

2025-2026 PCI Big Beam Competition

Final Report

May 5th, 2026

Northern Arizona University
Steve Sanghi College of Engineering
Flagstaff, AZ

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Table of Abbreviations

ASTM: American Society for Testing and Materials

FE: Fundamentals of Engineering Exam

INT: Engineering Intern

LBT: Lab Tech

NAU: Northern Arizona University

PCI: Precast/Prestressed Concrete Institute

PE: Principles and Practice of Engineering Exam

SE: Structural Engineering Exam

SENG: Senior Engineer

STEG: Structural Engineer

Section 1: Judging Form & Midspan Deflection Graph

Judging Form

PCI BIG BEAM COMPETITION 2025-2026

April 21, 2026

Date _____

Northern Arizona University

Student Team (school name)

March 27, 2026

Team Number

Date of Casting

Basic Information		Judging Criteria	
1. Age of beam at testing (days)	<u>26</u>	Teams MUST fill in these values.	
2. Compressive cylinder tests*		1. Center to center span (ft)	<u>17</u>
Number tested	<u>5</u>	2. Actual maximum applied load (kip)	<u>38.20</u>
Size of cylinders	<u>4" x 8"</u>	3. Measured cracking load (kip) [†]	<u>21.2</u>
Average (psi)	<u>7808.64</u>	4. Cost (dollars)	<u>299.37</u>
3. Concrete properties		5. Weight (lb)	<u>1079</u>
Unit weight of concrete (lb/ft ³)	<u>124.1</u>	6. Largest measured deflection (in.)	<u>2.64"</u>
Slump or spread (in.)	<u>21.5</u>	a. Measured deflection at applied load of 32 kip.	<u>0.85"</u>
Air content (%)	<u>3</u>	7. Most accurate calculations:	
Tensile strength (psi)	_____	a. Absolute value of (maximum applied load – calculated applied load)/calculated applied load	<u>0.064</u>
Circle one: <u>Split cylinder</u> MOR beam		b. Absolute value of (Measured deflection at 32 kips - calculated deflection) / (calculated deflection)	<u>0.466</u>
4. Pretest calculations		c. Absolute value of (measured cracking load – calculated cracking load)/calculated cracking load	<u>0.003</u>
a. Applied load (total) to cause cracking (kip)	<u>21.27</u>	Total of three absolute values (a + b + c) =	<u>0.533</u>
b. Maximum applied point load at midspan (kip)	<u>35.91</u>		
c. Anticipated deflection due to total live load application of 32 kips	<u>0.58"</u>		
Pretest calculations MUST be completed before testing.		[†] Measured cracking load is found from the "bend-over" point in the load/deflection curve. Provide load/deflection curve in report.	
* International entries may substitute the appropriate compressive strength test for their country.			

Test summary forms must be included with the final digital report, due June 5, 2026.

Sponsored by:



Figure 1: 2026 Judging Form [1]

Midspan Deflection Graph

Load Deflection Graph

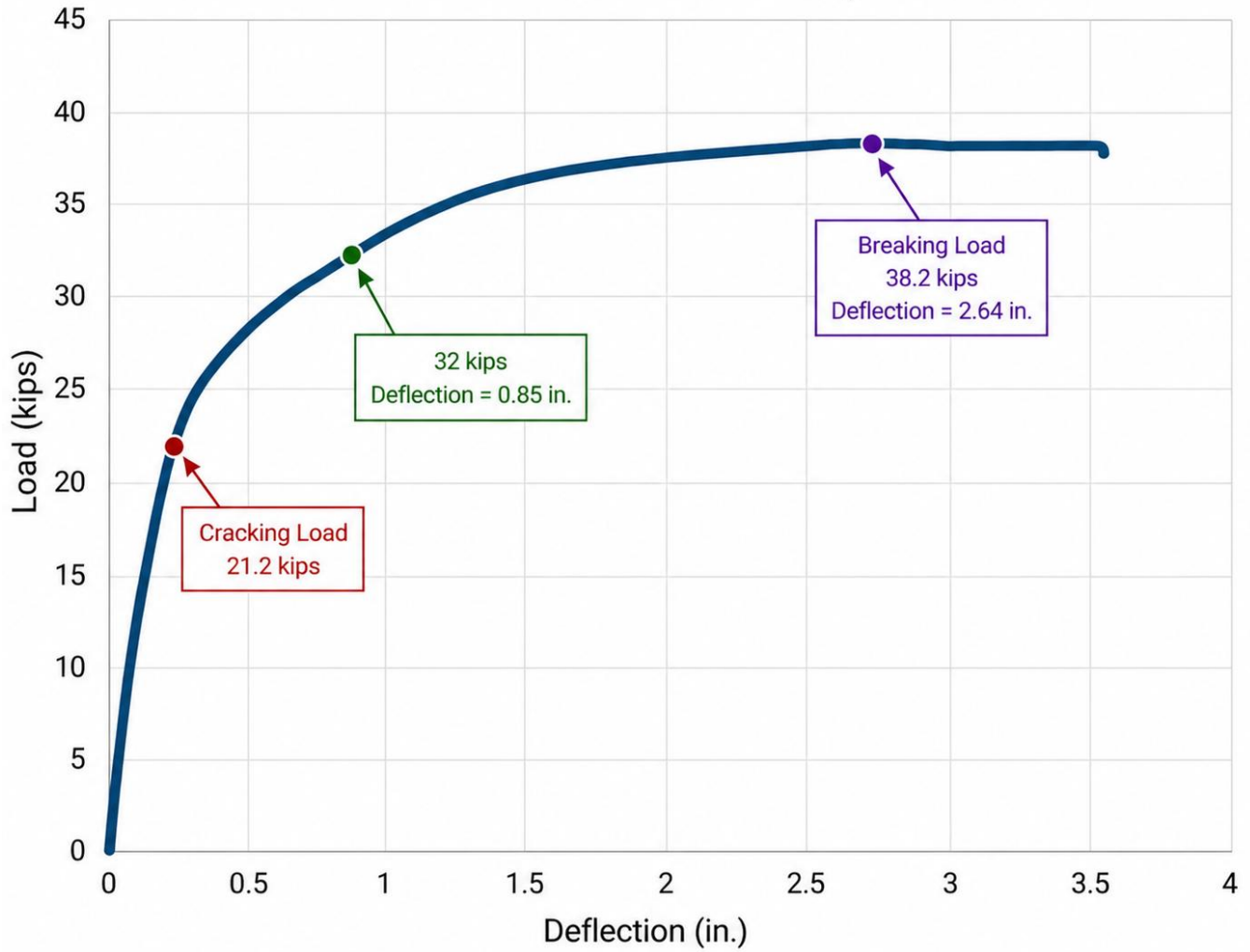



Figure 2: 2026 PCI Big Beam Load vs Deflection Graph

Section 2: Certification of Calculations



PCI BIG BEAM COMPETITION 2025-2026

CERTIFICATION


Tpac

As a representative of (name of PCI producer member or sponsoring organization)
Northern Arizona 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: Elias J. Fink

Name (please print): _____

Date: April 21, 2026

Predicted maximum load: 35.91 kips

Predicted cracking load: 21.27 kips

Predicted deflection load at 32 kip: 0.58 in.

THIS CERTIFICATION MUST BE PART OF THE FINAL REPORT.

Sponsored by:




Figure 3: 2026 Certification of Calculations [1]

Section 3: Shop Drawings

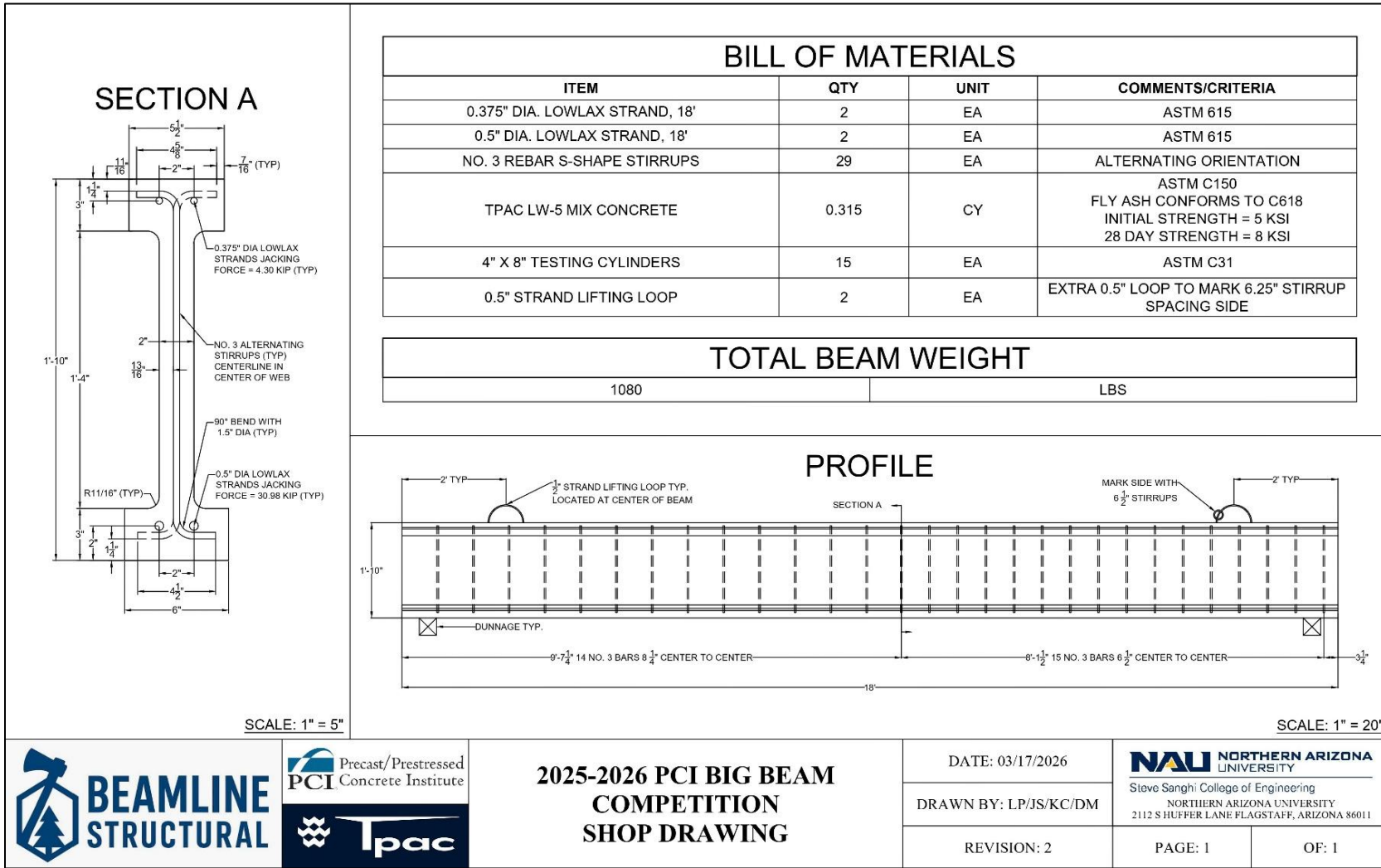


Figure 4: Final Beam Shop Drawings [2]

Section 4: Concrete Mix Design

Tpac Mix Selection

Rather than developing a custom mix, the team selected Tpac’s standard mix to take advantage of its established performance data. This approach reduces uncertainty in strength development and workability while avoiding the risks associated with trial batching and limited testing time. The team selected one of two concrete mixes provided by Tpac: a lightweight and a normal weight mix (see Appendix B for Tpac mixes). [3] Because the beam was scheduled to be cast on March 27th, the selected mix was required to reliably achieve design strength within a 28-day curing period. Key properties for both mixes are summarized in Table 1.

Table 1: Tpac’s Lightweight versus Normal-weight Concrete Mix Designs

	TPAC's Concrete Mix Designs	
	Lightweight	Normal weight
f'ci (psi)	5000	7500
f'c (psi)	8000	9000
Spread	27"±3"	27"±3"
W/C Ratio	0.35	0.31
Unit Weight (pcf)	124.1	147.5
Unit Weight Factor, λ [5]	0.75	1.00

The normal weight mix provides a higher compressive strength and lower water-cement ratio, while the lightweight mix provides a significantly reduced unit weight and a λ factor of 0.75 found in PCI Table 25.4.2.5. These parameters directly influence the beam’s self-weight, flexural stiffness, and strength.

Although the normal weight mix offers greater compressive strength, the lightweight mix was determined to be sufficient to meet both transfer and ultimate strength requirements while reducing the overall weight of the beam. This reduction in unit weight decreases dead load and improves structural efficiency, which is critical within the competition constraints. The reduced λ (lightweight modification factor) lowers the effective tensile strength of the concrete, which decreases the cracking moment compared to normal weight concrete. In shear, λ reduces the concrete contribution, leading to lower shear capacity; however, in this design it remained sufficient and was accounted for without governing the overall beam behavior. Based on these considerations, the lightweight mix was selected as the optimal balance between strength, weight, and reliability.

Mix Design

The selected lightweight mix design is summarized in Table 2. The water-to-cement ratio provides adequate strength development while maintaining workability through the use of admixtures. These admixtures control rheology, air content, and hydration behavior to ensure consistent placement and performance. All admixtures meet ASTM C494 requirements in accordance with competition rules. The use of expanded shale lightweight aggregate is the primary contributor to the reduced unit weight of the mix, allowing for a lighter beam without significantly compromising compressive strength.

