always learned better after going into the field and seeing the designs I've worked on come to life. The PCI Big Beam competition was also great for this reason, allowing me to take a design from inception to testing. I learned how designed beams truly alter from the completed fabricated versions, and how it's important to take everything into consideration in order to produce a final result that most closely replicates the initial vision. I've also had a new appreciation for the bridges and other structures that I use everyday, now that I understand the intricacies involved in their creation. Finally, I've learned how many people are involved in this process, and I admire the work they do to design and produce beams for everyday applications all over the world.

Ryan Bruce
42 Dartmouth St.
Valley Stream, NY 11581

Emails:
Lehigh- rtb324@lehigh.edu
Personal- RyanBruce2201@gmail.com

13. References

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- PCI Design Handbook, 7th Edition, Precast/Prestressed Concrete Institute, 2010.



Appendix A: Structural Drawings

NOTES:

CONCRETE PROPERTIES: CONCRETE RELEASE COMPRESSIVE STRENGTH =6800 PSI

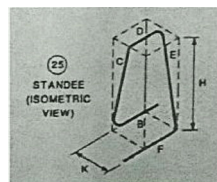
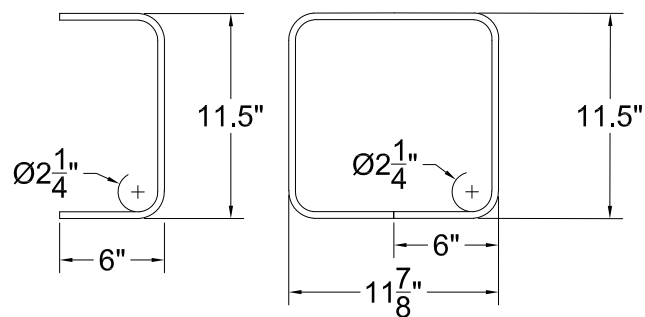
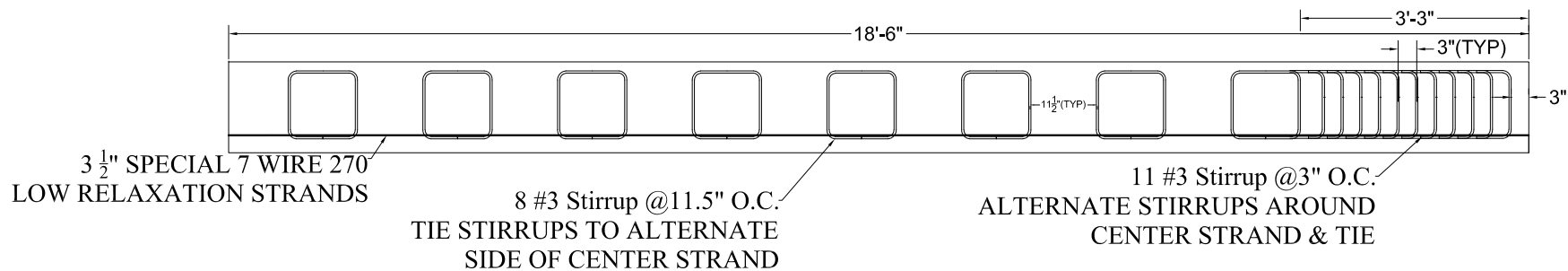
CONCRETE 28 DAY COMPRESSIVE STRENGTH =8000 PSI

STRAND PROPERTIES: $\frac{1}{2}$ " SPECIAL 7 WIRE GRADE 270 LOW RELAXATION STRANDS

JACKING STRESS = 0.75FPU=202.5 ksi

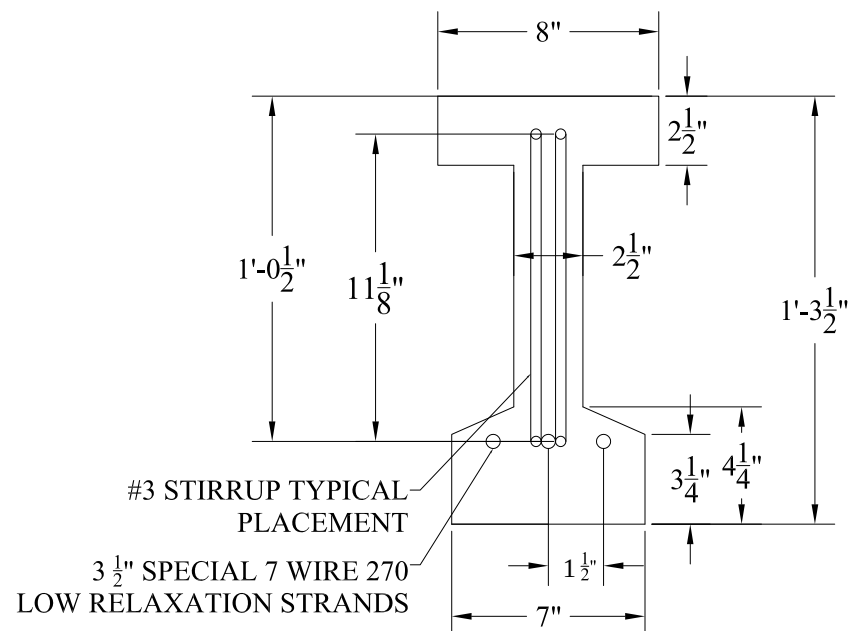
TOTAL JACKING FORCE = 101.45 kip

JACKING FORCE PER STRAND = 33.82 kip



Quantity 11
#3 STIRRUP DETAILS

Quantity 8



PROJECT:

**PCI BIG
BEAM
COMPETITION**

SHEET NOTES:

NO.	DESCRIPTION	DATE	BY

DESIGNED BY: TR/KS
DRAWN BY: KS
CHECKED BY: -
SCALE:
DATE: 03/26/2024
PROJECT NO.:
SHEET TITLE:

**Big Beam
Shear Details**

SHEET NO.:

Appendix B: Material Details

CS-4220 (10-21)				Date 4/10/2024			
 pennsylvania DEPARTMENT OF TRANSPORTATION		Batcher Mixer Slip					
						Time 1:19 pm	
						JMF Number 23-PASO8	
		ECMS Job #99998/171					
Contractor Lehigh University Big Beam			Plant Northeast Prestressed Products				
County Lehigh University			Project Location Cressona, Pa				
S.R. SECTION			Design Gallons of Water Per Cubic Yard 34.50				
Class Concrete SCC		W/C Ratio 0.34	Design Gallons of Water - Admixture Water Per C.Y 34.50				
MATERIALS		SATURATED SURFACE DRY WEIGHT (lbs)	SURFACE MOISTURE (%)	SURFACE MOISTURE (lbs)	BATCH WEIGHT PER C.Y. (lbs)		
Cement		567			567		
SCM		254			254		
SCM		25			25		
Sand		1270	3.90%	50	1320		
#8		460	2.60%	12	472		
#57		1075	1.20%	13	1088		
Admixture [oz.]		Weight per gal			Admixture (Solids+Water) [lbs]		
Admixture [oz.]		Weight per gal			Admixture (Solids+Water) [lbs]		
Ice [lbs]					Ice-Water [lbs]		
Target Slump	20-26	Surface Moisture in Aggregates [lbs]		75.00			
% Air	5-9%	Surface Moisture in Aggregates [gals]		9.00			
		Batched Mixing Water [gals]		25.50	212		
			Batched Mixing Water [lbs]				
PENNDOT Field Inspector (who gave release)				Total Batch Weight 3938 lbs.			
PENNDOT Plant Inspector				Batch Yield 27 cu. ft.			
Concrete Plant Technician JK				Wt/Cu.Ft. 145.85 lbs./cu.ft.			

Date: 4/10/2024



Operator: JK

Lehigh University Big Beam

Bed # 4

Lehigh University

Release: 6,800 psi

28 Day: 8,000 psi

Cement: Lehigh Type 3

99998/171

Mix: Pa Dot (SCC) / 23-PAS08

NPP Pour Sheet

567 / 254 / 25 (.34 w/c 145.86) Mt Holly Sand

Beam Marks	Ticket ID	Time	Ambient Temp.	Concrete Temp.	Probe Dry / Wet	Water	Air Tracker Reading	Air Content	Slump Flow	Slump Flow thru J-Ring	VSI Index	Cubic Yards	MasterAir AE90	MasterSet R100	VMA 362	MasterSure Z60	MasterGlenium 7710	Curing Duration	Cylinder #	Concrete Strength	Type Fracture	Page: 1 of 1 Silo # 5 Remarks:
Big beam		1:50	70	69	21.12	480	55	7.0	23	22	1	2 1/4	5		32		192	17h	SC 1	5213	3	143.75
																		20	SC 2	6936	4	
																		20	SC 3	7109	3	
																		50	SC 4	7726	3	
																		50	SC 5	7749	4	
																		50	SC 6	7736	5	
																			LEHIGH SC 01			
																			L SC 02			
																			L SC 03			
																			L SC 04			
																			L SC 05			
																			L SC 06			
																			L SC 07			
																			L SC 08			
																			BLOCK			
																			BLOCK			

total - 2 1/4
wast - 1 3/4
Actual - 1 1/2

batch

T-20 range

batch

T-20 range

Truck	Driver	User	Disp	Ticket Num	Ticket ID	Time	Date
					00013	13:46	04/10/2024
Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID	
2.25 yd	23-PAS08					WO002532	

design mix time in sec. 120

Material	Design Qty	Required	Batched	%Var	moist(%)	moist(lb)	
MTHOLLY3	1270LBS	2969LBS	2980LBS	0.37%	3.90%	111.86	0.00%
#67-4	537LBS	4191LBS	4189LBS	-0.05%	1.20%	14.47	0.00%
#67-5	538LBS	5417LBS	5411LBS	-0.11%	1.20%	14.47	0.00%
#8	460LBS	6479LBS	6477LBS	-0.03%	2.60%	26.86	0.00%
Cement 5	567LBS	1276LBS	1275LBS	-0.08%			
Micro	25LBS	1332LBS	1331LBS	-0.08%			
Slag3	254LBS	1904LBS	1907LBS	0.16%			
Water	288LBS	481LBS	480LBS	-0.12%		480.00	
AIR	2.00Z	4.50Z	5.00Z	11.11%*			
7710-2	86.00Z	193.50Z	192.00Z	-0.78%			
VMA362	14.00Z	31.50Z	32.00Z	1.59%			
Total weigh	4041LBS	9093LBS	9094LBS			647.65	
Baghes 1	Design W/C	0.340	Water/Cement	0.340			

Load Completed Load Time: 13:53

AGG SCL 0 CEM SCL 5 WAT SCL 0.0

Manual overwrite

#8 3280.00

AIR 8.00

Auto. Mois. Cor. : OFF

* = Tolerance error

Calculation
 Time period: 04/10/2024 / 00:00 - 04/10/2024 / 24:00
 Rec.Code 23-PAS08
 Date 04/10/2024 / 14:11:40

Code	Description	Unit	Actual	Price/\$

Aggregates				
67-DYER	#67-4	LBS	1220.00	0.00
67-DYER	#67-5	LBS	1220.00	0.00
MTHOLLY	MTHOLLY3	LBS	2980.00	0.00
8-DYER	#8	LBS	4340.00	0.00
Cement				
SF100	Micro	LBS	55.00	0.01
SLAG120	Slag3	LBS	575.00	0.02
TYPE3-LEHI	Cement 5	LBS	1275.00	0.00
Water				
WATER	Water	LBS	480.00	0.00
Admixture				
VMA362	VMA362	OZ	32.00	0.00
HRWA7710	7710-2	OZ	192.00	0.00
AER-MBAE-9	AIR	OZ	13.00	0.00

Batches 1
 Total quantity 2.25 cyd
 Total cost 0.02 \$
 Cost/cyd 0.01 \$

Lehigh University Big Beam
 Job # 99998/171
 WO-002532

Total - $2\frac{1}{4}$

wast - $1\frac{3}{4}$

Actual - $\frac{1}{2}$



Moistures

Date: 4/10/24 Time: 1:29 P.M.