Table 2: Lightweight Mix Design

Material	Material Type	lbs
AZ Portland Cement	Type II	730
Pozzolan	Class F (Fly Ash)	185
Aggregate	WCS Maricopa (Sand)	1306
	3/8" Expanded Shale (Utelite)	812
Water	38 Gal	217
Air	~3%	
Admixtures	Proprietary Name	fl oz
Water Reducer	Advacast 575	63
Viscosity Modifier	VmarF-100	24
Hydration Stabilizer	Recover	20
Air Entrainer	AE 90 Air	5
Rheology Modifier	Vmar3	10
Total Weight		3349.5 lbs

Cylinder Testing

The team tested 5 cylinders the day prior to the testing of the beam in order to obtain the most accurate information on the specified concrete batch. The compressive concrete strength was calculated using ASTM C39. The test cylinder data is shown in Table 3.

Table 3: Test Cylinder Results

	Age (days)	Compressive Strength (psi)
1	26	7800
2	26	8300
3	26	7700
4	26	7720
5	26	7530
Value Used in Prediction		7810

Section 5: Structural Design

Analysis Methodology

A MathCAD-based analysis spreadsheet was developed to streamline design iteration and maintain consistency in calculations. Cross-sectional geometry was defined parametrically using inputs such as flange dimensions, web depth, and chamfer size, while section properties (area and moment of inertia) were calculated using the parallel axis theorem. Material properties and reinforcement were incorporated directly, including concrete density and compressive strength, with modulus of elasticity computed accordingly. Prestressing strands were modeled as 270 ksi low-relaxation steel with adjustable size, quantity, and position, enabling evaluation of eccentricity and spacing, while stirrups were checked against minimum reinforcement and spacing requirements.

Loading included self-weight and applied live loads per competition requirements, with shear and moment diagrams generated and combined to determine total demand. Prestress losses—elastic shortening, creep, shrinkage, and relaxation—were incorporated using time-dependent methods, with jacking stress treated as a variable for iteration. Flexural capacity was evaluated using both the Whitney stress block and strain compatibility methods, with the latter used for final analysis. Stresses at transfer and service, shear capacity, and deflection were all checked, and an iteration process was used to efficiently assess cracking behavior and ultimate capacity.

Design Process and Iteration

Beamline Structural established target performance values prior to initiating design iterations. A cracking load of approximately 22 kips and an ultimate failure load of approximately 35 kips were selected to remain within competition constraints. Initial iterations were performed using two prestressing strands located in the bottom flange, with preliminary sections of 16 inches and 18 inches evaluated. While both configurations met strength requirements, the shallower section required increased material to achieve the same performance, resulting in higher weight and cost. These findings highlighted the importance of section depth in improving structural efficiency. Table 4 shows the final chosen designs.

Table 4: Design Comparison

	Design 1	Design 2	Design 3
Design			
Difference	<ul style="list-style-type: none"> Most Ductility Greatest bottom flange thickness Smallest overall height Greatest flange widths 	<ul style="list-style-type: none"> Most Economic Greatest top flange thickness Narrowest design 	<ul style="list-style-type: none"> Lightest Smaller chamfer radius Overall slender shape Uniform design for ease of construction
Result	Weight: 1660 lbs Cost: \$298.42	Weight: 1161 lbs Cost: \$293.61	Weight: 1079 lbs Cost: \$300.70

To further reduce weight and cost, additional iterations explored increasing prestressing force through the use of three 0.6-inch strands. Although this improved predicted efficiency, it caused excessive tensile stresses at the top fiber at transfer, leading to cracking. A 3/8-inch prestressing strand was introduced in the top flange to counteract these stresses, but this created constructability challenges with clear cover and spacing that required larger section dimensions, offsetting the benefits. The design was then revised to eliminate top-flange prestressing and focus on increasing section depth and reducing flange material, leveraging the parallel axis theorem for improved efficiency. The final design (Design 3) consists of a 22-inch-deep section with prestressing strands in both the top and bottom flange, providing a balanced solution that satisfies cracking and ultimate load requirements while minimizing weight and maintaining constructability.

Structural Performance Checks

Shear capacity was evaluated using the approximate method (PCI Table 5.3.2) along the span by comparing applied shear demand to nominal strength, including both concrete and stirrup contributions. Stirrups were designed to meet minimum reinforcement and spacing requirements, with asymmetrical spacing used to optimize material efficiency. Closer spacing was provided in regions of peak shear demand to resist higher forces, while wider spacing was used elsewhere to reduce unnecessary reinforcement, lowering both cost and overall beam weight. The final layout was verified to provide adequate shear resistance at all critical sections. The shear and flexural strength reduction factors outlined in PCI 5.3 and PCI 5.2.3 were intentionally not applied, prioritizing analytical accuracy over prescribed safety factors. A 20-kip load was used to represent service-level conditions, while a 32-kip load (factored using a 1.6 live load factor) was used for ultimate strength design.

Deflection was evaluated using the superposition method, accounting for prestress, self-weight, and applied loads by calculating each component independently and summing the results. This provided a consistent and efficient basis for comparing design iterations. Flexural performance was assessed by comparing moment demand to nominal capacity along the span, with stress checks performed at transfer and under service loading to ensure tensile and compressive stresses remained within allowable limits. The governing condition occurred at midspan, where moment demand is greatest, and results confirmed that the selected section satisfies all performance requirements.

Performance Against Design Criteria

Cylinder testing was performed before final predictions to obtain a more accurate concrete compressive strength, which was used to calculate cracking load, ultimate load, and deflection. Cracking and ultimate capacities were determined using a Mathcad spreadsheet, while deflection analysis was completed using Response 2000 and Excel. Prestress losses due to creep, shrinkage, and relaxation were estimated using standard methods, though actual conditions likely differed. Final cylinder strengths ranged from 7,528 to 8,297 psi, affecting properties such as modulus of elasticity and tensile strength, which influenced the beam's cracking behavior and overall performance.

Section 6: Fabrication & Testing

Fabrication

On March 27th, 2026, Beamline Structural visited the Tpac plant in Phoenix, Arizona, to observe fabrication following coordination of the design and shop drawings developed using AutoCAD. The team verified measurements as seen in the figures below.



Figures 5: Web Thickness, Total Height of Beam, and Top Flange Width

As seen in Section 3: Shop Drawings, the stirrups were spaced differently to reduce the cost and amount of stirrups required. As noted in Section 3: Shop Drawings, the stirrups were intentionally spaced differently to reduce the cost and total number required. During field installation, this variation led to confusion, and an error in spacing was identified. The discrepancy was caught through on-site measurement, where the installed spacing did not match the intended layout (8.25 in. versus 6.50 in.). The crew was notified, and the spacing was corrected in the field to align with the specified dimensions. This experience highlights an important lesson: varying stirrup spacing can increase the likelihood of installation errors if not clearly communicated and carefully checked.



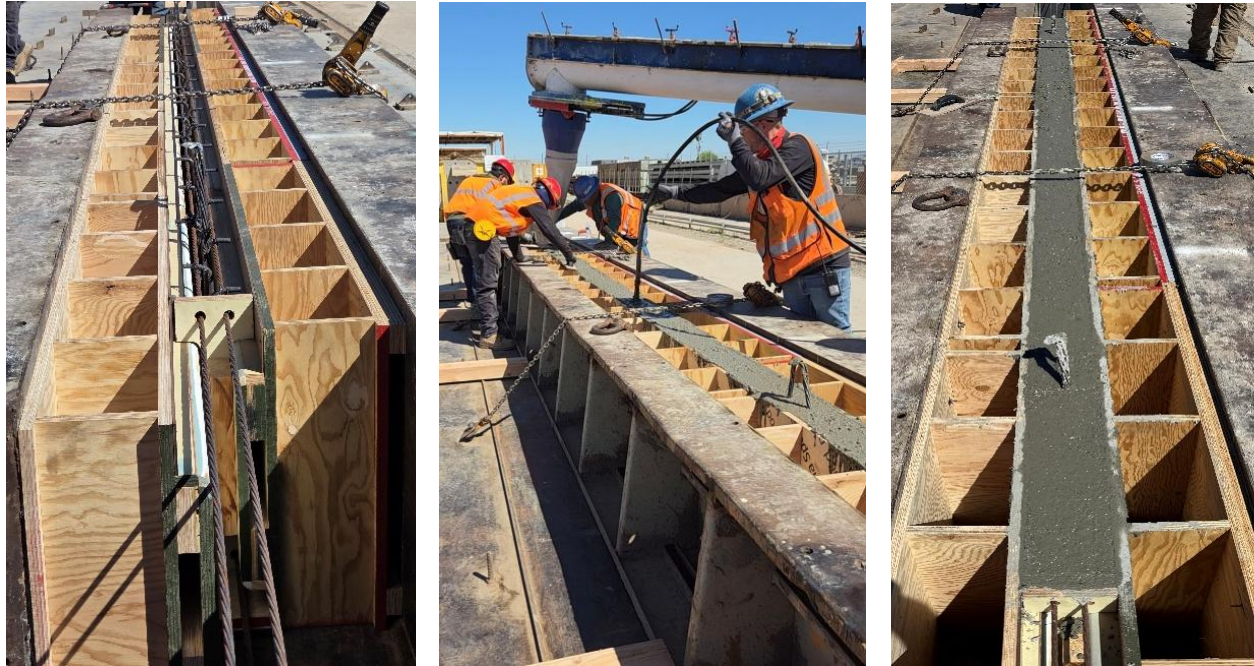
Figures 6: 8.25 in. Stirrup Spacing and 6.50 in. Stirrup Spacing

Following the quality control of the strand placement and shear reinforcement, the spread test was conducted. The measured spread was observed to be 21.5 inches, which is less than the specified range of 27 ± 3 inches for the self-consolidating concrete mix. This indicated reduced flowability compared to the design expectations. As a result, mechanical vibration was required during placement to ensure proper consolidation and to eliminate potential voids within the formwork. This deviation from the specified spread highlights the importance of verifying fresh concrete properties in the field and adjusting placement methods accordingly to maintain concrete quality.



Figures 7: Spread Test Set Up and Spread Test Results

Following the spread test, the forms of the beam were pulled and held together using a hand-operated cable winch to ensure a tight squeeze of the forms prior to concrete being poured into the form.



Figures 8: Formwork Setup, Concrete Pour with Tpac Employees, and Beam After Concrete Pour

Tpac shipped the beam to Northern Arizona University on April 10th, 14 days after fabrication. Tpac completed both the 3-day and 14-day cylinder testing, as the cylinders were shipped with the beam upon delivery. The average compressive strength at 3 days (release strength) was 6,334 psi, and the 14-day compressive strength, tested on April 10th, was 7,787 psi. The remaining cylinders retained in the laboratory were reserved for 28-day strength testing, while the rest were included with the beam shipment.



Figures 9: Received Cylinders for Testing and Broken Cylinder Test

Test Set Up

The beam arrived and was transported into the NAU concrete lab in Room 115.

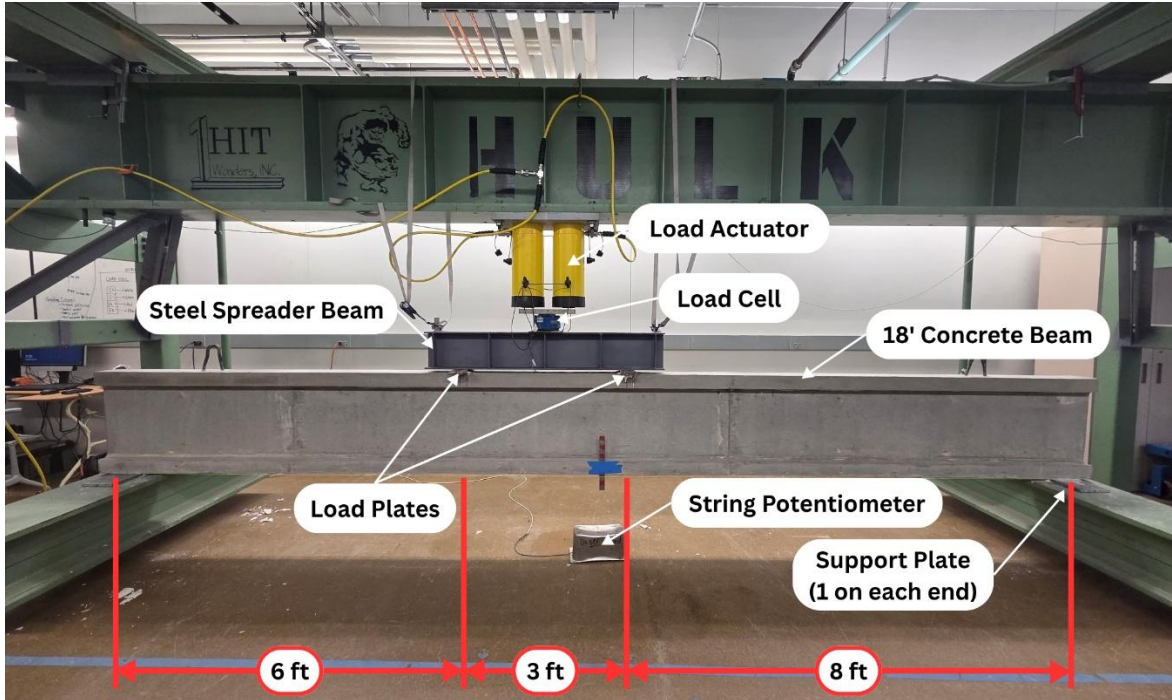


Figure 10: Overview of Test Set Up

Prior to the beam's arrival, the support beams were moved into place to ensure the span length was in accordance with the 2026 PCI Big Beam specifications. Support plate locations were marked, and grout was applied to mimic the pin-roller effect. Measurements of the beam were made and marked at the proper load locations. After ensuring proper measurements of the span length and point load locations, the load plates were grouted to the beam, and the spreader beam was employed with the load cell.

A Mason's string was placed and spanned the entire length of the beam with a ruler attached to the beam, behind the string. This visually showed the deflection during testing, as shown in Figure 10.

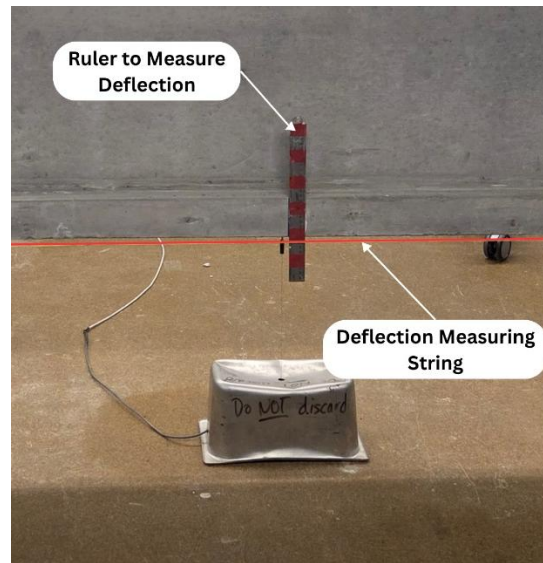


Figure 11: Testing Set Up to Show Visual Deflection

Beam Test Results

The NAU Big Beam test was conducted on April 22nd, 2026, following the cylinder tests and certification of predictions. The test included plotting the applied load and deflections measured at midspan. During testing, flexural cracking initiated near midspan where moment demand was greatest, followed by increased cracking and yielding behavior as the load increased.



Figure 12: Cracking Under Load

Failure was ultimately governed by flexural behavior, with significant cracking and crushing of the concrete occurring near the compression zone at ultimate load. The following graph shows the test data.



Figures 13: Beam at Failure Top View and Side View

Although the beam generally performed close to the predicted values, differences existed between the analytical predictions and the measured results. The actual beam exhibited greater deflection and slightly different cracking behavior than expected. These differences were likely influenced by variations in concrete properties, prestress losses, material assumptions, and simplifications used in the analytical models. In particular, long-term prestress losses were likely overestimated, while the actual stiffness of the beam may have been lower than predicted due to cracking progression and material variability. If the design and analysis process were repeated, additional calibration using measured material properties, refined prestress loss estimates, and more advanced nonlinear modeling could improve prediction accuracy and better represent the observed behavior during testing. The following graph presents the measured load versus midspan deflection response recorded during testing.

Load Deflection Graph

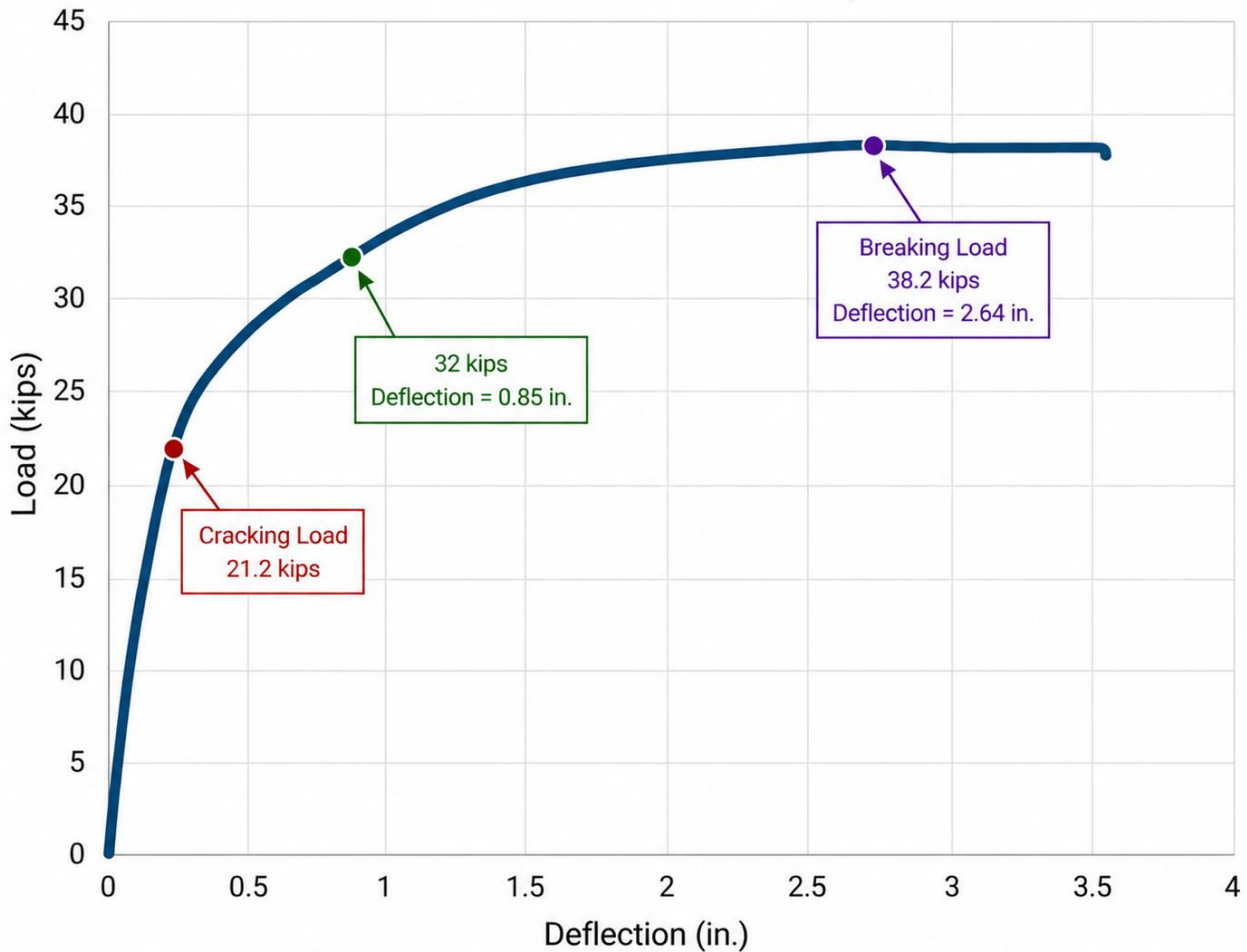


Figure 14: Load vs Deflection Graph

The following table compares the predicted cracking load, ultimate load, and deflection values against the measured results obtained during beam testing. Overall, the beam behavior aligned reasonably well with the analytical predictions, particularly in ultimate capacity. However, the measured deflections were greater than predicted, indicating that the actual beam stiffness was lower than expected. The comparison highlights both the effectiveness of the analytical design approach and the importance of accounting for material variability, prestress losses, and nonlinear cracking behavior when predicting full-scale structural performance.

Table 5: Comparison of Results and Predictions

	Beam Predictions	Test Results	% Difference
Cracking Load (kip)	21.27	21.2	-0.3%
Breaking Load (kip)	35.91	38.2	6.4%
Deflection @ 32 kips (in)	0.58	0.85	46.6%

Section 7: Lessons Learned

David Lucas Macaraeg



Participating in this competition will remain one of the defining experiences of my college career. It was incredibly rewarding to see a concept evolve from an initial idea into detailed designs, then into a physical structure—one that was ultimately tested to its limits. The process felt deeply personal, as if I were nurturing something from creation to its final moment. I'm grateful for the opportunity to collaborate with such a dedicated team to develop a successful prestressed beam and competition entry. This experience serves as a meaningful capstone, marking the close of an important chapter in both my academic journey and the beginning of my professional path.

2335 South Peppertree Dr. Gilbert, AZ 85295

Jonah Simminger



The PCI Big Beam Competition provided a great opportunity for me to gain hands-on experience designing a real prestressed concrete beam. This was a unique experience, as practicing engineers rarely get the chance to see their designs tested all the way to failure. It was especially rewarding to watch something I helped design come to life, since in my limited professional experience, I have not yet had the opportunity to see a project through to its final form. Prestressed concrete has been my favorite topic I've studied, so I am especially appreciative to have been part of this project and to apply that knowledge in a real, tangible way.

1056 West Lisa Ln. Tempe, AZ 85284

Lander Porter



The PCI Big Beam Competition has been one of the most valuable experiences of my time at Northern Arizona University. Being able to take a design from an idea, to calculations, to fabrication, and ultimately to full-scale testing is something that most engineers do not get to experience this early in their careers. This project pushed me to better understand prestressed concrete beyond theory and apply it in a real, physical way. I also learned how important iteration is in design, as small changes in geometry or strand layout had significant impacts on performance. Beyond the technical side, this experience reinforced the importance of communication, coordination, and staying on top of deadlines. Overall, this project helped bridge the gap between academic learning and real-world engineering,

and it gave me much stronger confidence in my abilities moving forward.

3295-B East Calle Agassiz, Vail, AZ 85641

Kaylynn Calvin



This competition was an amazing opportunity to learn and understand the precast/prestressed concrete world. It allowed me to apply what I've learned throughout my academic career to a tangible, real -world project. I enjoyed challenging myself to understand the design aspect of prestressed concrete, from analyzing stress and capacity to watching the beam being fabricated and tested. This experience also showed the importance of teamwork, communication, and time management, as we collaborated to solve problems and meet deadlines. I am proud of the work our team has accomplished and the technical skills we have all developed. I feel more confident about my ability to apply precast/prestressed concrete design in my future career.

303 West King Rd. Tucson, AZ 85705

Section 8: Introduction

Project Overview

This project involves the design, fabrication, and testing of a prestressed concrete beam for the PCI Big Beam Competition. The project is intended to simulate real-world structural engineering practice by requiring teams to design a beam, predict its behavior, and verify those predictions through full-scale laboratory testing. Beamline Structural, representing Northern Arizona University, is collaborating with Tpac to complete this work. The competition challenges student teams to partner with an industry precast producer and develop a beam that meets specific performance targets for strength, serviceability, efficiency, and constructability.

Project Objectives

The primary objective of this project is for Beamline Structural to design a structurally efficient prestressed concrete beam that performs as predicted during laboratory testing. The beam must remain uncracked under a specified service load, reach a target peak load within a defined range, deflect as much as possible, and have a ductile failure mode. A key goal of the project is to accurately predict cracking load, ultimate load, and midspan deflection, demonstrating a clear understanding of prestressed concrete behavior.

In addition to meeting technical performance requirements, the project emphasizes professional engineering skills such as collaboration with industry partners, constructability considerations, scheduling, and technical communication. Final deliverables include design calculations, drawings, fabrication coordination, laboratory testing, and a comprehensive report documenting the design, fabrication, and testing results.

Project Location and Setting

The beam will be fabricated at Tpac's precast facility in Phoenix, Arizona, using industry-standard pre-tensioned concrete casting methods. After fabrication, the beam will be transported to Northern Arizona University in Flagstaff, Arizona, where it will be tested in the NAU Structural Laboratory. Testing will follow the PCI Big Beam Competition loading configuration, allowing the measured performance of the beam to be directly compared to analytical predictions.

The project reflects realistic conditions encountered in professional practice, including off-site fabrication, transportation logistics, and controlled laboratory testing. These conditions provide Beamline Structural with experience that closely mirrors how prestressed concrete elements are produced and evaluated in industry.

Constraints and Design Considerations

The design and execution of this project are shaped by several constraints related to public welfare, environmental, social, economic, and practical considerations. Public welfare and safety influence the project's emphasis on predictable structural behavior. Although the beam is tested in a laboratory



environment, the design principles applied are consistent with those used in real infrastructure systems.

Environmental and economic factors influence material efficiency and design decisions. The competition rewards beams that meet performance requirements while minimizing material usage and weight, encouraging responsible use of resources and cost-effective construction practices. Fabrication constraints at Tpac, including prestressing bed availability and production schedules, also affect the project timeline and require careful coordination.

Implications


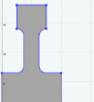



Social and educational considerations play a significant role in shaping the project. Participation in the competition supports engineering education and workforce development by providing hands-on experience with industry collaboration and performance verification. On a broader scale, the project reflects the global use of prestressed concrete in infrastructure systems and highlights the importance of efficient, durable structural design.

Section 9: Final Design Recommendation

Initial iterations (Table 6) evaluated varying beam geometries and strand layouts while maintaining a constant strand diameter. These iterations considered key engineering constraints, including structural performance (strength and stress limits), constructability, economic efficiency, and material usage. Shallower sections required additional material to meet strength demands, which increased weight and reduced efficiency. Although all early designs satisfied minimum design requirements, the team aimed to increase moment capacity while reducing weight.