Sand: MT. Holly-3

12.16	wet	4.00	dry	3.49	wet net
2.67	tare	2.67	tare	3.33	dry net
<u>3.49</u>	wet net	<u>3.33</u>	dry net	<u>4.80</u>	
				96	%moisture absorption
				<u>3.90</u>	%moisture

(3.90)

Temp. 58

Concrete Tech. _____

Stone: #8-1

5.00	wet	4.89	dry	3.33	wet net
1.67	tare	1.67	tare	3.22	dry net
<u>3.33</u>	wet net	<u>3.22</u>	dry net	<u>3.41</u>	
				.85	% moisture absorption
				<u>2.56</u>	% moisture

(2.60)

Temp. _____

Concrete Tech. _____

_____	wet	_____	dry	_____	wet net
_____	tare	_____	tare	_____	dry net
_____	wet net	_____	dry net	_____	
				_____	% moisture absorption
				_____	% moisture

Temp. _____

Concrete Tech. _____

Moistures

Date: 4-10-24 Time: 1:19 PM

Sand: 67-4

<u>7.47</u>	wet	<u>7.38</u>	dry	<u>4.80</u>	
<u>2.67</u>	tare	<u>2.67</u>	tare	<u>4.71</u>	wet net
<u>4.80</u>	wet net	<u>4.71</u>	dry net	<u>.09</u>	dry net
				<u>1.91</u>	
				<u>.53</u>	%moisture absorption
				<u>1.38</u>	%moisture

Temp. 55 Concrete Tech. _____

Stone: 67-5

<u>7.15</u>	wet	<u>7.08</u>	dry	<u>4.48</u>	
<u>2.67</u>	tare	<u>2.67</u>	tare	<u>4.41</u>	wet net
<u>4.48</u>	wet net	<u>4.41</u>	dry net	<u>.07</u>	dry net
				<u>1.58</u>	
				<u>.53</u>	% moisture absorption
				<u>1.05</u>	% moisture

Temp. 54 Concrete Tech. _____

_____ wet	_____ dry	_____ wet net
_____ tare	_____ tare	_____ dry net
_____ wet net	_____ dry net	
		_____ % moisture absorption
		_____ % moisture

Temp. _____ Concrete Tech. _____



INSTEEL WIRE PRODUCTS COMPANY
UNIFORM STRAIGHT BILL OF LADING
ORIGINAL - NOT NEGOTIABLE

Bill of Lading No. **00385366-9813025**

Date: 02-FEB-24

Stop 1 of 1

Page 1 of 1

SHIP FROM

Name: INSTEEL WIRE PRODUCTS COMPANY
Address: 630 NATIONAL DRIVE
GALLATIN, TN 37066

CARRIER

ANNETT HOLDINGS INC
4335 PAYSPHERE CIRCLE
CHICAGO, IL 60674

SHIP TO DESTINATION (CONSIGNEE)

Name: NORTHEAST PRESTRESSED PRODUCTS, LLC
Address: 135 GORDON NAGLE TRAIL
POTTSVILLE PA 17901

FREIGHT PAYMENT METHOD



Prepaid



Customer Truck

SPECIAL INSTRUCTIONS/COMMENTS

(570) 385-2352; MUST DELIVER BY NOON ;MUST SEND PA DOT 4171 FORM WITH LOAD; PLEASE SEND A COPY OF ALL CERTS AND PAPERWORK BY EMAIL TO SSCHWALM@NPP-LLC.COM; NO RUST; Actual area for 1/2 Special must be greater than .160; ALL SPLICED PACKS MUST ONLY HAVE 1 SPLICE; .600 SHORT PACKS MUST BE AT LEAST 5,000 FEET.
Nicole 3023

CARGO

NOTE: Wire carriers, if used, remain Insteel's property.
To return, please call 1-336-719-9000

Hazardous Material	Units	Package Type	Sales Order No.	Unit Weight	Weight	Commodity Description, Special Marks, Exceptions
	82599 FT	PACKS	560595	.5746	47461	591-166175 1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416 PO: 7616

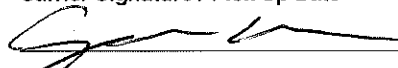
Total Weight: 47,461 LBS

RECEIVED, subject exclusively to the Terms and Conditions stated herein to the exclusion of any rates, classifications, or tariffs established or maintained by the Carrier. The Carrier has received from the Shipper, the property described above in actual good order and condition, except as noted, at the location noted in the "SHIP FROM" Box above and will properly and carefully load, handle, carry, keep, care for, and deliver it to the destination noted in the "SHIP TO" Box above, in exchange for certain freight charges, the adequacy of which is hereby acknowledged by the Carrier. Notwithstanding the fact that Shipper may provide recommendations and personnel to assist in loading the Cargo on Carrier's vehicles, Carrier and its agents and employees remain solely responsible for proper arrangement of the Cargo on Carrier's vehicles. It is mutually agreed by and between the Shipper and Carrier that every service to be performed hereunder is subject to the Terms and Conditions hereof. The Carrier hereby certifies that it is familiar with all of those Terms and Conditions and that it irrevocably agrees to them for itself and its assigns.

NOTE QUANTITY & QUALITY EXCEPTIONS AT DESTINATION HERE

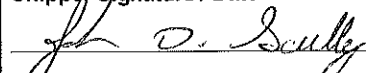
NOTE: Failure to specify exceptions at destination here does not affect the Shipper's rights against the Carrier.

Carrier Signature / Pick Up Date

 2-2-24

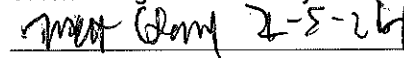
Carrier acknowledges receipt of the property described above in actual good order and condition, except as noted. By signing this form, the driver accepts the Shipper's Terms and Conditions as provided. A Driver copy of the Terms and Conditions page may be requested from the Shipper, if desired.

Shipper Signature / Date

 2-2-24

Shipper certifies that the property described above is properly packaged, marked, and labeled and in proper condition for transportation according to the applicable regulations of the DOT.

Customer Signature / Delivery Date

 2-5-24

Customer acknowledges receipt of the property described above in actual good order and condition, except as noted.



MATERIAL CERTIFICATION OF COMPLIANCE

630 National Drive
Gallatin, TN 37066
336-719-9000

NORTHEAST PRESTRESSED PRODUCTS, LLC
135 GORDON NAGLE TRAIL
POTTSVILLE PA 17901

Bill of Lading: 00385366
Order Number: 560595
PO Number: 7616

Insteel Wire Products Company hereby certifies that the specimens taken from production lot(s) consisting of one or more of the following Lot/serial numbers were tested in accordance with and met the specification requirements of ASTM A416-18. The attached test report(s) represent the result of such test(s).

1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416

Test Report Number: 40240202115431

Lot/Serial Numbers

1201404203538
1201404203539
1201404203540
1201404203541
1201404203542
1201404203543
1201404203544

Heat Number

61746

The products listed in this certification were manufactured and fabricated in the United States of America.

Insteel Wire Products Company hereby certifies that the prestressing strand described above meets or exceeds the minimum bonding requirements as currently accepted in the NASP (North American Strand Producers) pull-out test and the Moustaffa block pull-out test.

All Domestic Prestressing Strand was made from steel rod that was melted, manufactured, and processed completely in the United States of America. The rod was then manufactured into PC Strand in the United States at Insteel Wire Products Company plant in either Sanderson, FL; Houston, TX; or Gallatin, TN. The material meets the "Buy America" requirements of 23 CFR 635.410.

The products listed in this certification were manufactured in the U.S.A. from wire rod which was manufactured in the U.S.A.

Quality Assurance Manager:

A handwritten signature in black ink that reads "Josh D. Scully".