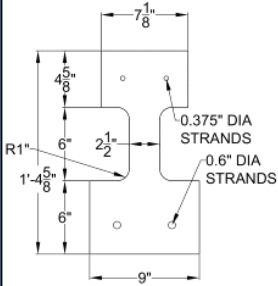
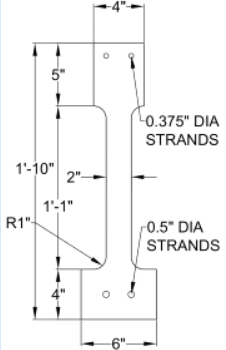
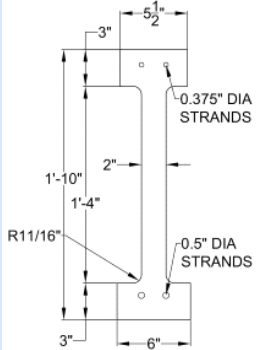
To address this, designs incorporating 0.6-inch-diameter prestressing strands were evaluated. However, configurations relying solely on increased prestressing in the bottom flange produced undesirable tensile stresses at the top fiber during transfer, violating serviceability constraints. To resolve this issue without increasing section size or adding excessive reinforcement, top strands jacked to a controlled stress level were introduced. This targeted modification improved stress distribution while maintaining constructability and geometric efficiency.

Table 6: Preliminary Decision Matrix

Name	Depth	Image	Cracking/ Capacity	Cost	Weight	Deflect	Pra/Inn/ Code	Total
2-Strand Symmetrical	15.5"		10	5	9	0	3	27
2-Strand Averaged Beam	18"		9	6	5	5	3	28
2-Strand Optimized Beam	18"		9	10	9	5	3	36
2-Strand Wide Beam	16"		19	0	0	10	3	32
3-Strand Beam	14.25"		6	8	10	36	3	35

Following this iterative process, a decision matrix was developed to further refine the beam design with respect to weight, cost, and deflection performance.

Table 7: Refined Decision Matrix

	Design 1	Design 2	Design 3
Design			
Cracking/ Capacity	20	20	20
Cost	3	10	0
Weight	0	9	10
Deflection	10	0	9
Prac/Inn/Code	3	3	4
Total	36	42	43

Beamline Structural recommends a final prestressed concrete beam consisting of a 22-inch-deep section utilizing prestressing strands in both the bottom and top flanges, combined with Tpac’s lightweight concrete mix with a specified compressive strength of 8000 psi. This design balances structural efficiency, constructability, economic cost, and performance requirements within the PCI Big Beam Competition constraints.

The selected section geometry was developed to maximize moment capacity while minimizing weight. Increasing the depth to 22 inches significantly improved the moment of inertia compared to earlier 16-inch and 18-inch sections, enhancing flexural capacity without a proportional increase in material usage. The prestressing layout includes two 0.5-inch-diameter strands in the bottom flange and two 0.375-inch-diameter strands in the top flange. The bottom strands provide primary flexural resistance with an eccentricity of approximately 8.79 inches, while the top strands are lightly stressed to reduce tensile stresses at the top fiber during transfer. This configuration satisfies stress limits while avoiding constructability challenges.

The final beam satisfies all structural performance requirements. Stress checks at transfer and under service conditions confirm compliance with ACI 318 and PCI limits, addressing safety and serviceability constraints. Shear capacity was verified along the full span with appropriately designed stirrups, ensuring overall structural integrity.

Table 8: Predicted and Target Values

	Predicted	Target
Cracking Load (kips)	21.38	21.00
Failure Load (kips)	35.96	35.00

This design provides a balanced and reliable solution that prioritizes efficiency, constructability, safety, economic viability, and performance. By combining optimized prestressing, increased section depth, and lightweight concrete, the beam meets all requirements while minimizing material usage and fabrication complexity. With an estimated cost of \$300.70, the design remains economically efficient and competitive. Beamline Structural confidently submits this design for fabrication and testing in the PCI Big Beam Competition.

Section 10: Project Impacts

Price

The economic impacts of the prestressed beam design were evaluated based on competition cost management, material savings, and time to construct compared to a conventional reinforced concrete alternative. The beam cost ended up being \$299.37 with an ultimate capacity of 35.96 kips, resulting in a cost efficiency of $\$299.37/35.96 \text{ kip} = \$8.32/\text{kip}$ per the competition costs. If a normal-weight reinforced concrete design were used instead, the beam weight would increase by approximately $(147.5 \text{ normal-weight pcf} - 124.1 \text{ lightweight pcf})/147.5 \text{ normal-weight pcf} = 15.9\%$, leading to a proportional increase in material cost. This added weight would increase material demand and labor effort, resulting in $\$299.37 \times 1.159 \approx \346.97 and a cost efficiency of $\$346.97/35.96 \text{ kip} = \$9.65/\text{kip}$, which represents a $(\$9.65/\text{kip})/(\$8.32/\text{kip}) = 15.9\%$ increase in cost per unit strength for the conventional reinforced design.

From a global economic perspective, prestressed concrete reduces material consumption and long-term infrastructure costs when applied at scale in transportation and structural systems. From a cultural or project-level perspective, the prestressed system improved competition efficiency by reducing reinforcement demand and simplifying construction sequencing. Additionally, excess prestressing strands were repurposed as lifting loops for other uses instead of being wasted, improving material utilization.

Planet

The environmental impacts of the competition beam entry were evaluated based on material usage, weight reduction, and associated emissions compared to a conventional reinforced normal weight concrete beam. The use of lightweight concrete reduced unit weight from 147.5 pcf to 124.1 pcf, a reduction of $(147.5 \text{ normal weight pcf} - 124.1 \text{ lightweight pcf})/147.5 \text{ normal weight pcf} = 15.9\%$ and about 1283 lbs – 1079 lbs = 204 lbs reduction in total beam mass. Reducing concrete volume directly reduces cement usage, which is a major contributor to CO₂ emissions. Given that cement production emits approximately 0.9 lb CO₂ per lb of cement, this reduction results in a $204 \text{ lbs} \times 0.9 \text{ lb CO}_2/\text{lb cement} = 183.6 \text{ lb CO}_2$ decrease during beam fabrication.

From a global environmental perspective, prestressed lightweight systems reduce embodied carbon and resource consumption when adopted across infrastructure networks. From a cultural or local perspective, precast fabrication improves material efficiency and reduces waste through controlled batching and reusable formwork, but transportation of the beam 143 miles from Phoenix to Northern Arizona University introduces localized fuel use and emissions that would not change significantly between prestressed and conventional systems.

People

The social impacts of the competition were evaluated in terms of construction safety, installation demands, and long-term public benefit compared to a conventional reinforced concrete beam. As



stated earlier, the prestressed beam is 204 lbs lighter than an equivalent normal-weight reinforced concrete design, improving safety during lifting and placement operations. Lower weight reduces crane load demand and rigging forces, decreasing the likelihood of lifting-related incidents and improving worker safety during construction.

From a global social perspective, prestressed concrete enables faster construction of bridges and infrastructure, reducing long-term traffic disruptions and improving public access and safety through more durable structural systems. From a cultural or project-level perspective, the reduced weight and precast nature of the beam made handling safer and more manageable for the student competition setting, reducing risk during lifting and installation.

In contrast, a conventional reinforced beam would increase construction difficulty due to higher weight, longer handling times, and increased exposure to on-site hazards, which can negatively impact both worker safety and public inconvenience during construction periods.

In addition, participation in this competition has contributed to the development of our engineering judgment and practical understanding of structural behavior. The experience of integrating analytical methods with experimental results has strengthened our ability to evaluate assumptions, interpret variability in material properties, and refine design decisions. Ultimately, this process enhances our preparedness to make informed, responsible engineering decisions that prioritize safety, reliability, and the well-being of the public.

Section 11: Work

Overall, the actual project hours (629 hrs) were lower than the planned estimate (693 hrs), showing a reduction of 64 hours. This came mainly from improved efficiency in design, documentation, and fabrication coordination, where fewer iterations were needed as the team reached workable solutions earlier and reused calculations and drawings across tasks. Fabrication and delivery also took less time due to effective coordination with the producer.

Role differences explain how the hours shifted. Differed. STEG carried the largest workload due to detailed analysis, reinforcement design, and code compliance. INT hours decreased as reporting and iterations became more streamlined, while SENG remained steady due to consistent oversight duties. LBT varied the most, with reduced fabrication time but slightly increased testing time due to real-world setup and loading adjustments. Overall, the results reflect a more efficient workflow and shifting effort based on project needs.

Table 9: Estimated and Completed Work Hours

Task Name	Estimated Work Hours					Completed Work Hours				
	SENG	STEG	INT	LBT	Total Hours	SENG	STEG	INT	LBT	Total Hours
Task 1 Research & Preparation	0	10	20	0	30	0	8	16	5	29
Task 2 Beam Analysis & Design	20	145	82	0	247	17	113	105	0	235
Task 3 Engineering Shop Drawings	5	30	20	0	55	8	25	20	0	53
Task 4 Fabrication & Engineer's Site Visit	10	6	16	17	49	6	11	12	9	38
Task 5 Delivery & Setup	5	5	10	5	25	4	5	8	4	21
Task 6 Beam Testing	6	0	8	0	14	5	0	4	8	17
Task 7 Finalize Report & Submit to PCI	5	15	40	0	60	8	10	32	0	50
Task 8 Project Impacts	1	2	5	2	10	1	3	6	2	12
Task 9 Deliverables	8	14	104	0	126	7	18	72	1	98
Task 10 Project Management	5	24	24	24	77	5	25	26	20	76
Total Hours	59	234	284	46	693	61	218	301	49	629

Section 12: Costs

Overall, the actual project cost (\$83,061) was lower than the proposed estimate (\$83,436), resulting in a reduction of \$375. This reflects improved coordination with the subcontractor and more efficient deliverable production. Personnel costs also shifted slightly: STEG decreased due to faster design iterations and analysis effort, while INT and LBT increased as documentation, fabrication, and testing required more hours than planned. Travel, supplies, and subcontracting costs stayed the same, indicating accurate initial estimates for logistics and equipment usage. Overall, the minimal differences reflect improved execution efficiency throughout the project.

Table 10: Cost Summary

		Proposed Costs			Actual Costs		
	Unit	Quantity	\$/unit	Cost	Quantity	\$/unit	Cost
<u>1.0 Personnel</u>		<u>1.0 Personnel</u>					
SENG	HR	59	\$275	\$16,225	61	\$275	\$16,775
STEG	HR	234	\$140	\$32,760	218	\$140	\$30,520
INT	HR	284	\$65	\$18,460	301	\$65	\$19,565
LBT	HR	46	\$70	\$3,220	49	\$70	\$3,430
Total Personnel	HR	693		\$70,665	693		\$70,290
<u>2.0 Travel</u>		<u>2.0 Travel</u>					
Mileage Rate	MILE	288	\$0.15	\$43	288	\$0.15	\$43
Sedan Rental	DAY	1	\$40.00	\$40	1	\$40.00	\$40
Total Travel				\$83			\$83
<u>3.0 Supplies</u>		<u>3.0 Supplies</u>					
Lab Rental + Consumables	DAY	6	\$100	\$600	6	\$100	\$600
Software Licensing	WEEK	16	\$93	\$1,488	16	\$93	\$1,488
Forklift and Operator	HR	2	\$300	\$600	2	\$300	\$600
Total Supplies				\$2,688			\$2,688
<u>4.0 Subcontract</u>		<u>4.0 Subcontract</u>					
Tpac	LS	1	\$10,000	\$10,000	1	\$10,000	\$10,000
<u>Combined Total</u>				\$83,436			\$83,061

Section 13: Conclusion

The objective of this project was to design, fabricate, and test a precast, prestressed concrete beam in accordance with the PCI Big Beam Competition requirements for the 2025–2026 academic year. The beam was developed through collaboration with a PCI producer member and was required to satisfy all prescribed structural and material criteria, including compliance with ACI 318-19 or the PCI Design Handbook. The design ensured that the beam remained uncracked under a total service load of 20 kips, achieved an ultimate capacity between 32 and 40 kips, and exhibited measurable midspan deflection under loading.

The primary goal of the project was to accurately predict the beam’s cracking load, ultimate load, and midspan deflection before testing, as these predictions were directly evaluated in the competition scoring. In addition, the project emphasized optimization of beam performance based on competition judging criteria, including minimizing cost and weight while maximizing deflection and maintaining structural efficiency. The project also required the development and justification of a concrete mix design, integration of prestressed reinforcement, and preparation of detailed calculations, drawings, and documentation. Through fabrication and full-scale testing, the project aimed to replicate real-world precast concrete practice while demonstrating accuracy, constructability, and sound engineering judgment.

The final beam design successfully fulfilled the objectives established for the PCI Big Beam Competition by meeting all required structural, analytical, and practical performance criteria. The beam was designed and fabricated in compliance with competition rules, including material specifications, prestressing requirements, and geometric constraints. Analytical predictions were completed before testing and produced results that closely aligned with target performance values, including a cracking load of 22.5 kips and an ultimate capacity of 38.2 kips, which fell within the required 32–40 kip range and were somewhat close to our predicted cracking load of 21.38 kips and ultimate capacity of 35.96 kips. Our measured deflection of 0.85” at 32 kips was not in the desirable range of our predicted deflection at 0.58”. The design satisfied the serviceability requirement of remaining uncracked under the 20-kip service load and was expected to demonstrate appropriate deflection behavior at higher load levels. The use of refined material properties from cylinder testing improved the accuracy of predicted behavior, directly supporting the objective of minimizing error between predicted and measured results.

Performance-based objectives related to efficiency were also achieved. The beam was composed of a lightweight concrete mix and an optimized prestressing layout to reduce overall weight while maintaining sufficient strength and stiffness. This resulted in a cost-efficient design that aligned with competition scoring criteria for both cost and weight. Additionally, the beam was designed to exhibit ductile behavior and a clear failure mechanism, satisfying testing and evaluation requirements. The project met its objectives by delivering a structurally efficient, code-compliant, prestressed concrete beam with accurate performance predictions, optimized competition metrics, and successful implementation from design through fabrication.

Section 14: References

- [1] "PCI Big Beam Competition," 2024. [Online]. Available: <https://www.pci.org/bigbeam/>.
- [2] "Autodesk," 3D Design, Engineering & Construction Software, 2025. [Online]. Available: <https://www.autodesk.com/>.
- [3] "Tpac - Providing Engineering Concrete Solutions," 2024. [Online]. Available: <https://www.Tpacaz.com/>.
- [4] "PTC: MathCAD," 2026. [Online]. Available: <https://www.ptc.com/en>.



Section 15: Appendix

Appendix A: 2025-2026 PCI Big Beam MathCAD Spreadsheet

DESIGN SUMMARY AND PERFORMANCE PREDICTIONS

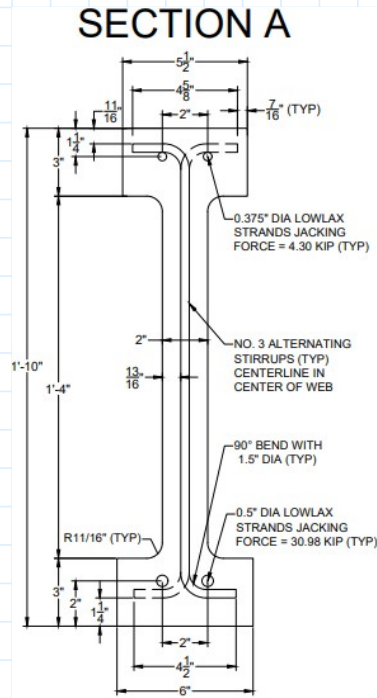


Figure 1: Cross-Section Profile

Beam Predictions

CrackingLoad = 21.27 kip

BreakingLoad = 35.91 kip

Deflection = 0.58 in @ 32 kip

Test Results

Cracking Load = 22.50 kip

Breaking Load = 38.20 kip

Deflection = 0.85 in @ 32 kip

Cost

DollarCost = 299.37

Weight

Weight = 1079.122 lbf

CROSS SECTION PROPERTIES

$$l := 18 \text{ ft}$$

Total Beam Length

$$l_s := 17 \text{ ft}$$

Beam Span Length

$$x := 0 \text{ ft}, 0.01 \text{ ft} \dots l_s \quad AB := 8 \text{ ft} \quad BC := 3 \text{ ft} \quad CD := 6 \text{ ft} \quad AC := AB + BC = 11 \text{ ft}$$

$$t_{ft} := 3 \text{ in}$$

Top Flange Thickness

$$b_{ft} := 3 \text{ in}$$

Bottom Flange Thickness

$$t_{fw} := 5.5 \text{ in}$$

Top Flange Width

$$b_{fw} := 6 \text{ in}$$

Bottom Flange Width

$$w_d := 16 \text{ in}$$

Web Depth/Height

$$w_w := 2 \text{ in}$$

Web Width

$$c_r := 0.6875 \text{ in}$$

One Chamfer Radius

$$h := t_{ft} + w_d + b_{ft} = 22 \text{ in}$$

Beam Height

$$l_{perim} := 2 \cdot c_r \cdot \pi + \left(2 \cdot w_d + 2 \cdot t_{fw} + 2 \cdot t_{ft} + (2 \cdot b_{fw} + 2 \cdot b_{ft} - 8 \cdot c_r) - 2 \cdot w_w \right) = 61.82 \text{ in}$$

Cross Sectional Perimeter

Cross Sectional Areas and Volume

$$A_{tf} := t_{ft} \cdot t_{fw} = 16.5 \text{ in}^2$$

Area of Top Flange

$$A_{bf} := b_{ft} \cdot b_{fw} = 18 \text{ in}^2$$

Area of Bottom Flange

$$A_{webrect} := w_d \cdot w_w = 32 \text{ in}^2$$

Area of Web Rectangle

$$A_{ch} := c_r^2 - \frac{\pi \cdot c_r^2}{4} = 0.101 \text{ in}^2$$

Area of Chamfers

$$A_{web} := A_{webrect} + A_{ch} = 32.101 \text{ in}^2$$

Area of Total Web

$$A_{total} := A_{tf} + A_{web} + A_{bf} = 66.601 \text{ in}^2$$

Total Cross Sectional Area

$$V_{total} := A_{total} \cdot l = 0.308 \text{ yd}^3$$

Cross Sectional Volume

Cross Sectional Centroids

$$y_{tf} := \frac{t_{ft}}{2} + w_d + b_{ft} = 20.5 \text{ in}$$

Centroid of Top Flange

$$y_{bf} := \frac{b_{ft}}{2} = 1.5 \text{ in}$$

Centroid of Bottom Flange

$$y_{web} := b_{ft} + \frac{w_d}{2} = 11 \text{ in}$$

Centroid of Web Rectangle
or Total Web

$$y_{tcham} := b_{ft} + w_d - 4 \frac{c_r}{3 \cdot \pi} = 18.708 \text{ in}$$

Centroid of Top Chamfers

$$y_{bcham} := b_{ft} + 4 \frac{c_r}{3 \cdot \pi} = 3.292 \text{ in}$$

Centroid of Bottom
Chamfers

$$y_{bmbot} := \frac{A_{tf} \cdot y_{tf} + A_{web} \cdot y_{web} + A_{bf} \cdot y_{bf}}{A_{total}} = 10.786 \text{ in}$$

Beam Centroid From
Bottom

$$y_{bmtop} := h - y_{bmbot} = 11.214 \text{ in}$$

Beam Centroid From Top

Moment of Inertia (MOI)

$$I_{tf} := \frac{1}{12} t_{fw} \cdot t_{ft}^3 + A_{tf} \cdot (y_{tf} - y_{bmbot})^2 = (1.569 \cdot 10^3) \text{ in}^4$$

MOI of Top Flange

$$I_{webrect} := \frac{1}{12} w_w \cdot w_d^3 + A_{web} \cdot (y_{web} - y_{bmbot})^2 = 684.136 \text{ in}^4$$

MOI of Web Rectangle

$$I_{tcha} := 2 \left(\frac{\pi}{8} c_r^4 + A_{ch} \cdot (y_{tcham} - y_{bmbot})^2 \right) = 12.907 \text{ in}^4$$

MOI of Top Chamfers

$$I_{bcha} := 2 \left(\frac{\pi}{8} c_r^4 + A_{ch} \cdot (y_{bcham} - y_{bmbot})^2 \right) = 11.569 \text{ in}^4$$

MOI of Bottom Chamfers

$$I_{bf} := \frac{1}{12} b_{fw} \cdot b_{ft}^3 + A_{bf} \cdot (y_{bf} - y_{bmbot})^2 = (1.566 \cdot 10^3) \text{ in}^4$$

MOI of Top Flange

$$I_{total} := I_{tf} + I_{webrect} + I_{tcha} + I_{bcha} + I_{bf} = (3.844 \cdot 10^3) \text{ in}^4$$

Total MOI

BEAM COMPOSITION

Concrete; Updated Based on Recorded Cylinder Test Data

$$\rho := 124.1 \text{ pcf}$$

Lightweight

$$\lambda := 0.75$$

$$d_{agr} := 0.5 \text{ in}$$

$$Rel_{hud} := 40$$

$$f_{ci} := 6334 \text{ psi}$$

$$f_c := 7808.64 \text{ psi}$$

$$E_{ci} := 33 \cdot \left(\frac{\rho}{\text{pcf}} \right)^{1.5} \cdot \sqrt{\frac{f_{ci}}{\text{psi}}} \cdot \text{psi} = 3630.87 \text{ ksi}$$

$$E_c := 33 \cdot \left(\frac{\rho}{\text{pcf}} \right)^{1.5} \cdot \sqrt{\frac{f_c}{\text{psi}}} \cdot \text{psi} = 4031.432 \text{ ksi}$$

Concrete Density

Concrete Type

Lightweight Factor

Maximum Aggregate Diameter

Relative Humidity (%)

Initial Concrete Strength (at transfer)

Strength of Concrete (ASTM C78)

Initial Concrete Modulus of Elasticity

Concrete Modulus of Elasticity

7-Wire Strand (Tension)

$$f_{pu} := 270 \text{ ksi}$$

$$E_{ps} := 28500 \text{ ksi}$$

$$d_{ps} := 0.5 \text{ in}$$

$$w_{ps} := 0.52 \text{ plf}$$

$$A_{ps} := 0.153 \text{ in}^2$$

$$n_{ps} := 2$$

$$y_{ps1} := 2 \text{ in}$$

$$y_{ps2} := 2 \text{ in}$$

$$y_{ps3} := 0 \text{ in}$$

$$s_{min1} := \max \left(2 \text{ in}, \frac{4}{3} (d_{agr} + d_{ps}) \right) = 2 \text{ in}$$

Strand Ultimate Strength

Modulus of Elasticity of Strands

Diameter of Tension Prestressing Strands

Weight of Prestressing Strands

Nominal Area of 7-Wire Low-Lax Strands

Number of Prestressing Strands

Distance from Bottom of Beam to Strand 1

Distance from Bottom of Beam to Strand 2

Distance from Bottom of Beam to Strand 3

Minimum Center to Center Spacing
Pretensioned Strands (ACI 318-18, 25.2.4)

7-Wire Strand (Compression)

$$d_{psc} := 0.375 \text{ in}$$

$$A_{psc} := 0.085 \text{ in}^2$$

$$n_{psc} := 2$$

$$w_{psc} := 0.273 \text{ plf}$$

$$y_{psc1} := 1.25 \text{ in}$$

$$y_{psc2} := 1.25 \text{ in}$$

$$s_{min2} := \max\left(1.75 \text{ in}, \frac{4}{3} (d_{agr} + d_{psc})\right) = 1.75 \text{ in}$$

Diameter of Compression Prestressing Strands

Nominal Area of Compression 7-Wire Low-Lax Strands

Number of Compression Prestressing Strands

Weight of Compression Prestressing Strands

Distance from Top of Beam to Strand 1

Distance from Top of Beam to Strand 2

Minimum Center to Center Spacing Pretensioned Compression Strands (ACI 318-18, 25.2.4)

Steel Rebar (Compression)

$$E_r := 29000 \text{ ksi}$$

$$d_r := 0 \text{ in}$$

$$w_r := 0 \text{ plf}$$

$$A_r := 0 \text{ in}^2$$

$$n_r := 0$$

$$y_{r1} := 0 \text{ in}$$

$$y_{r2} := 0 \text{ in}$$

Modulus of Elasticity of Steel Rebar

Diameter of Steel Rebar

Weight of Steel Rebar

Nominal Area of Steel Rebar

Number of Compression Reinforcement Bars

Distance from Bottom of Beam to Rebar 1

Distance from Bottom of Beam to Rebar 2

Steel Stirrups (Shear)

$$f_y := 60 \text{ ksi}$$

$$d_{stir} := 0.375 \text{ in}$$

$$w_{stir} := 0.376 \text{ plf}$$

$$A_{stir} := 0.110 \text{ in}^2$$

$$n_{legs} := 1$$

$$n_{stir} := 29$$

$$l_{stir} := 23.4375 \text{ in}$$

Stirrup Strength

Diameter of Stirrup

Weight of Stirrups

Nominal Area of Stirrup

Number of Stirrup Legs

Number of Stirrups

Length of Stirrups

Eccentricity of Bottom Strands

$$y_{stl} := \left(\frac{(A_{ps} \cdot y_{ps1}) + (A_{ps} \cdot y_{ps2}) + (A_{ps} \cdot y_{ps3}) + (A_r \cdot y_{r1}) + (A_r \cdot y_{r2})}{A_{ps} \cdot n_{ps} + A_r \cdot n_r} \right) \downarrow \downarrow = 2 \text{ in}$$

Centroid of Steel Within the Beam Designed to Resist Moment

$$h_{barc} := h - y_{stl} = 20 \text{ in}$$

Height to Center of Bars

$$e := h_{barc} - y_{bmtop} = 8.786 \text{ in}$$

Beam Eccentricity

Eccentricity of Top Strands

$$y_{stlc} := \left(\frac{(A_{psc} \cdot y_{psc1}) + (A_{psc} \cdot y_{psc2}) + (A_r \cdot y_{r1}) + (A_r \cdot y_{r2})}{A_{psc} \cdot n_{psc} + A_r \cdot n_r} \right) \downarrow \downarrow = 1.25 \text{ in}$$