Joshua Scully

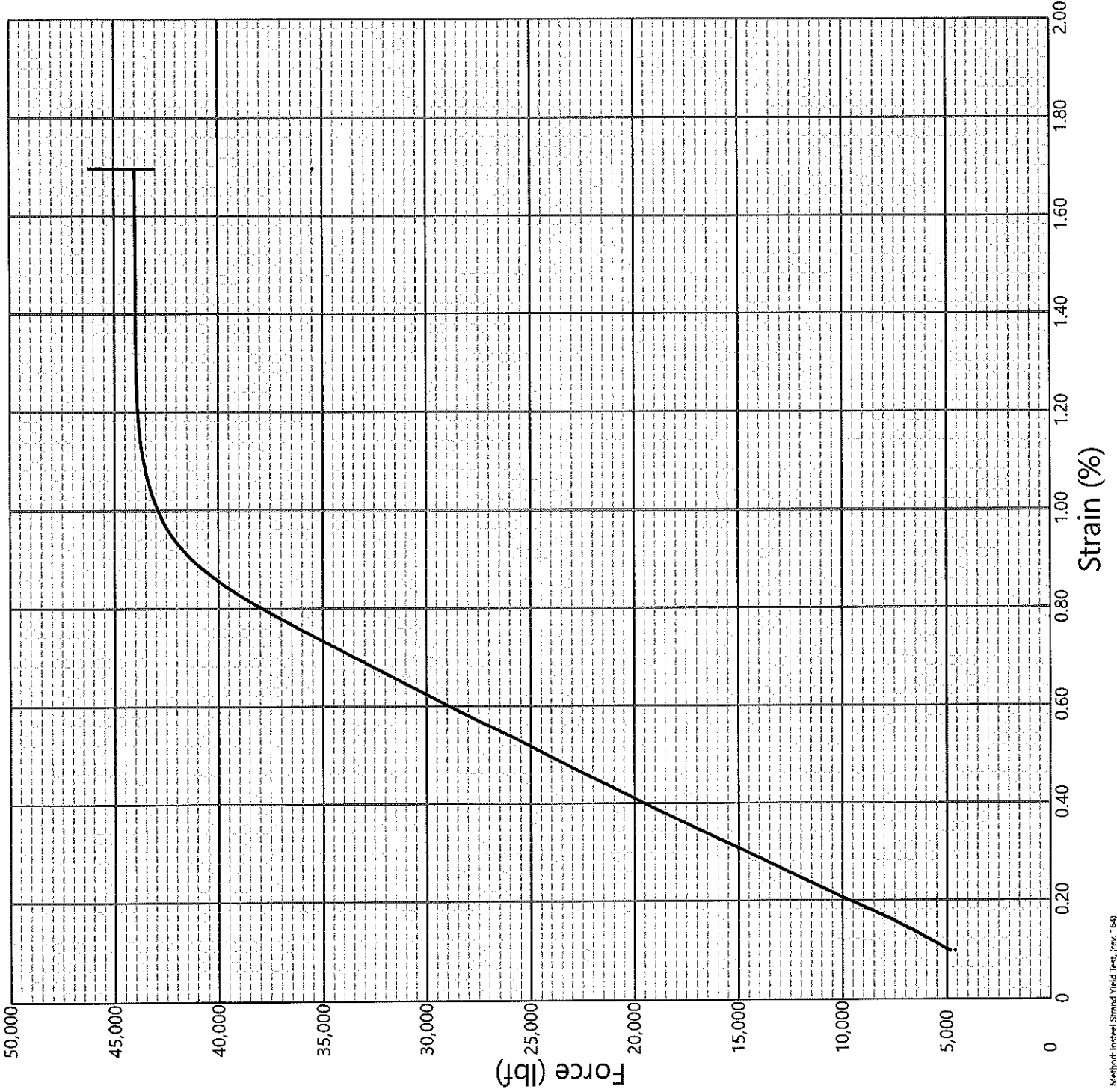
Date: 02-FEB-2024



This test performed at
630 National Drive
Gallatin, TN 37066
(800) 791-4108

Test Type: 1/2" SPECIAL 270 7W LR

Test Number: 40240202115431
Tested By: JDS
Ultimate Breaking Strength: 46,180 lbf
Ultimate Breaking Strength: 205 kN
Load @ 1% Extension: 42,887 lbf
Load @ 1% Extension: 191 kN
Ultimate Elongation: 6.5 %
Strand Diameter: 0.520 in
Rep. Area: 0.167 in²
Rep. Area: 108 mm²
Actual Area: 0.1659 in²
Actual Area: 107.1 mm²
Lay Length: 7.25 in
Avg Modulus of Elasticity: 28.8 Mpsi
Avg Modulus of Elasticity: 198,569 MPa
Reference:





PACKING LIST

Gallatin, TN

NORTHEAST PRESTRESSED PRODUCTS, LLC
135 GORDON NAGLE TRAIL
POTTSVILLE PA 17901

Bill of Lading: 00385366
Order Number: 560595
PO Number: 7616
Date: 02-FEB-24

Lot Number	Description	Length	Weight
1201404203538	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416	11998	6894.0508
1201404203539	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416	11998	6894.0508
1201404203540	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416	11998	6894.0508
1201404203541	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416	11998	6894.0508
1201404203542	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416	11998	6894.0508
1201404203543	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416	11998	6894.0508
1201404203544	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416	10611	6097.0806
Total Number of Packs 7		Totals	82599 47461



pennsylvania
DEPARTMENT OF TRANSPORTATION
www.penndot.gov

CERTIFICATE OF COMPLIANCE

1. **COUNTY:** N/A **LR/SR:** N/A **SEC/SEG:** N/A **ECMS#:** N/A
(♦ - To be completed by the party that will ship the material to the project, otherwise enter N/A.)

2. I / WE hereby certify that the material listed on line 5 was:
If a single company performs more than one operation (e.g., a company manufactures and coats guiderail), more than one box may be checked.

☒ Manufactured ☐ Fabricated ☐ Coated ☐ Precasted ☐ Produced

By INSTEEL WIRE PRODUCTS INC

INST2 15

(Name of Manufacturer, Fabricator, Coater, Precaster or Producer)

(Supplier Code) Must match exactly as in eCAMMS

3. and the party listed above certifies that the material(s) on line 5 meets the requirements of

Publication 408, Section(s) 1107.2

AASHTO, ASTM, Federal or other designation ASTM-A-416-18

4. The material listed below is being shipped to (Company Name): NORTHEAST PRESTRESSED PRODUCTS, LLC

5. **LOT NO. HEAT NO. QUANTITY UNIT OF MEASURE APPROVED MATERIAL AS LISTED IN PennDOT BULLETIN**

1201404203538	61746	11998	Linear Foot	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416
1201404203539	61746	11998	Linear Foot	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416
1201404203540	61746	11998	Linear Foot	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416
1201404203541	61746	11998	Linear Foot	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416
1201404203542	61746	11998	Linear Foot	1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416

6. ☒ **CHECK HERE IF YOUR PRODUCT CONTAINS IRON OR STEEL.** I certify the material identified above conforms to Sections 106.01 and 106.10(a) of Publication 408.

CHECK ONE OF THE TWO BOXES:

☒ Product is 100% US steel.

☐ Product contains minimal foreign steel in accordance with Act 3 and Buy America.

Attach Form CS-4171S with receipts or invoices.

CHECK THE BOX THAT APPLIES TO YOUR PRODUCT:

☐ 'Identifiable Steel' - Steel products that contain permanent markings that identify that the material was melted and manufactured in the United States. **Only Form CS-4171 is required.**

☐ Steel Products and Products Containing Steel with In-Plant Inspection by the Department or a Department Representative - **For 100% US steel products where in-plant inspection has verified that the steel was melted and manufactured in the United States, only Form CS-4171 is required. For products where in-plant inspection has verified minimal foreign steel in accordance with Act 3 and Buy America, attach bills of lading or shipping documents for foreign steel, and attach Form CS-4171S with supporting documentation.**

☒ 'Unidentified Steel' - Steel products that do not meet the definition of "Identifiable Steel" and do not receive in-plant inspection as defined above. **For 100% US steel products, attach supporting documentation including invoices, bills of lading and mill test reports that positively identify that the steel was melted and manufactured in the United States. For products containing minimal foreign steel in accordance with Act 3 and Buy America, attach bills of lading or shipping documents for foreign steel, and attach Form CS-4171S with supporting documentation.**

7. **VENDOR CLASSIFICATION (CHECK ONE BLOCK ONLY) -**

☒ #1 **Manufacturer, Fabricator, Coater, Precaster**
Listed in Bulletin # 15, or Producer Listed in
Bulletin # 14, 41 or 42

I certify that the above statements are true and to the best of my knowledge, fairly and accurately describe the product(s) listed.

☐ #2 **Distributor, Supplier or *Private Label Company**
Not Listed in Bulletin # 15.
Also, complete line 9

I certify that the material being supplied is one and the same as provided to us by the manufacturer listed on this document and quantities listed above are accurate.

8. **NAME :** Joshua D. Scully

TITLE: QUALITY ASSURANCE/SHIPPING MANAGER

COMPANY NAME : INSTEEL WIRE PRODUCTS INC

SHIPMENT/CERTIFICATION DATE: 02/02/2024

SIGNATURE : Joshua D. Scully

DATE: 2/2/2024 | 2:01 PM EST

DocuSigned by:

D217E159710840A...

By Responsible Company Official

9. List company that sold you the material(s) documented above: _____
(Complete if you checked Block # 2 on line # 7, otherwise leave blank.) (Company Name)

1/2 SPECIAL (13.2mm) 7W 270 LR ASTM A416

[illegible]



Optimus Steel, LLC
100 Old Highway 90 West
Vidor TX 77662
USA

CERTIFIED MATERIAL TEST REPORT

INSTEEL WIRE PRODUCTS COMPANY

CUSTOMER SHIP TO NASHVILLE (GALLATIN) 1040 MILE 193 3 CUMBERLAND RIVER NASHVILLE TN 37210-2208 USA		CUSTOMER BILL TO INSTEEL WIRE PRODUCTS COMPANY 1373 BOGGS DR MOUNT AIRY NC 27030-2145 USA		GRADE 1080M26	SHAPE / SIZE WRD / 7/16
SALES ORDER 0000034105		CUSTOMER MATERIAL No 111-041616		WEIGHT 231,970.00	HEAT / BATCH OT0061746
CUSTOMER PURCHASE ORDER NUMBER 536051		BILL OF LADING 80083467		SPECIFICATION / DATE OR REVISION	

CHEMICAL COMPOSITION									
C	Mn	P	S	SI	Cu	NI	Cr	Mo	N
%	%	%	%	%	%	%	%	%	%
0.81	0.65	0.006	0.015	0.25	0.15	0.06	0.12	0.02	0.0080

MECHANICAL PROPERTIES				
Tensile	Tensile	Std dev	ROA	Tensile
Min	Max	psi	%	Mpa
167760	169780	806	38.5	1165

COMMENTS / NOTES
No Weld repairs performed. Mercury, radium and alpha source materials in any form have not been used in the production of this Material. The radioactivity levels are lower than the limits defined for unconditional release by. IAE.

The above figures are certified chemical and physical test records as contained in the permanent records of company. CMTR complies with EN 10204 3.1
We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA.

Leonardo Radicchi
LEONARDO RADICCHI
QUALITY ASSURANCE MGR

Phone: 409-769-1086
leonardo.radicchi@optimus-steelusa.com

Compression test on concrete: ASTM C39

Certificate number: Bigbeam

Certificate date: 04/16/24

Testing machine: CONTROLS - Automax Multitest

Client:

Reference:

Specimen type: CC

Cement quantity [kg/m³]:

Cement type:

Preparation date: 04/10/24 - 05:33 PM

Sample conditions:

Condition when received:

Condition at test time: Room Temp

Sampling location:

Sampling date: 04/10/24 - 05:33 PM

Preparation method:

Specimen ID: S1

Dimensions: d(inch) 3.970

h(inch) 8.000

Area [inch²]: 12.3786

Mass [lb]: 0.000

Density [lb/in³]: 0.0000

Specimen age [dd]:

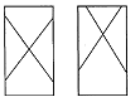
Load Rate [psi/s]: 34.784

Test date: 04/16/24 - 03:22 PM

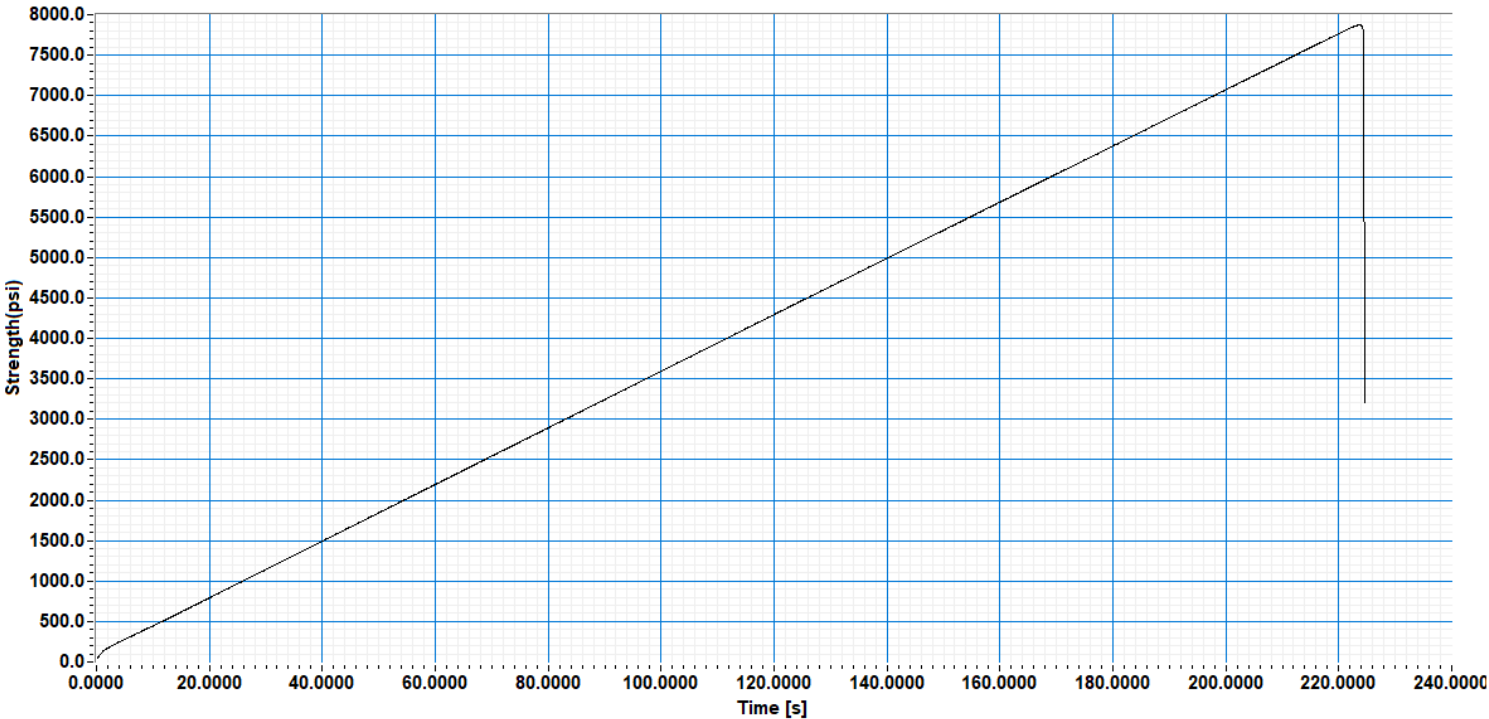
Max Load [lbf]: 97433.00

Strength [psi]: 7871.12

Failure type: TYPE 1



Notes:



Operator:
Huaian

Compression test on concrete: ASTM C39

Certificate number: Bigbeam

Certificate date: 04/16/24

Testing machine: CONTROLS - Automax Multitest

Client:

Reference:

Specimen type: CC

Cement quantity [kg/m³]:

Cement type:

Preparation date: 04/10/24 - 05:33 PM

Sample conditions:

Condition when received:

Condition at test time: Room Temp

Sampling location:

Sampling date: 04/10/24 - 05:33 PM

Preparation method:

Specimen ID: S2

Dimensions: d(inch) 3.970

h(inch) 8.000

Area [inch²]: 12.3786

Mass [lb]: 0.000

Density [lb/in³]: 0.0000

Specimen age [dd]:

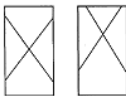
Load Rate [psi/s]: 34.772

Test date: 04/16/24 - 04:27 PM

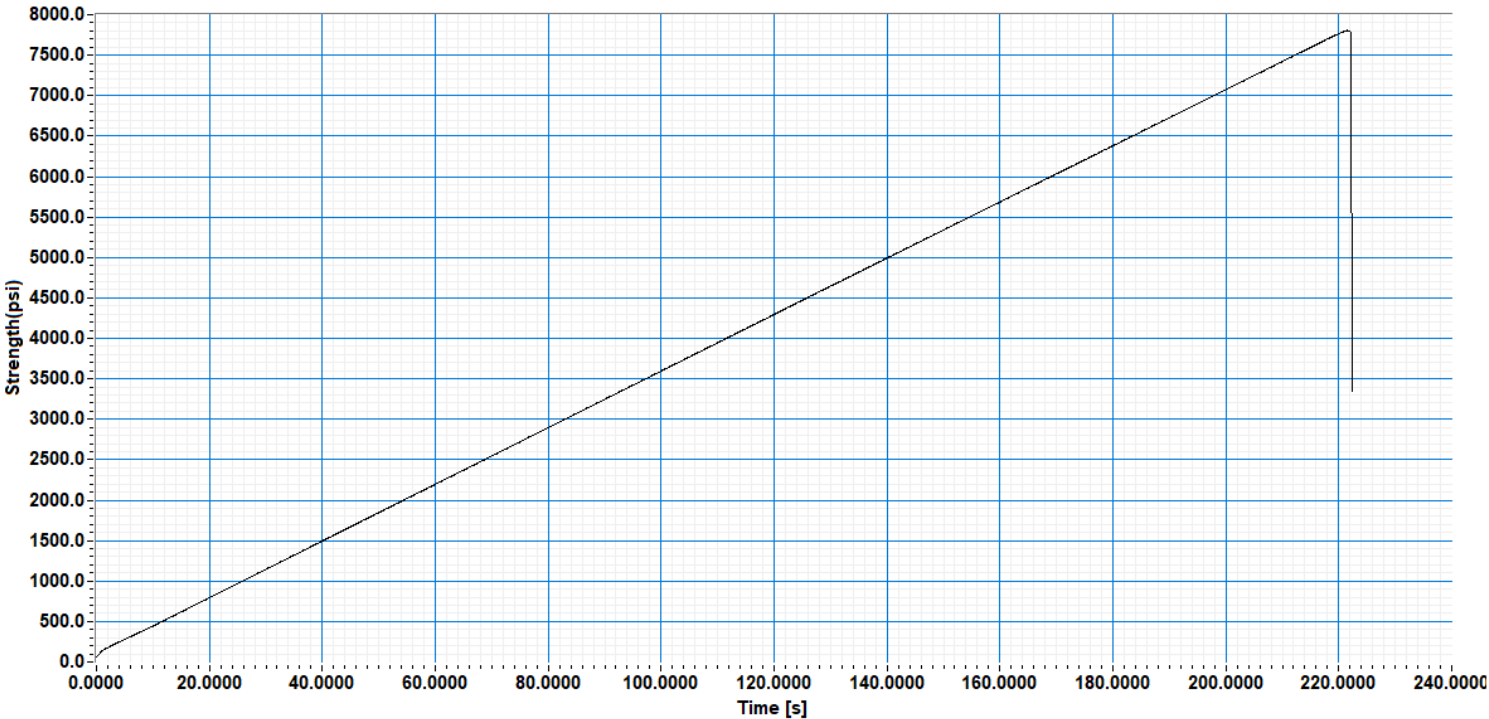
Max Load [lbf]: 96621.00

Strength [psi]: 7805.47

Failure type: TYPE 1



Notes:



Operator:
Huaian

Compression test on concrete: ASTM C39

Certificate number: Bigbeam

Certificate date: 04/16/24

Testing machine: CONTROLS - Automax Multitest

Client:

Reference:

Specimen type: CC

Cement quantity [kg/m³]:

Cement type:

Preparation date: 04/10/24 - 05:33 PM

Sample conditions:

Condition when received:

Condition at test time: Room Temp

Sampling location:

Sampling date: 04/10/24 - 05:33 PM

Preparation method:

Specimen ID: S3

Dimensions: d(inch) 3.980

h(inch) 8.000

Area [inch²]: 12.4410

Mass [lb]: 0.000

Density [lb/in³]: 0.0000

Specimen age [dd]:

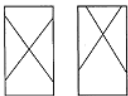
Load Rate [psi/s]: 34.756

Test date: 04/16/24 - 04:27 PM

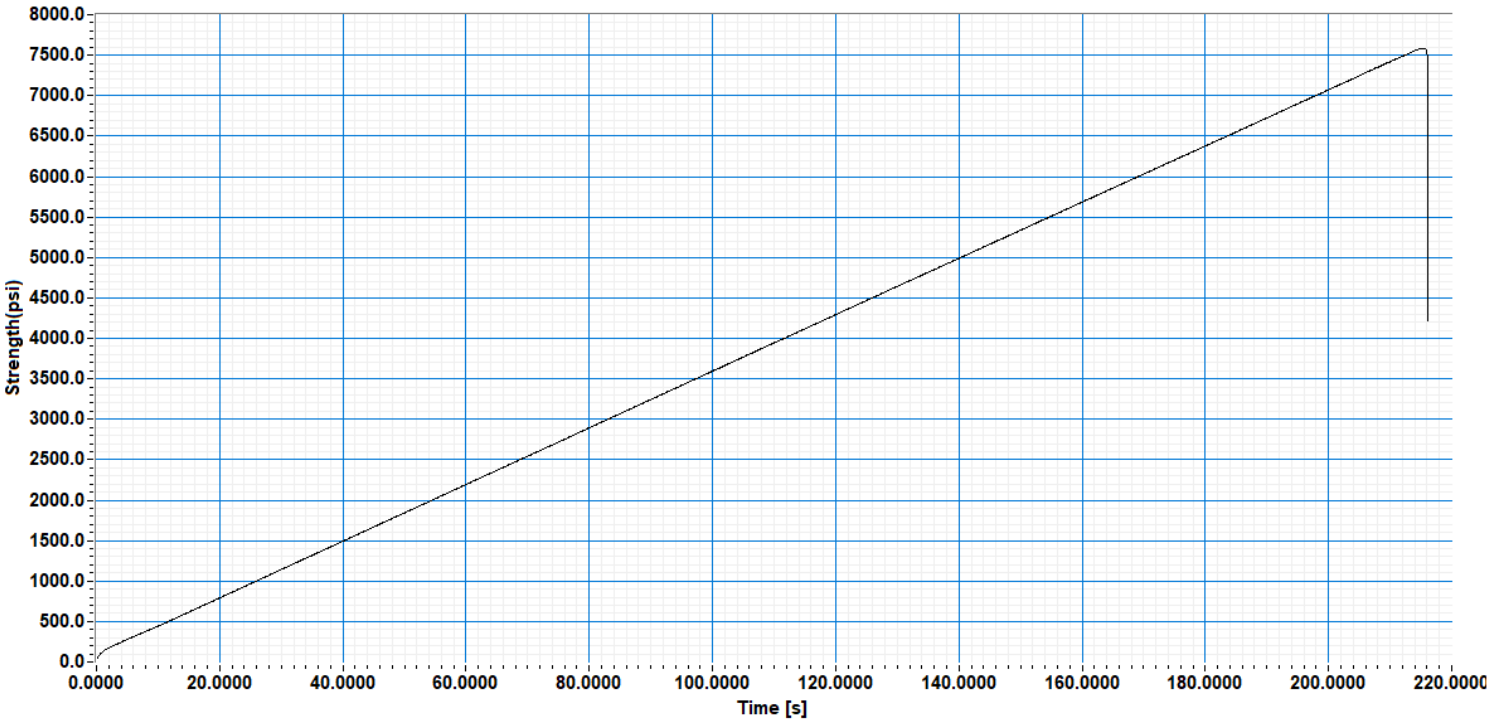
Max Load [lbf]: 94364.00

Strength [psi]: 7584.95

Failure type: TYPE 1



Notes:



Operator:
Huaian

Client :
Test Organization :
Specimen ID : EM-S1
Test date : 4/16/2024

MODULUS OF ELASTICITY ACCORDING TO ASTM C469

Specimen data

Specimen : Area [inch²] : 12.3786
Dimensions [inch] : 3.97 x 0.00 Mass [lb] : 0.00
Age : Est. Ultimate load : 7000.00
Corr. Factor AX : 0.50 Corr. Factor RAD : 0.50
Strain transducers :
Transducer type : Sampling date : 4/10/2024

Test results

40% Ultimate load : 2800.00

Modulus of Elasticity results

	σ_i [psi]	σ_f [psi]	$\epsilon_{ax\ i}$ [ue]	$\epsilon_{ax\ f}$ [ue]	E.Module [psi]	EM Round. [psi]
Cycle 2	327.36	2802.12	48.63	621.00	4323709.16	4300000
Cycle 3	229.33	2799.37	48.63	624.74	4461026.13	4450000
Avg.					4392367.64	4375000