Centroid of Top Steel Within the Beam Designed to Resist Moment

$$h_{cbarc} := y_{stlc} = 1.25 \text{ in}$$

Height to Center of Bars

$$e_c := h_{cbarc} - y_{bmbot} = -9.536 \text{ in}$$

Beam Eccentricity

LOADING, MOMENT, AND SHEAR

Selfweight

$$w_{ship} := \left(\begin{aligned} &(-A_{ps} - A_{psc}) \cdot \rho_{\downarrow} \\ &+ n_{ps} \cdot w_{ps} + n_{psc} \cdot w_{psc} \end{aligned} \right) \cdot l_{\downarrow} = 1079.122 \text{ } \mathbf{lb_f} \quad \text{Shipping Weight}$$

$$+ (V_{total} - A_{stir} \cdot l_{stir}) \cdot \rho_{\downarrow}$$

$$+ l_{stir} \cdot n_{stir} \cdot w_{stir}$$

$$w_{sw} := w_{ship} \div l = 59.951 \text{ } \mathbf{plf} \quad \text{Selfweight}$$

$$\text{Weight} \equiv 1079.122 \cdot \mathbf{lb_f}$$

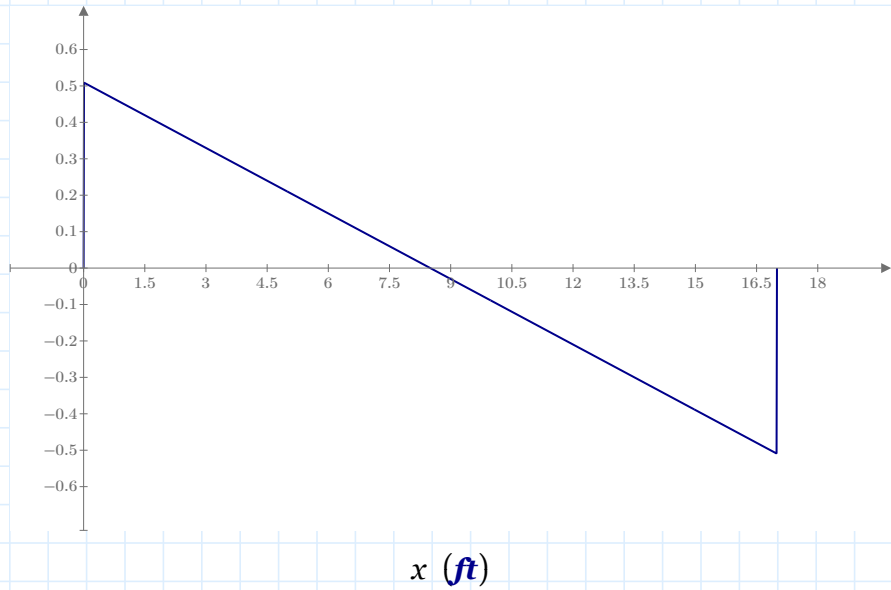
$$\text{check} := \text{if}(w_{ship} < 2000 \text{ } \mathbf{lb_f}, \text{"OK"}, \text{"NG"}) = \text{"OK"}$$

Truck Capacity Check

$$V_{sw}(x) := \text{if}(0 < x < l_s, w_{sw} \cdot (0.5 \cdot l_s - x), 0)$$

Selfweight Shear vs Beam Span Length

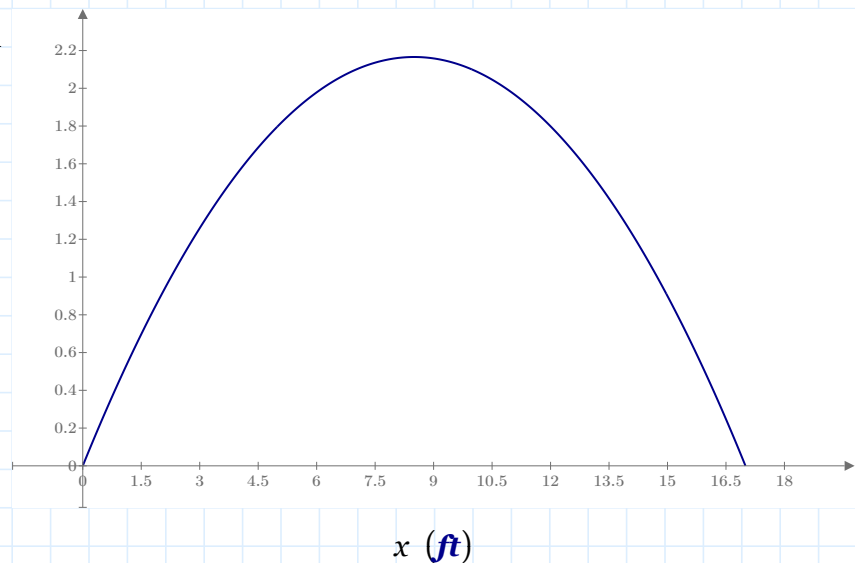
$V_{sw}(x)$ (**kip**)



$$M_{sw}(x) := \frac{w_{sw} \cdot x}{2} (l_s - x)$$

Selfweight Moment vs Beam Span Length

$M_{sw}(x)$ (**ft·kip**)



Live Load

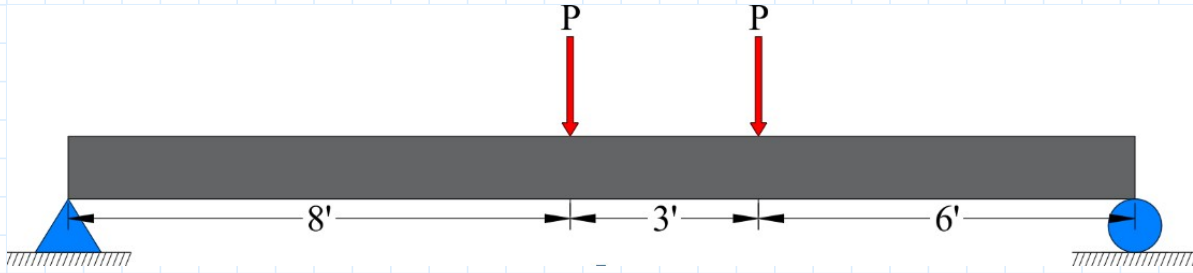


Figure 2: Competition Loading Diagram

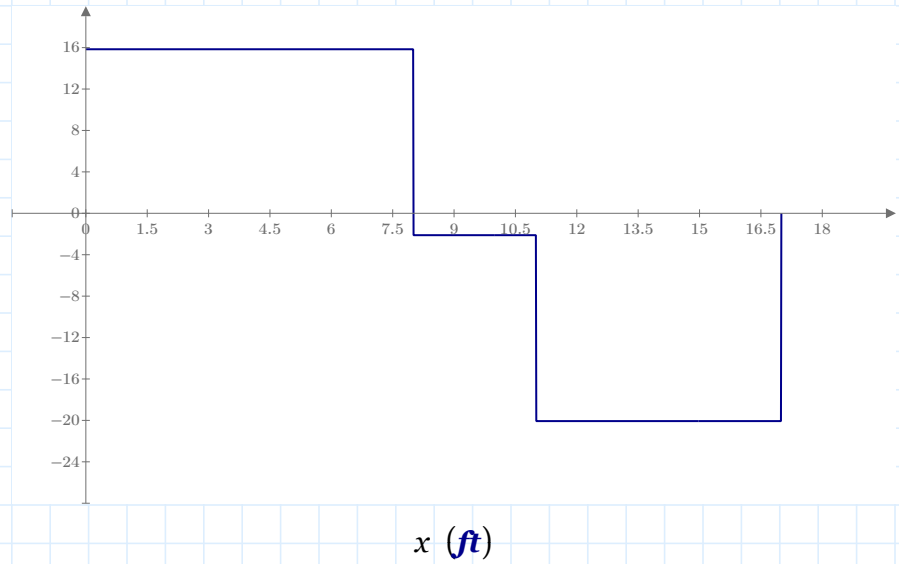
$$P := 17.954 \text{ kip} \quad \Sigma M = 0 \text{ kip} \cdot \text{ft} \quad \Sigma F_y = 0 \text{ kip} \quad \Sigma F_x = 0 \text{ kip} \quad A_x = 0 \text{ kip}$$

$$D_y := \frac{P \cdot (AB) + P \cdot (AC)}{l_s} = 20.066 \text{ kip} \quad A_y := 2 P - D_y = 15.842 \text{ kip}$$

$$V_{LL}(x) := \text{if} \left(x \leq AB, A_y, \text{if} \left(AB < x \leq AC, \frac{P}{l_s} \cdot (CD - AB), \text{if} \left(AC < x < l_s, -D_y, 0 \text{ kip} \right) \right) \right)$$

Live Load Shear vs Beam Span Length

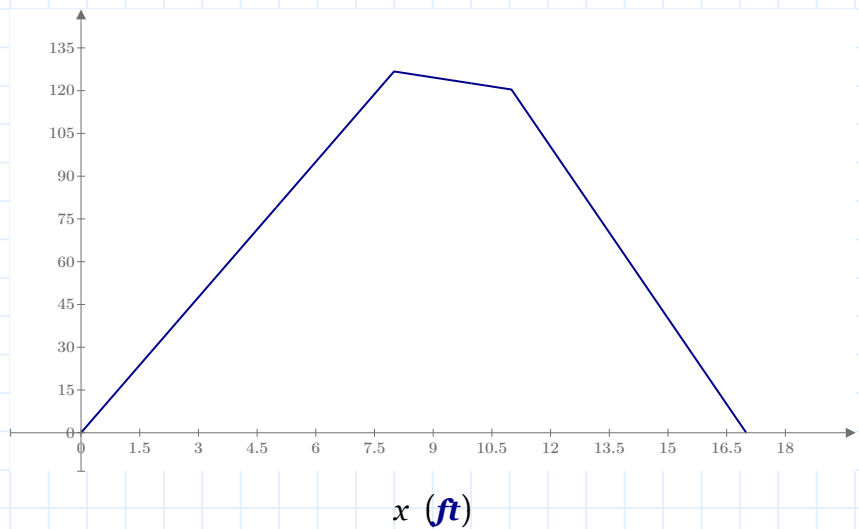
$V_{LL}(x)$ (kip)



$$M_{LL}(x) := \text{if} \left(x \leq AB, A_y \cdot x, \text{if} \left(AB < x < AC, A_y \cdot x - P \cdot (x - AB), D_y \cdot CD - D_y \cdot (x - AC) \right) \right)$$

Live Load Moment vs Beam Span Length

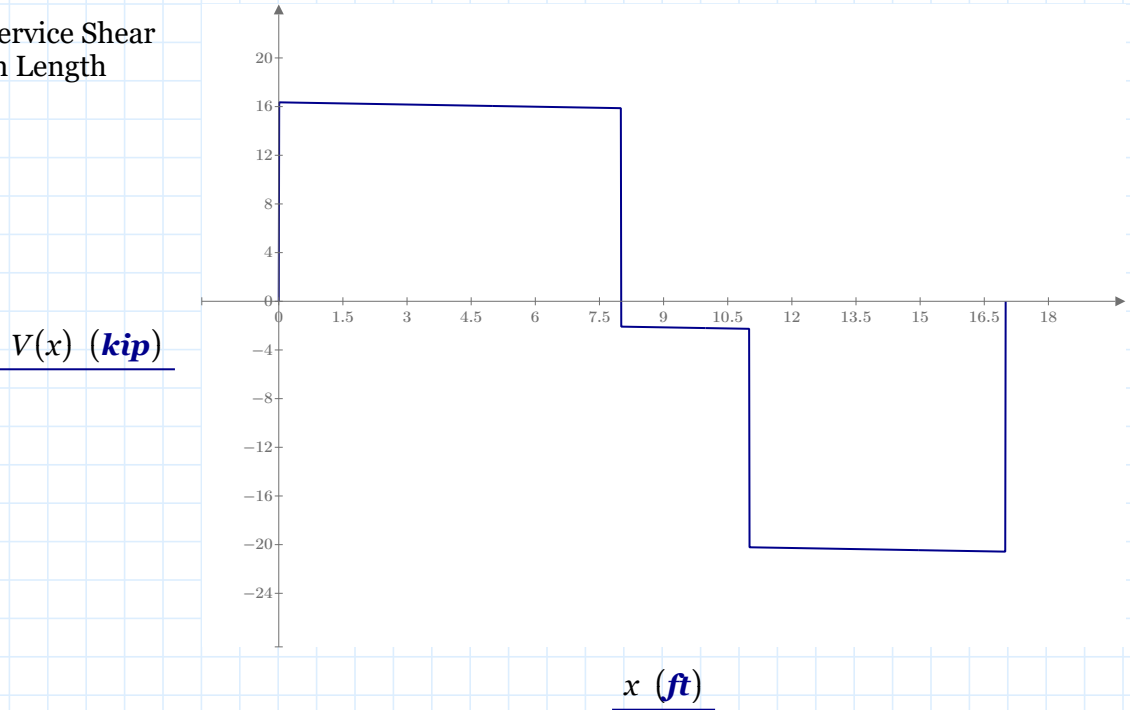
$M_{LL}(x)$ (kip·ft)