Poisson's Ratio results

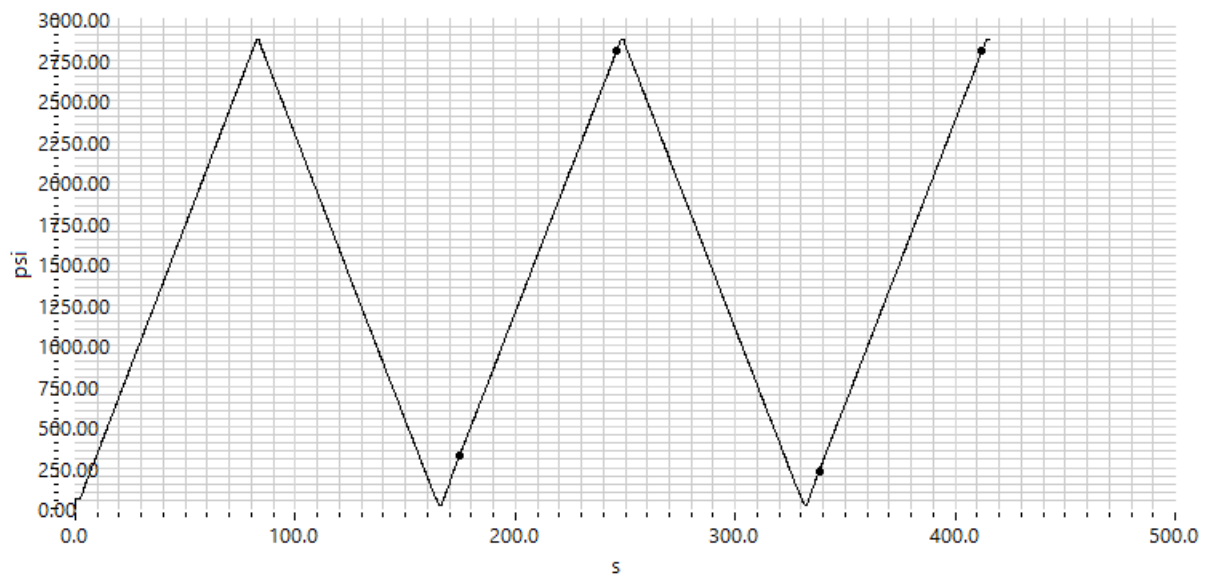
	σ_i [psi]	σ_f [psi]	$\epsilon_{rad\ i}$ [ue]	$\epsilon_{rad\ f}$ [ue]	Poisson ratio	Poisson Rounded
Cycle 2	327.36	2802.12	-15.00	-142.53	0.223	0.22
Cycle 3	229.33	2799.37	-7.50	-138.78	0.228	0.23
Avg.					0.225	0.23

Descriptions :

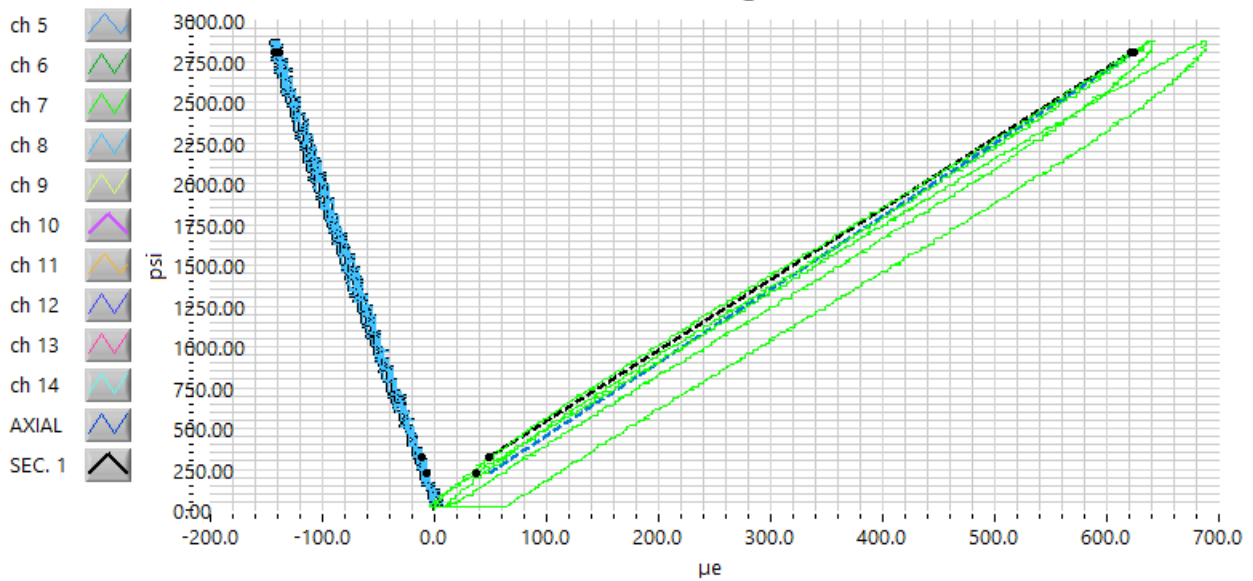
Certificate no. : Bigbeam Certificate date : 4/16/2024
Testing apparatus :
Notes :

Operator Qualification :

Stress / Time Diagram



Stress / Strain Diagram



Certificate number : Bigbeam

Certificate date : 4/16/2024

Testing apparatus :

Notes :

Operator

Qualification :

Client :
Test Organization :
Specimen ID : EM-S2
Test date : 4/16/2024

MODULUS OF ELASTICITY ACCORDING TO ASTM C469

Specimen data

Specimen : Area [inch²] : 12.4410
Dimensions [inch] : 3.98 x 0.00 Mass [lb] : 0.00
Age : Est. Ultimate load : 7000.00
Corr. Factor AX : 0.50 Corr. Factor RAD : 0.50
Strain transducers :
Transducer type : Sampling date : 4/10/2024

Test results

40% Ultimate load : 2800.00

Modulus of Elasticity results

	σ_i [psi]	σ_f [psi]	$\epsilon_{ax\ i}$ [ue]	$\epsilon_{ax\ f}$ [ue]	E.Module [psi]	EM Round. [psi]
Cycle 2	306.55	2796.87	48.63	617.26	4379531.99	4400000
Cycle 3	224.82	2802.33	48.63	628.48	4445121.02	4450000
Avg.					4412326.50	4425000

Poisson's Ratio results

	σ_i [psi]	σ_f [psi]	$\epsilon_{rad\ i}$ [ue]	$\epsilon_{rad\ f}$ [ue]	Poisson ratio	Poisson Rounded
Cycle 2	306.55	2796.87	-7.48	-127.20	0.211	0.21
Cycle 3	224.82	2802.33	-3.74	-127.20	0.213	0.21
Avg.					0.212	0.21

Descriptions :

Certificate no. : Bigbeam Certificate date : 4/16/2024
Testing apparatus :
Notes :

Operator Qualification :

The graph displays a periodic wave representing pressure (psi) as a function of distance (s). The y-axis is labeled 'psi' and ranges from 0.00 to 3000.00 with major ticks every 250.00. The x-axis is labeled 's' and ranges from 0.0 to 500.0 with major ticks every 100.0. The wave has a period of approximately 170 units of s. The peaks occur at s ≈ 80, 250, and 420, with a pressure of approximately 2900 psi. The troughs occur at s ≈ 170, 340, and 510, with a pressure of approximately 100 psi. There are four data points plotted on the wave: (170, 300), (250, 2900), (340, 300), and (420, 2900).

s	psi
0	0
80	2900
170	100
250	2900
340	100
420	2900
510	100

Certificate date : 4/16/2024

Qualification :

Appendix C: Calculations

2024 Big Beam Calculations- Lehigh University

$$A_{strand} := 0.167 \text{ in}^2 \quad f'_{ci} := 7023 \text{ psi} \quad f'_c := 7752 \text{ psi} \quad \gamma_c := 143.75 \cdot \text{pcf}$$

$$f_{pu} := 278.36 \text{ ksi} \quad L := 18 \text{ ft} \quad P_{service} := 10 \text{ kip}$$

$$f_{pi} := 0.75 \cdot f_{pu} = 208.77 \text{ ksi} \quad P_{max} := 20 \text{ kip}$$

ASD Design

Concrete Dimensions:

Guess Height: $h := 15.5 \text{ in}$

Width of Top Flange: $b_{tf} := 8 \text{ in}$ Width of Bottom Flange: $b_{bf} := 7 \text{ in}$

Top Flange height: $h_{tf} := 2.5 \text{ in}$ Bottom Flange height: $h_{bf} := 3.75 \text{ in}$

Width of Web: $b_w := 2.5 \text{ in}$

Height of Web: $h_w := h - h_{tf} - h_{bf} = 9.25 \text{ in}$

Total Area of Concrete: $A_c := b_{tf} \cdot h_{tf} + b_w \cdot h_w + b_{bf} \cdot h_{bf} = 69.375 \text{ in}^2$

Centroid: $y_b := \frac{b_{tf} \cdot h_{tf} \cdot \left(h - \frac{h_{tf}}{2}\right) + b_{bf} \cdot h_{bf} \cdot \left(\frac{h_{bf}}{2}\right) + b_w \cdot h_w \cdot \left(h_{bf} + \frac{h_w}{2}\right)}{A_c} = 7.609 \text{ in}$

$$y_t := h - y_b = 7.891 \text{ in}$$

Moment of Inertia: $I := \left(\frac{1}{12} \cdot b_{tf} \cdot h_{tf}^3 + b_{tf} \cdot h_{tf} \cdot \left(y_t - \frac{h_{tf}}{2}\right)^2 \right) \downarrow = 1964.758 \text{ in}^4$

$$+ \left(\frac{1}{12} \cdot b_{bf} \cdot h_{bf}^3 + b_{bf} \cdot h_{bf} \cdot \left(y_b - \frac{h_{bf}}{2}\right)^2 \right) \downarrow$$

$$+ \frac{1}{12} \cdot b_w \cdot h_w^3 + b_w \cdot h_w \cdot \left(y_t - \left(h_{tf} + \frac{h_w}{2}\right)\right)^2$$

Self weight and resulting Moment demands:

$$W_{sw} := A_c \cdot \gamma_c = 69.255 \text{ plf} \quad M_{SW} := \frac{(W_{sw} \cdot L^2)}{8} = 33.658 \text{ kip} \cdot \text{in}$$
$$a := 12 \text{ ft} \quad b := 3 \text{ ft} \quad M_{SWPL} := \frac{W_{sw} \cdot a}{2} (L - a) = 29.918 \text{ kip} \cdot \text{in}$$
$$R_1 := \frac{P_{service}}{L} (L - a + b) = 5 \text{ kip} \quad R_2 := \frac{P_{service}}{L} (L - b + a) = 15 \text{ kip}$$

$$M_{LL} := R_1 \cdot a = 720 \text{ kip} \cdot \text{in} \quad M_{LLmid} := R_1 \cdot 9 \text{ ft} = 540 \text{ kip} \cdot \text{in}$$

Maximum Load:

$$R_1 := \frac{P_{max}}{L} (L - a + b) = 10 \text{ kip} \quad R_2 := \frac{P_{max}}{L} (L - b + a) = 30 \text{ kip}$$

$$M_{maxLL} := R_1 \cdot a = 1440 \text{ kip} \cdot \text{in}$$

Allowable Stress Limits:

$$\sigma_{ti} := 6 \cdot \sqrt{f'_c} = 502.82 \text{ psi}$$

$$\sigma_{cd} := -0.45 \cdot f'_c = -3488.4 \text{ psi} \quad \sigma_{cs} := -0.60 \cdot f'_c = -4651.2 \text{ psi}$$

$$\sigma_{ts} := 7.5 \cdot \sqrt{f'_c} = \text{psi} \quad \sigma_{ci} := -0.70 \cdot f'_c = -4916.1 \text{ psi}$$

$$R := 0.85$$

Eccentricity Required: Same along length

$$d_p := 12.5 \text{ in}$$

$$e := d_p - y_t = 4.609 \text{ in}$$

Number of Strands and Placement in the Section:

$$n := 3$$

$$A_{ps} := n \cdot A_{strand} = 0.501 \text{ in}^2$$

Elastic Shortening Check:

$$K_{es} := 1 \quad K_{cir} := 0.9 \quad E_{ps} := 28.8 \cdot 10^6 \text{ psi} \quad P_j := 0.75 \cdot f_{pu} \cdot A_{ps} = 104.594 \text{ kip}$$

$$f_{cir} := K_{cir} \cdot \left(\frac{P_j}{A_c} + \frac{(P_j \cdot e^2)}{I} \right) - \frac{(M_{sw} \cdot e)}{I} = 2295.813 \text{ psi}$$

$$E_{ci} := \left(\gamma_c \cdot \frac{1}{\text{pcf}} \right)^{1.5} \cdot 33 \cdot \sqrt{f'_{ci} \cdot \text{psi}} = 4766.362 \text{ ksi}$$

$$ES := \frac{(K_{es} \cdot E_{ps} \cdot f_{cir})}{E_{ci}} = 13.872 \text{ ksi}$$

$$f_{pi} := 0.75 \cdot f_{pu} - ES = 194.898 \text{ ksi} \quad P_i := A_{ps} \cdot f_{pi} = 97.644 \text{ kip}$$

CR:

$$K_{cr} := 2$$

$$E_c := \left(\gamma_c \cdot \frac{1}{\text{pcf}} \right)^{1.5} \cdot 33 \cdot \sqrt{f'_c \cdot \text{psi}} = 5007.634 \text{ ksi}$$

$$E_c := 4400 \text{ ksi}$$

$$CR := K_{cr} \cdot \left(\frac{E_{ps}}{E_c} \right) \cdot (f_{cir}) = 30054.281 \text{ psi}$$

SH:

$$K_{sh} := 1 \quad RH := 70 \quad VS := 1.79$$

$$SH := 8.2 \cdot 10^{-6} \cdot K_{sh} \cdot E_{ps} \cdot (1 - 0.06 \cdot VS) \cdot (100 - RH) = 6323.892 \text{ psi}$$

RE:

$$J := 0.04 \quad K_{re} := 5000 \text{ psi}$$

$$C := \begin{cases} \text{if } \frac{f_{pi}}{f_{pu}} \geq 0.54 & = 0.76 \\ \left| \frac{\left(\frac{f_{pi}}{f_{pu}} \right)}{0.21} \cdot \left(\frac{\left(\frac{f_{pi}}{f_{pu}} \right)}{0.9} - 0.55 \right) \right| & \\ \text{else} & \\ \left| \frac{\left(\frac{f_{pi}}{f_{pu}} \right)}{4.25} \right| & \end{cases}$$

$$RE := (K_{re} - J \cdot (SH + CR + ES)) \cdot C = 2272.539 \text{ psi}$$

Calculation of Pe and fpe:

$$f_{pe} := f_{pi} - CR - SH - RE = 156.247 \text{ ksi}$$

$$P_e := f_{pe} \cdot A_{ps} = 78.28 \text{ kip}$$

Total Loss and the Ratio of Pi to Pe, R:

$$TL := ES + CR + SH + RE = 52.523 \text{ ksi}$$

$$R := \frac{P_e}{P_i} = 0.802$$

ACI Allowable Stress Checks

$$W_{sw} := A_c \cdot \gamma_c = 69.255 \text{ plf} \quad L := 18.5 \text{ ft}$$

$$M_{SW} := \frac{(W_{sw} \cdot L^2)}{8} = 35.554 \text{ kip} \cdot \text{in} \quad M_{SWPL} := \frac{W_{sw} \cdot a}{2} (L - a) = 32.411 \text{ kip} \cdot \text{in}$$

At Transfer:

$$\text{Midspan:} \quad e = 4.609 \text{ in} \quad P_i = 97.644 \text{ kip} \quad y_t = 7.891 \text{ in}$$

$$\sigma_t := \frac{-P_i}{A_c} + \frac{(P_i \cdot e \cdot y_t)}{I} - \frac{(M_{SW} \cdot y_t)}{I} = 257.255 \text{ psi} < 3 \cdot \sqrt{f'_{ci}} \cdot \text{psi} = 251.41 \text{ psi} \quad \text{OK}$$

$$\sigma_b := \frac{-P_i}{A_c} - \frac{(P_i \cdot e \cdot y_b)}{I} + \frac{(M_{SW} \cdot y_b)}{I} = -3012.818 \text{ psi} < 0.6 \cdot f'_{ci} = 4213.8 \text{ psi}$$

Support:

$$\sigma_t := \frac{-P_i}{A_c} + \frac{(P_i \cdot e \cdot y_t)}{I} = 400.044 \text{ psi} < 6 \cdot \sqrt{f'_{ci} \cdot \text{psi}} = 502.82 \text{ psi} \quad OK$$

$$\sigma_b := \frac{-P_i}{A_c} - \frac{(P_i \cdot e \cdot y_b)}{I} = -3150.512 \text{ psi} < 0.70 \cdot f'_{ci} = 4916.1 \text{ psi}$$

Full Service:

Midspan:

$$\sigma_t := \frac{-P_e}{A_c} + \frac{(P_e \cdot e \cdot y_t)}{I} - \frac{(M_{SWPL} \cdot y_t)}{I} - \frac{(M_{LL} \cdot (y_t))}{I} = -2701.087 \text{ psi} < 0.6 \cdot f'_c = 4651.2 \text{ psi}$$

$$\sigma_b := \frac{-P_e}{A_c} - \frac{(P_e \cdot e \cdot y_b)}{I} + \frac{(M_{SWPL} \cdot y_b)}{I} + \frac{(M_{LL} \cdot (y_b))}{I} = 388.258 \text{ psi} < 7.5 \cdot \sqrt{f'_c \cdot \text{psi}} = 660.341 \text{ psi}$$

Support:

$$12 \cdot \sqrt{f'_c \cdot \text{psi}} = 1056.545 \text{ psi}$$

$$\sigma_t := \frac{-P_e}{A_c} + \frac{(P_e \cdot e \cdot y_t)}{I} = 320.71 \text{ psi} < 7.5 \cdot \sqrt{f'_c \cdot \text{psi}} = 660.341 \text{ psi}$$

$$\sigma_b := \frac{-P_e}{A_c} - \frac{(P_e \cdot e \cdot y_b)}{I} = -2525.725 \text{ psi} < 0.6 \cdot f'_c = 4651.2 \text{ psi}$$

Strength Check

$$f_{py} := 258.45 \text{ ksi}$$

Check to see if ACI method can be used

$$f_{pe} := \frac{P_e}{A_{ps}} = 156.247 \text{ ksi} > 0.5 f_{pu} = 139.18 \text{ ksi} \quad \text{ACI simplified method is acceptable}$$

$$\beta_1 := \left\{ \begin{array}{l} \text{if } f'_c \leq 4 \cdot \text{ksi} \\ \quad \parallel 0.85 \\ \text{else if } 4 \text{ ksi} < f'_c \leq 8 \text{ ksi} \\ \quad \parallel 0.85 - \frac{0.05 (f'_c - 4000 \text{ psi})}{1000 \text{ psi}} \\ \text{else} \\ \quad \parallel 0.65 \end{array} \right\} = 0.662$$

$$\rho_p := \frac{A_{ps}}{b \cdot d_p} = 0.001 \quad \gamma_p := 0.28$$

$$f_{ps} := f_{pu} \cdot \left(1 - \frac{\gamma_p}{\beta_1} \left(\rho_p \cdot \frac{f_{pu}}{f'_c} \right) \right) = 273.656 \text{ ksi}$$

$$a := \frac{A_{ps} \cdot f_{ps}}{0.85 \cdot f'_c \cdot b_{tf}} = 2.601 \text{ in} \quad \text{assuming } a \text{ in flange} \quad h_{tf} = 2.5 \text{ in}$$

$$c := \frac{a}{\beta_1} = 3.926 \text{ in}$$

$$M_n := \begin{cases} \text{if } a > h_{tf} & = 1563.313 \text{ kip} \cdot \text{in} \\ \quad \left\| \text{return } 0.85 \cdot f'_c \cdot h_{tf} \cdot (b - b_w) \cdot \left(\frac{a}{2} - \frac{h_{tf}}{2} \right) + A_{ps} \cdot f_{ps} \cdot \left(d_p - \frac{a}{2} \right) \right. \\ \quad \text{else} \\ \quad \left\| \text{return } A_{ps} \cdot f_{ps} \cdot \left(d_p - \frac{a}{2} \right) \right. \end{cases}$$

$$\varepsilon_{ps} := 0.003 \left(\frac{d_p - c}{c} \right) = 0.007$$

$$\phi := \begin{cases} \text{if } \varepsilon_{ps} \leq 0.002 & = 0.9 \\ \quad \left\| 0.65 \right. \\ \quad \text{else if } 0.002 \leq \varepsilon_{ps} < 0.005 \\ \quad \quad \left\| 0.65 + 0.25 \frac{(\varepsilon_{ps} - 0.002)}{0.003} \right. \\ \quad \text{else} \\ \quad \left\| 0.9 \right. \end{cases}$$

$$M_{u1} := (M_{SW}) = 35.554 \text{ kip} \cdot \text{in} \quad M_{u2} := (M_{SWPL}) + 1.6 M_{LL} = 1184.411 \text{ kip} \cdot \text{in}$$

$$M_u := \max(M_{u1}, M_{u2}) = 1184.411 \text{ kip} \cdot \text{in} \quad \phi \cdot M_n = 1406.982 \text{ kip} \cdot \text{in}$$

$$M_{max} := M_{SW} + M_{maxLL} = 1475.554 \text{ kip} \cdot \text{in} \quad \phi \cdot M_n > M_u = 1 \quad \phi \cdot M_n < M_{max} = 1$$

Passes strength check

Check Additional reinforcement

$$f_r := 7.5 \cdot 1 \cdot \sqrt{f'_c} \cdot \text{psi} = 660.341 \text{ psi} \quad M_{service} := (M_{SWPL}) + M_{LL} = 752.411 \text{ kip} \cdot \text{in}$$

$$f_r := 805.5 \text{ psi}$$

$$M_{cr} := \frac{I}{y_b} \left(f_r + \frac{(P_e \cdot e \cdot y_b)}{I} + \frac{P_e}{A_c} \right) = 860.146 \text{ kip} \cdot \text{in}$$