Total Factored Shear

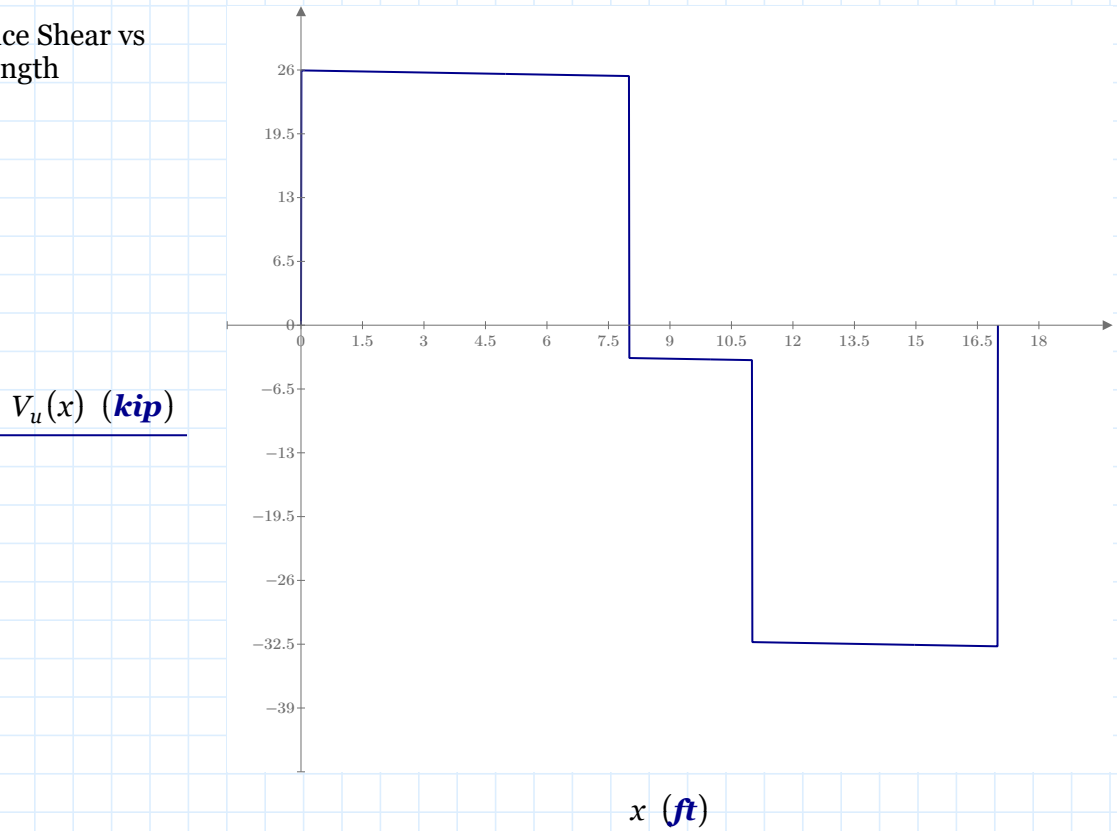
$$V(x) := \text{if}(0 < x < l_s, V_{sw}(x) + V_{LL}(x), 0 \text{ kip})$$

Unfactored Service Shear vs Beam Span Length



$$V_u(x) := \text{if}(0 < x < l_s, 1.2 V_{sw}(x) + 1.6 V_{LL}(x), 0 \text{ kip})$$

Factored Service Shear vs Beam Span Length

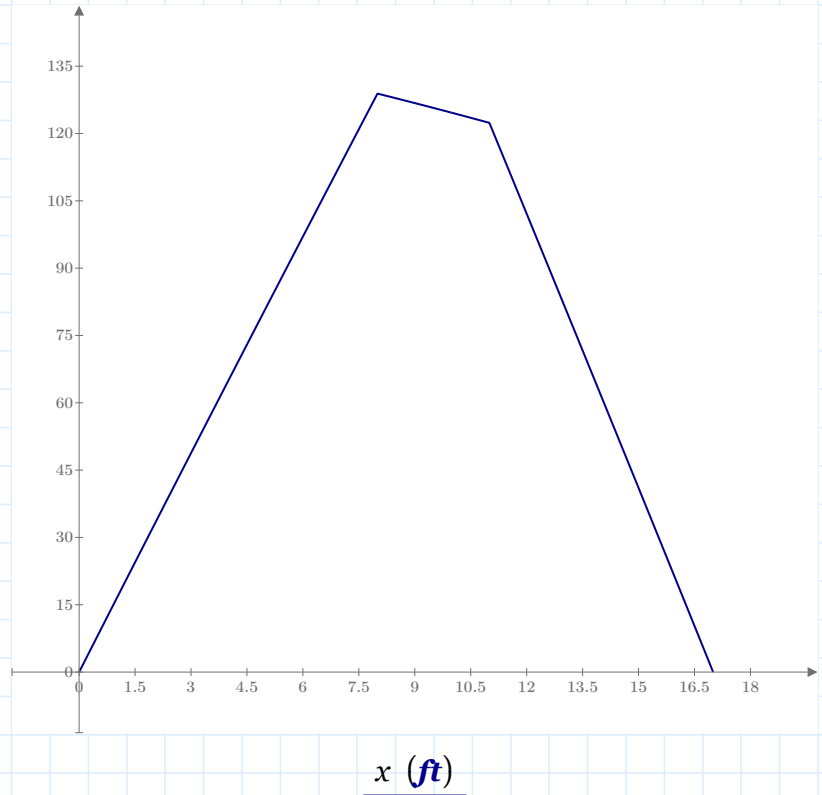


Total Factored Moment

$$M(x) := M_{sw}(x) + M_{LL}(x)$$

Unfactored Service Moment vs
Beam Span Length

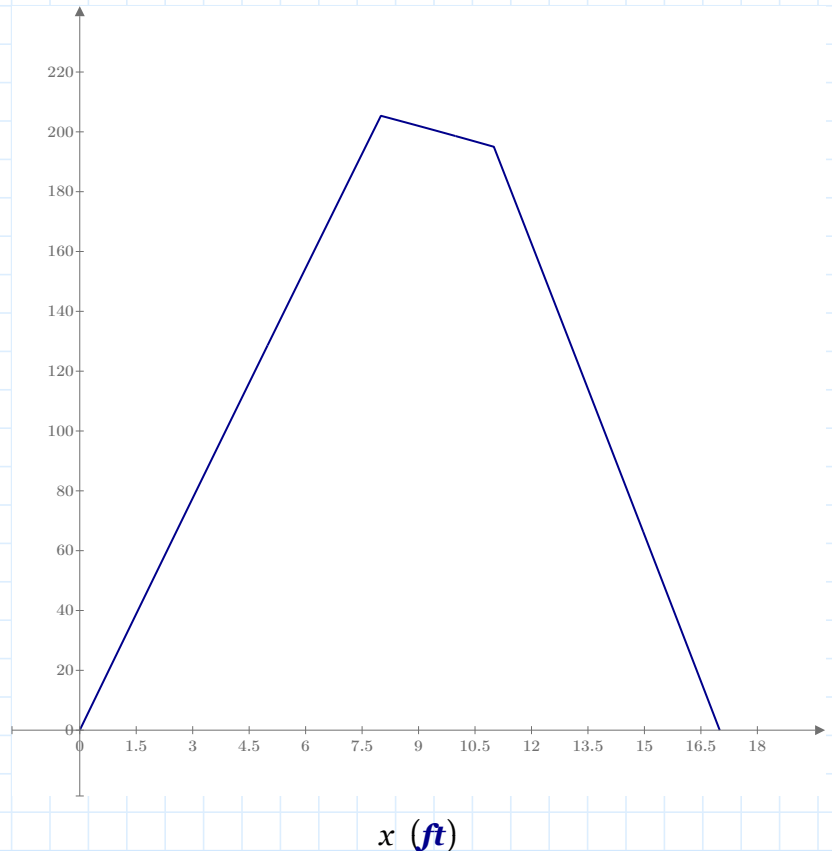
$M(x)$ (kip·ft)



$$M_u(x) := 1.2 M_{sw}(x) + 1.6 M_{LL}(x)$$

Factored Service Moment vs Beam
Span Length

$M_u(x)$ (kip·ft)



LOSSES

Elastic Shortening

$$f_j := 0.75 \cdot f_{pu} = 202.5 \text{ ksi}$$

$$P_j := f_j \cdot A_{ps} \cdot n_{ps} = 61.965 \text{ kip}$$

$$P_{j.ind} := \frac{P_j}{n_{ps}} = 30.983 \text{ kip}$$

$$k_{cir} := 0.9$$

$$k_{es} := 1.0$$

$$M_{midsw} := \frac{w_{sw} \cdot l^2}{8} = 29.136 \text{ kip} \cdot \text{in}$$

$$f_{cir} := k_{cir} \cdot \left(\frac{P_j}{A_{total}} + \frac{P_j \cdot e^2}{I_{total}} \right) - \frac{M_{midsw} \cdot e}{I_{total}} = 1.891 \text{ ksi}$$

$$ES := \frac{E_{ps}}{E_{ci}} \cdot k_{es} \cdot f_{cir} = 14.842 \text{ ksi}$$

Jacking Stress

Jacking Force

Individual Jacking Force per Strand

Elastic Shortening Coefficient

Initial Camber Coefficient

Maximum Moment of the Beam due to Selfweight

Strand Stress at the Strand Centroid

Elastic Shortening

Creep

$$k_{cr} := \text{if}(\lambda < 1, 1.6, 2) = 1.6$$

$$CR := k_{cr} \cdot \left(\frac{E_{ps}}{E_c} \right) \cdot (f_{cir}) = 21.387 \text{ ksi}$$

Shrinkage

$$V_{overs} := \frac{A_{total}}{l_{perim}} = 1.077 \text{ in}$$

$$k_{sh} := 1.0$$

$$SH := 8.2 \cdot 10^{-6} \cdot k_{sh} \cdot E_{ps} \cdot \left(1 \text{ ft} - 0.06 \cdot V_{overs} \right) = 13.946 \text{ ksi}$$

$$\cdot (1 \text{ ft} - 0.06 \cdot V_{overs})$$

$$\cdot (100 - Rel_{hud}) \cdot \frac{1}{\text{ft}}$$

Lightweight/Normalweight Concrete Cracking Coefficient

Concrete Creep

Effective Thickness for Shrinkage

Shrinkage Constant

Concrete Shrinkage

Steel Relaxation

$$K_{re} := 5 \text{ ksi}$$

$$J := 0.04$$

$$C := 1.0$$

$$ju_{ps} := \frac{f_j - ES}{f_{pu}} = 0.695$$

$$C_{ps} := \text{if} \left(ju_{ps} \geq 0.54, \frac{ju_{ps}}{0.21} \cdot \left(\frac{ju_{ps}}{0.9} - 0.55 \right), \frac{ju_{ps}}{4.25} \right) = 0.736$$

$$RE := C_{ps} \cdot (K_{re} - J \cdot (SH + CR + ES)) = 2.202 \text{ ksi}$$

Initial Relaxation Stress

Relaxation Curve Factor

Strand Adjustment Coefficient

Normalized Jacking Stress Factor

Stress Dependent Relaxation Factor

Steel Relaxation

Stress After Losses

$$L_{short} := ES = 14.842 \text{ ksi}$$

$$L_{long} := CR + SH + RE = 37.535 \text{ ksi}$$

$$L_{total} := L_{short} + L_{long} = 52.377 \text{ ksi}$$

$$f_{pi} := f_j - L_{short} = 187.658 \text{ ksi}$$

$$f_{pe} := f_j - L_{long} = 164.965 \text{ ksi}$$

Short Term Losses

Long Term Losses

Total Losses

Initial Stress After Elastic Shortening

Final Stress After Creep, Shrinkage, and Steel Relaxation

Forces After Losses

$$P_i := A_{ps} \cdot n_{ps} \cdot f_{pi} = 57.423 \text{ kip}$$

$$P_e := A_{ps} \cdot n_{ps} \cdot f_{pe} = 50.479 \text{ kip}$$

Prestress Force After Short Term Losses

Prestress Force After Long Term Losses

Elastic Shortening Top Strands

$$f_{jc} := 0.1875 \cdot f_{pu} = 50.625 \text{ ksi}$$

$$P_{jc} := f_{jc} \cdot A_{psc} \cdot n_{psc} = 8.606 \text{ kip}$$

Jacking Stress

Jacking Force

$$P_{j.indc} := \frac{P_{jc}}{n_{psc}} = 4.303 \text{ kip}$$

Individual Jacking Force per Strand

$$k_{circ} := 0.9$$

Elastic Shortening Coefficient

$$k_{esc} := 1.0$$

Initial Camber Coefficient

$$M_{midswc} := \frac{w_{sw} \cdot l^2}{8} = 29.136 \text{ kip} \cdot \text{in}$$

Maximum Moment of the Beam due to Selfweight

$$f_{circ} := k_{cir} \cdot \left(\frac{P_{jc}}{A_{total}} + \frac{P_{jc} \cdot e_c^2}{I_{total}} \right) - \frac{M_{midswc} \cdot e_c}{I_{total}} = 0.372 \text{ ksi}$$