Strain Compatibility

$$\varepsilon_{pe} := \frac{f_{pe}}{E_{ps}} = 0.005 \quad \varepsilon_1 := \varepsilon_{pe}$$

$$f_{p2} := \frac{P_e}{A_c} + \frac{P_e \cdot e^2}{I} = 1974.802 \text{ psi}$$

$$\varepsilon_2 := \frac{f_{p2}}{E_c} = 4.488 \cdot 10^{-4}$$

Guess: $\varepsilon_{ps} := 0.013 \quad \varepsilon_{py} := 0.0085$

$$f_{ps} := \begin{cases} \text{if } \varepsilon_{ps} < \varepsilon_{py} & = 259.855309 \text{ ksi} \\ \quad \parallel \text{return } \varepsilon_{ps} \cdot E_{ps} \\ \text{else if } \varepsilon_{ps} \geq \varepsilon_{py} \\ \quad \parallel \text{return } (255.23 + 355.793 \cdot \varepsilon_{ps}) \cdot \text{ksi} \end{cases}$$

$$a := \frac{A_{ps} \cdot f_{ps}}{0.85 \cdot f'_c \cdot b_{tf}} = 2.47 \text{ in}$$

$$c := \frac{a}{\beta_1} = 3.728 \text{ in}$$

Check:

$$\varepsilon_3 := \frac{d_p - c}{c} \cdot 0.003 = 0.007$$

$$\varepsilon_{ps} := \varepsilon_1 + \varepsilon_2 + \varepsilon_3 = 0.013$$

$$M_n := A_{ps} \cdot f_{ps} \cdot \left(d_p - \frac{a}{2} \right) = 1466.581 \text{ kip} \cdot \text{in}$$

Final Size Dimensions:

$$\begin{aligned} h &= 15.5 \text{ in} & h_{tf} &= 2.5 \text{ in} & h_{bf} &= 3.75 \text{ in} & b_w &= 2.5 \text{ in} \\ & & b_{tf} &= 8 \text{ in} & b_{bf} &= 7 \text{ in} & & \\ d_p &= 12.5 \text{ in} & n &= 3 & 1/2" \text{ Special Strands} & h - d_p &= 3 \text{ in} & \text{from bottom} \\ f_{pi} &= 194.898 \text{ ksi} & f_{pe} &= 156.247 \text{ ksi} & f_{ps} &= 259.855 \text{ ksi} \\ I &= 1964.758 \text{ in}^4 & A_c &= 69.375 \text{ in}^2 \end{aligned}$$

Loading Predictions:

$$L := 18 \text{ ft} \quad a := 12 \text{ ft} \quad b = 3 \text{ ft}$$

$$\text{Predict Cracking P:} \quad M_{cr} = 860.146 \text{ kip} \cdot \text{in} \quad M_{SWPL} = 32.411 \text{ kip} \cdot \text{in}$$

$$P_{crack} := \frac{\left(\frac{(M_{cr} - M_{SWPL})}{a} \cdot L \right)}{L - a + b} = 11.496 \text{ kip}$$

$$\text{Predict Max P:} \quad M_n = 1466.581 \text{ kip} \cdot \text{in} \quad M_{SWPL} = 32.411 \text{ kip} \cdot \text{in}$$

$$\phi := 1.0$$

$$P_n := \frac{\left(\frac{(M_n \cdot \phi - M_{SWPL})}{a} \cdot L \right)}{L - a + b} = 19.919025 \text{ kip}$$

Shear:

$$A_{ps} \cdot f_{pe} = 78.28 \text{ kip} > 0.4 (A_{ps} \cdot f_{pu} + 0) = 55.783 \text{ kip}$$

use Simple Method $f_y := 60 \text{ ksi}$

$$\lambda := 1 \quad V_u := 1.6 R_2 + \frac{1.2 \cdot W_{sw} \cdot L}{2} = 48.748 \text{ kip}$$

$$M_u := (1.2 \cdot M_{SWPL}) + 1.6 M_{LL} = 1190.893 \text{ kip} \cdot \text{in}$$

$$d := \max(0.8 h, d_p) = 12.5 \text{ in}$$

$$V_{c1} := \left(0.6 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} + 700 \cdot \frac{V_u \cdot d_p \cdot \text{psi}}{M_u} \right) \cdot b_w \cdot d = 12.844 \text{ kip}$$

$$V_{c2} := (0.6 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} + 700 \text{ psi}) \cdot b_w \cdot d = 23.526 \text{ kip}$$

$$V_{c3} := (5 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}}) \cdot b_w \cdot d = 13.757 \text{ kip}$$

$$V_c := \min(V_{c1}, V_{c2}, V_{c3}) = 12.844 \text{ kip}$$

$$V_{min} := 2 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} \cdot b_w \cdot d = 5.503 \text{ kip}$$

$$\phi := 0.75$$

$$\phi \cdot V_c = 9.633 \text{ kip} < V_u = 48.748 \text{ kip} \quad \text{Steel is needed}$$

$$V_{sreq} := \frac{(V_u - \phi \cdot V_c)}{\phi} = 52.154 \text{ kip}$$

$$s := 12 \frac{\text{in}}{\text{ft}} \quad \text{Finding area of steel per foot}$$

$$A_{vreqd} := \frac{V_{sreq}}{f_y \cdot d} \cdot s = 0.834 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1.1} := 0.75 \cdot \sqrt{f'_c \cdot \text{psi}} \cdot \frac{b_w}{f_y} \cdot s = 0.033 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1.2} := 50 \text{ psi} \cdot \frac{b_w}{f_y} \cdot s = 0.025 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1} := \max(A_{vmin1.1}, A_{vmin1.2}) = 0.033 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin2} := \frac{A_{ps} \cdot f_{pu}}{80 \cdot f_y \cdot d} \cdot \sqrt{\frac{d}{b_w}} \cdot s = 0.062 \frac{1}{ft} \cdot in^2$$

$$A_{vmin} := \min(A_{vmin1}, A_{vmin2}) = 0.033 \frac{1}{ft} \cdot in^2$$

$$A_{vactual} := 0.11 in^2 \quad \text{Try \#3 Stirrups}$$

$$s_{req} := \frac{A_{vactual}}{A_{vreqd}} = 1.582 in$$

$$V_{sreq} = 52.154 kip > 4 \cdot \lambda \cdot \sqrt{f'_c \cdot psi} \cdot b_w \cdot d = 11.006 kip$$

$$s_{max} := \min(0.375 \cdot h, 12 in) = 5.813 in$$

#3 Stirrups at 3" O.C. Until L=3'

$$\text{From } L=3' \text{ to } L=18' \quad L := 18 ft$$

$$x := L - 3.1 ft = 14.9 ft \quad b := 3 ft \quad a := 12 ft$$

$$V_x := 1.6 \left(\frac{P_{service}}{L} (a - b) \right) + 1.2 \left(W_{sw} \cdot \left(\frac{L}{2} - x \right) \right) = 7.51 kip$$

$$M_x := 1.2 \cdot \left(\frac{W_{sw} \cdot x}{2} \cdot (L - x) \right) + 1.6 (R_1 \cdot x - P_{service} \cdot (x - a)) = 193.919 kip \cdot ft$$

$$V_{c1} := \left(0.6 \cdot \lambda \cdot \sqrt{f'_c \cdot psi} + 700 \cdot \frac{V_x \cdot d_p \cdot psi}{M_x} \right) \cdot b_w \cdot d = 2.533 kip$$

$$V_{c2} := (0.6 \cdot \lambda \cdot \sqrt{f'_c \cdot psi} + 700 psi) \cdot b_w \cdot d = 23.526 kip$$

$$V_{c3} := (5 \cdot \lambda \cdot \sqrt{f'_c \cdot psi}) \cdot b_w \cdot d = 13.757 kip$$

$$V_c := \min(V_{c1}, V_{c2}, V_{c3}) = 2.533 kip$$

$$V_{min} := 2 \cdot \lambda \cdot \sqrt{f'_c \cdot psi} \cdot b_w \cdot d = 5.503 kip$$

$$\phi := 0.75$$

$$\phi \cdot V_c = 1.9 kip < V_u = 48.748 kip \quad \text{Steel is needed}$$

$$V_{sreq} := \frac{(V_u - \phi \cdot V_c)}{\phi} = 62.464 kip$$

$$V_{sreq} := \frac{(V_x - \phi \cdot V_c)}{\phi} = 7.48 \text{ kip}$$

$$s := 12 \frac{\text{in}}{\text{ft}} \quad \text{Finding area of steel per foot}$$

$$A_{vreqd} := \frac{V_{sreq}}{f_y \cdot d} \cdot s = 0.12 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1.1} := 0.75 \cdot \sqrt{f'_c \cdot \text{psi}} \cdot \frac{b_w}{f_y} \cdot s = 0.033 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1.2} := 50 \text{ psi} \cdot \frac{b_w}{f_y} \cdot s = 0.025 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1} := \max(A_{vmin1.1}, A_{vmin1.2}) = 0.033 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin2} := \frac{A_{ps} \cdot f_{pu}}{80 \cdot f_y \cdot d} \cdot \sqrt{\frac{d}{b_w}} \cdot s = 0.062 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin} := \min(A_{vmin1}, A_{vmin2}) = 0.033 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vactual} := 0.11 \text{ in}^2 \quad \text{Try \#3 Stirrups}$$

$$s_{req} := \frac{A_{vactual}}{A_{vreqd}} = 11.03 \text{ in}$$

$$V_{sreq} = 7.48 \text{ kip} < 4 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} \cdot b_w \cdot d = 11.006 \text{ kip}$$

$$s_{max} := \min(0.75 \cdot h, 12 \text{ in}) = 11.625 \text{ in}$$

Use #3 Stirrups at 11.5" O.C.

$$x := L - 6 \text{ ft} = 12 \text{ ft} \quad b := 3 \text{ ft} \quad a := 12 \text{ ft}$$

$$V_x := 1.6 \left(\frac{P_{service}}{L} (L - a + b) \right) + 1.2 \left(W_{sw} \cdot \left(\frac{L}{2} - x \right) \right) = 7.751 \text{ kip}$$

$$M_x := 1.2 \cdot \left(\frac{W_{sw} \cdot x}{2} \cdot (L - x) \right) + 1.6 (R_1 \cdot x) = 194.992 \text{ kip} \cdot \text{ft}$$

$$V_{c1} := \left(0.6 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} + 700 \cdot \frac{V_x \cdot d_p \cdot \text{psi}}{M_x} \right) \cdot b_w \cdot d = 2.557 \text{ kip}$$

$$V_{c2} := (0.6 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} + 700 \text{ psi}) \cdot b_w \cdot d = 23.526 \text{ kip}$$

$$V_{c3} := (5 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}}) \cdot b_w \cdot d = 13.757 \text{ kip}$$

$$V_c := \min(V_{c1}, V_{c2}, V_{c3}) = 2.557 \text{ kip}$$

$$V_{min} := 2 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} \cdot b_w \cdot d = 5.503 \text{ kip}$$

$$\phi := 0.75$$

$$\phi \cdot V_c = 1.917 \text{ kip} < V_u = 48.748 \text{ kip} \quad \text{Steel is needed}$$

$$V_{sreq} := \frac{(V_u - \phi \cdot V_c)}{\phi} = 62.441 \text{ kip}$$

$$V_{sreq} := \frac{(V_x - \phi \cdot V_c)}{\phi} = 7.778 \text{ kip}$$

$$s := 12 \frac{\text{in}}{\text{ft}} \quad \text{Finding area of steel per foot}$$

$$A_{vreqd} := \frac{V_{sreq}}{f_y \cdot d} \cdot s = 0.124 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1.1} := 0.75 \cdot \sqrt{f'_c \cdot \text{psi}} \cdot \frac{b_w}{f_y} \cdot s = 0.033 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1.2} := 50 \text{ psi} \cdot \frac{b_w}{f_y} \cdot s = 0.025 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1} := \max(A_{vmin1.1}, A_{vmin1.2}) = 0.033 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin2} := \frac{A_{ps} \cdot f_{pu}}{80 \cdot f_y \cdot d} \cdot \sqrt{\frac{d}{b_w}} \cdot s = 0.062 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin} := \min(A_{vmin1}, A_{vmin2}) = 0.033 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vactual} := 0.11 \text{ in}^2 \quad \text{Try \#3 Stirrups}$$

$$s_{req} := \frac{A_{vactual}}{A_{vreqd}} = 10.607 \text{ in}$$

$$V_{sreq} = 7.778 \text{ kip} < 4 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} \cdot b_w \cdot d = 11.006 \text{ kip}$$

$$s_{max} := \min(0.75 \cdot h, 12 \text{ in}) = 11.625 \text{ in}$$

Use #3 Stirrups at 11.5" O.C.

$$x := L - 9 \text{ ft} = 9 \text{ ft} \quad b := 3 \text{ ft} \quad a := 12 \text{ ft}$$

$$V_x := 1.6 \left(\frac{P_{service}}{L} (L - a + b) \right) + 1.2 \left(W_{sw} \cdot \left(\frac{L}{2} - x \right) \right) = 8 \text{ kip}$$

$$M_x := 1.2 \cdot \left(\frac{W_{sw} \cdot x}{2} \cdot (L - x) \right) + 1.6 (R_1 \cdot x) = 147.366 \text{ kip} \cdot \text{ft}$$

$$V_{c1} := \left(0.6 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} + 700 \cdot \frac{V_x \cdot d_p \cdot \text{psi}}{M_x} \right) \cdot b_w \cdot d = 2.888 \text{ kip}$$

$$V_{c2} := (0.6 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} + 700 \text{ psi}) \cdot b_w \cdot d = 23.526 \text{ kip}$$

$$V_{c3} := (5 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}}) \cdot b_w \cdot d = 13.757 \text{ kip}$$

$$V_c := \min(V_{c1}, V_{c2}, V_{c3}) = 2.888 \text{ kip}$$

$$V_{min} := 2 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} \cdot b_w \cdot d = 5.503 \text{ kip}$$

$$\phi := 0.75$$

$$\phi \cdot V_c = 2.166 \text{ kip} < V_u = 48.748 \text{ kip} \quad \text{Steel is needed}$$

$$V_{sreq} := \frac{(V_u - \phi \cdot V_c)}{\phi} = 62.109 \text{ kip}$$

$$V_{sreq} := \frac{(V_x - \phi \cdot V_c)}{\phi} = 7.779 \text{ kip}$$

$$s := 12 \frac{\text{in}}{\text{ft}} \quad \text{Finding area of steel per foot}$$

$$A_{vreqd} := \frac{V_{sreq}}{f_y \cdot d} \cdot s = 0.124 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1.1} := 0.75 \cdot \sqrt{f'_c \cdot \text{psi}} \cdot \frac{b_w}{f_y} \cdot s = 0.033 \frac{1}{\text{ft}} \cdot \text{in}^2$$

$$A_{vmin1.2} := 50 \text{ psi} \cdot \frac{b_w}{f_y} \cdot s = 0.025 \frac{1}{ft} \cdot in^2$$

$$A_{vmin1} := \max(A_{vmin1.1}, A_{vmin1.2}) = 0.033 \frac{1}{ft} \cdot in^2$$

$$A_{vmin2} := \frac{A_{ps} \cdot f_{pu}}{80 \cdot f_y \cdot d} \cdot \sqrt{\frac{d}{b_w}} \cdot s = 0.062 \frac{1}{ft} \cdot in^2$$

$$A_{vmin} := \min(A_{vmin1}, A_{vmin2}) = 0.033 \frac{1}{ft} \cdot in^2$$

$$A_{vactual} := 0.11 in^2 \quad \text{Try \#3 Stirrups}$$

$$s_{req} := \frac{A_{vactual}}{A_{vreqd}} = 10.606 in$$

$$V_{sreq} = 7.779 kip < 4 \cdot \lambda \cdot \sqrt{f'_c} \cdot psi \cdot b_w \cdot d = 11.006 kip$$

$$s_{max} := \min(0.75 \cdot h, 12 in) = 11.625 in$$

Use #3 Stirrups at 11.5" O.C.

**#3 Stirrup @ 11.5" O.C. from 0' to 15',
#3 Stirrups @ 3" O.C. from 15' to 18'**

Deflections:

Curvature Calculations:

Curvatures due to P_e

$$\sigma_t := \frac{-P_e}{A_c} + \frac{(P_e \cdot e \cdot y_t)}{I} = 320.71 \text{ psi}$$

$$\sigma_b := \frac{-P_e}{A_c} - \frac{(P_e \cdot e \cdot y_b)}{I} = -2525.725 \text{ psi}$$

$$E_c = 4400 \text{ ksi}$$

$$\varepsilon_{cet} := \frac{\sigma_t}{E_c} = 7.289 \cdot 10^{-5}$$

$$\varepsilon_{ceb} := \frac{\sigma_b}{E_c} = -5.74 \cdot 10^{-4}$$

$$\phi_1 := \frac{\varepsilon_{ceb} - \varepsilon_{cet}}{h} = -4.174 \cdot 10^{-5} \frac{1}{\text{in}}$$

Curvature at M_{cr}

$$\sigma_t := \frac{-P_e}{A_c} + \frac{(P_e \cdot e \cdot y_t)}{I} - \frac{(M_{cr} \cdot y_t)}{I} = -3133.766 \text{ psi}$$

$$\sigma_b := \frac{-P_e}{A_c} - \frac{(P_e \cdot e \cdot y_b)}{I} + \frac{(M_{cr} \cdot y_b)}{I} = 805.5 \text{ psi}$$

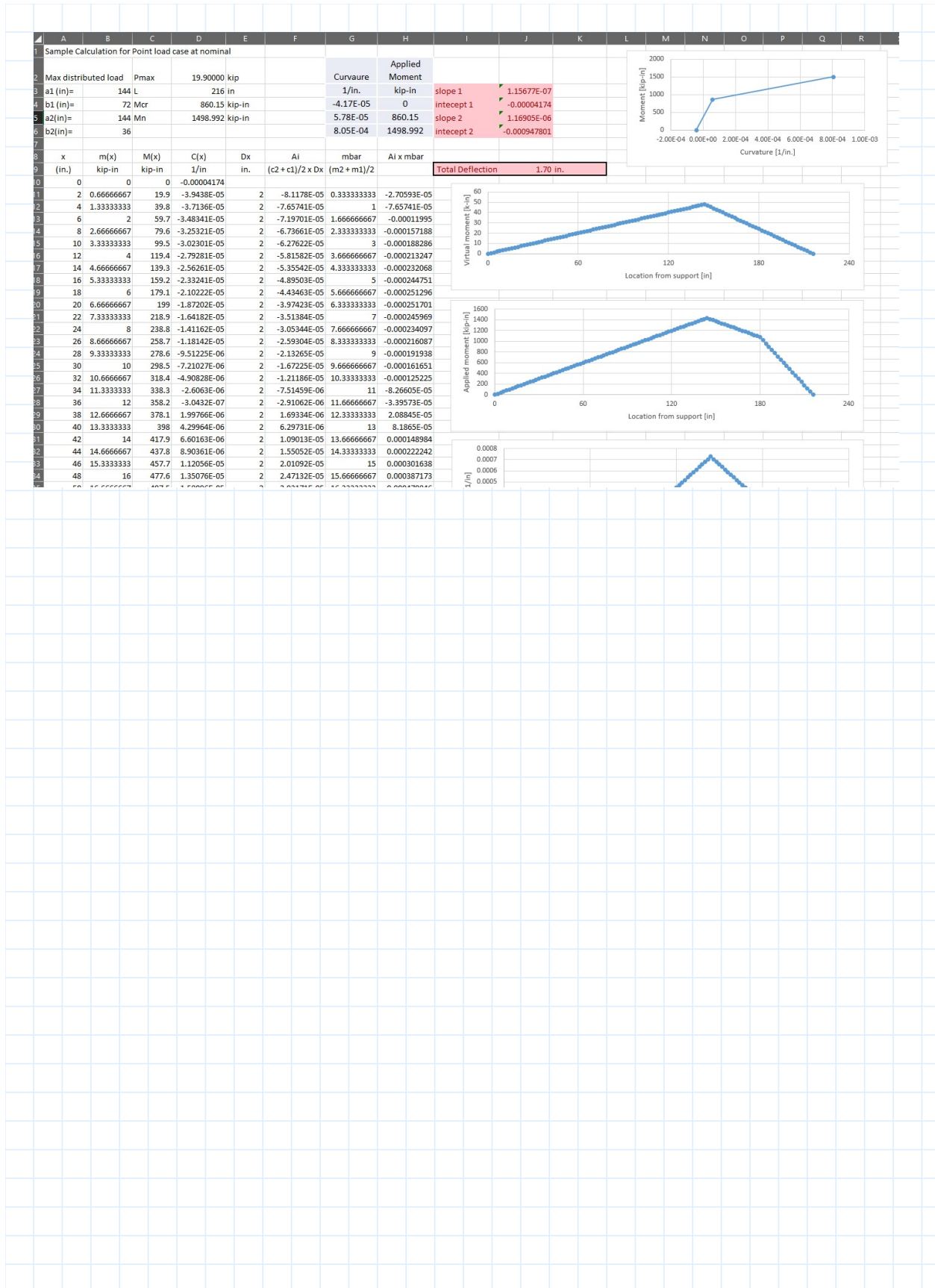
$$\varepsilon_{crt} := \frac{\sigma_t}{E_c} = -7.122 \cdot 10^{-4}$$

$$\varepsilon_{crb} := \frac{\sigma_b}{E_c} = 1.831 \cdot 10^{-4}$$

$$\phi_2 := \frac{\varepsilon_{crb} - \varepsilon_{crt}}{h} = (5.776 \cdot 10^{-5}) \frac{1}{\text{in}}$$

Final Curvature

$$\phi_2 := \frac{0.003}{c} = (8.046 \cdot 10^{-4}) \frac{1}{\text{in}}$$



Development Length:

$$d_{strand} := 0.520 \text{ in} \quad f_{pe} := \frac{P_e}{A_{ps}} = 156.247 \text{ ksi} \quad L_t := \frac{f_{pe} \cdot d_{strand}}{3 \text{ ksi}} = 27.083 \text{ in}$$

$$f_{ps} = 259.855 \text{ ksi}$$

$$L_d := L_t + \frac{(f_{ps} - f_{pe})}{1 \text{ ksi}} \cdot d_{strand} = 80.959 \text{ in}$$