Strand Stress at the Strand Centroid

$$ES_c := \frac{E_{ps}}{E_{ci}} \cdot k_{es} \cdot f_{circ} = 2.919 \text{ ksi}$$

Elastic Shortening

Creep Top Strands

$$k_{crc} := \text{if}(\lambda < 1, 1.6, 2) = 1.6$$

Lightweight/Normalweight Concrete Cracking Coefficient

$$CR_c := k_{cr} \cdot \left(\frac{E_{ps}}{E_c} \right) \cdot (f_{circ}) = 4.206 \text{ ksi}$$

Concrete Creep

Steel Relaxation Top Strands

$$K_{rec} := 5 \text{ ksi}$$

Initial Relaxation Stress

$$J_c := 0.04$$

Relaxation Curve Factor

$$C_c := 1.0$$

Strand Adjustment Coefficient

$$ju_{psc} := \frac{f_{jc} - ES}{f_{pu}} = 0.133$$

Normalized Jacking Stress Factor

$$C_{psc} := \text{if} \left(ju_{psc} \geq 0.54, \frac{ju_{psc}}{0.21} \cdot \left(\frac{ju_{psc}}{0.9} - 0.55 \right), \frac{ju_{psc}}{4.25} \right) = 0.031$$

Stress Dependent Relaxation Factor

$$RE_c := C_{psc} \cdot (K_{re} - J \cdot (SH + CR_c + ES_c)) = 0.13 \text{ ksi}$$

Steel Relaxation

Stress After Losses Top Strands

$$L_{shortc} := ES_c = 2.919 \text{ ksi}$$

Short Term Losses

$$L_{longc} := CR_c + SH + RE_c = 18.282 \text{ ksi}$$

Long Term Losses

$$L_{totalc} := L_{shortc} + L_{longc} = 21.201 \text{ ksi}$$

Total Losses

$$f_{pic} := f_{jc} - L_{shortc} = 47.706 \text{ ksi}$$

Initial Stress After Elastic Shortening

$$f_{pec} := f_{jc} - L_{longc} = 32.343 \text{ ksi}$$

Final Stress After Creep, Shrinkage, and Steel Relaxation

Forces After Losses Top Strands

$$P_{ic} := A_{psc} \cdot n_{psc} \cdot f_{pic} = 8.11 \text{ kip}$$

Prestress Force After Short Term Losses

$$P_{ec} := A_{psc} \cdot n_{psc} \cdot f_{pec} = 5.498 \text{ kip}$$

Prestress Force After Long Term Losses

FLEXURAL CAPACITY

Whitney Stress Block Method

check := if ($f_{pe} \geq 0.5 f_{pu}$, "OK", "NG") = "OK"

$$\rho_r := \frac{A_{ps} \cdot n_{ps}}{t_{fw} \cdot h_{barc}} = 0.003$$

$$\gamma := 0.28$$

$$\beta := \max \left(0.65, \min \left(0.85, 0.85 - 0.05 \cdot \left(\frac{f_c - 4 \text{ ksi}}{1 \text{ ksi}} \right) \right) \right) = 0.66$$

$$f_{ps} := f_{pu} \cdot \left(1 - \frac{\gamma}{\beta} \cdot \left(\rho_r \cdot \frac{f_{pu}}{f_c} \right) \right) = 258.975 \text{ ksi}$$

$$a := \frac{A_{ps} \cdot n_{ps} \cdot f_{ps}}{0.85 f_c \cdot t_{fw}} = 2.171 \text{ in}$$

$$c := \frac{a}{\beta} = 3.291 \text{ in}$$

Minimum Steel Stress Requirement

Prestress Reinforcement Ratio

Prestressing Reinforcement Factor

Whitney Stress Block Depth Factor

Strength to Compute Flexural Capacity

Depth of Whitney Stress Block

Initial Guess; Depth Towards the Neutral Axis

Refine Guess With Strain Compatibility

$$\epsilon_{losses} := \frac{f_{pe}}{E_{ps}} = 5.788 \cdot 10^{-3}$$

$$\epsilon_{decomp} := \frac{P_e}{A_{total} \cdot E_c} \cdot \left(1 + \frac{e^2 \cdot A_{total}}{I_{total}} \right) = 4.395 \cdot 10^{-4}$$

$$\epsilon_{cult} := 0.003$$

$$\epsilon_{stlcrsh} := \epsilon_{cult} \cdot \left(\frac{h_{barc} - c}{c} \right) = 1.523 \cdot 10^{-2}$$

$$\epsilon_{str} := \epsilon_{losses} + \epsilon_{decomp} + \epsilon_{stlcrsh} = 2.146 \cdot 10^{-2}$$

$$f_{ps2} := \text{if} \left(\epsilon_{str} < 0.0085, 28500 \text{ ksi} \cdot \epsilon_{str}, 270 \text{ ksi} \cdot \left(\frac{0.04}{\epsilon_{str} - 0.007} \right) \right)$$

$$f_{ps2} = 267.233 \text{ ksi}$$

$$c_2 := \frac{A_{ps} \cdot n_{ps} \cdot f_{ps2}}{0.85 \cdot f_c \cdot \beta \cdot t_{fw}} = 3.396 \text{ in}$$

$$a_2 := \frac{A_{ps} \cdot n_{ps} \cdot f_{ps2}}{0.85 \cdot f_c \cdot t_{fw}} = 2.24 \text{ in}$$

check := if ($a < t_{ft}$, "OK", "NG") = "OK"

Strain Due to Long Term Losses

Steel Strain From Concrete Elastic Shortening

Concrete Ultimate Strain

Steel Strain At Concrete Ultimate Strain Limit

Combined Prestressed Strand Strain During Failure

Refined Strength to Compute Flexural Capacity

Refined Guess; Depth Towards the Neutral Axis

Refined Depth of Whitney Stress Block

Check to See if Compression Block is Deeper Than Flange Thickness

$$M_n := \text{if} \left(a_2 > t_{ft}, \left(\left(0.85 \cdot f_c \cdot t_{ft} \cdot (b_{fw} - w_w) \cdot \left(\frac{a_2}{2} - \frac{t_{ft}}{2} \right) \right) + A_{ps} \cdot n_{ps} \cdot f_{ps2} \cdot \left(h_{barc} - \frac{a_2}{2} \right) \right), A_{ps} \cdot n_{ps} \cdot f_{ps2} \cdot \left(h_{barc} - \frac{a}{2} \right) \right)$$

$$M_n = 128.893 \text{ kip} \cdot \text{ft}$$

Nominal Moment Capacity

TRANSFER AND DEVELOPMENT LENGTH

Prestress Force Function After Elastic Shortening

$$l_t := \frac{f_{pe}}{3 \text{ ksi}} d_{ps} = 2.291 \text{ ft}$$

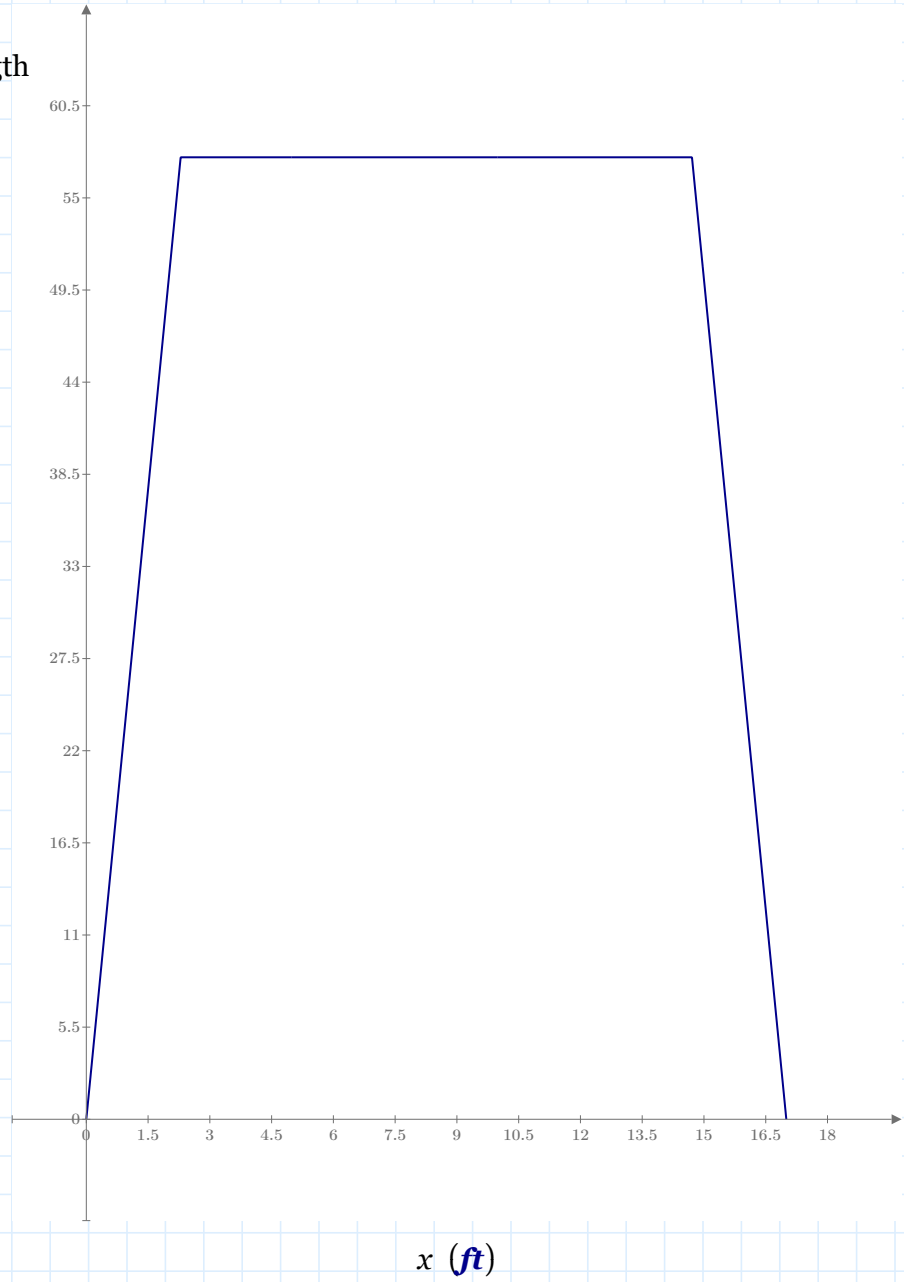
Transfer Length

$$P_i(x) := \text{if} \left(x \leq l_t, \frac{x}{l_t} \cdot P_i, \text{if} \left(l_t < x < l_s - l_t, P_i, P_i - \frac{P_i}{l_t} \cdot (x - (l_s - l_t)) \right) \right)$$

Prestress Force After Elastic Shortening Function (Short Term Losses)

Prestress Force After Elastic Shortening vs Beam Span Length

$P_i(x)$ (kip)



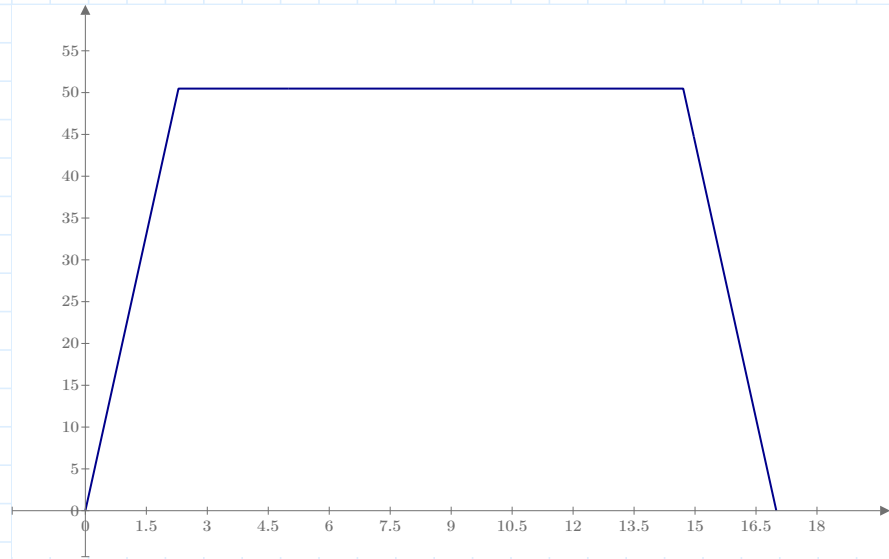
Prestress Force Function After Creep, Shrinkage, and Steel Relaxation

$$P_e(x) := \text{if} \left(x \leq l_t, \frac{x}{l_t} \cdot P_e, \text{if} \left(l_t < x < l_s - l_t, P_e, P_e - \frac{P_e}{l_t} \cdot (x - (l_s - l_t)) \right) \right)$$

Prestress Force After Creep, Shrinkage, and Steel Relaxation Function (Long Term Losses)

Prestress Force After Creep, Shrinkage, and Steel Relaxation vs Beam Span Length

$$P_e(x) \text{ (kip)}$$



$$x \text{ (ft)}$$

Top Strands Prestress Force Function After Elastic Shortening

$$l_{tc} := \frac{f_{pec}}{3 \text{ ksi}} d_{psc} = 0.337 \text{ ft}$$

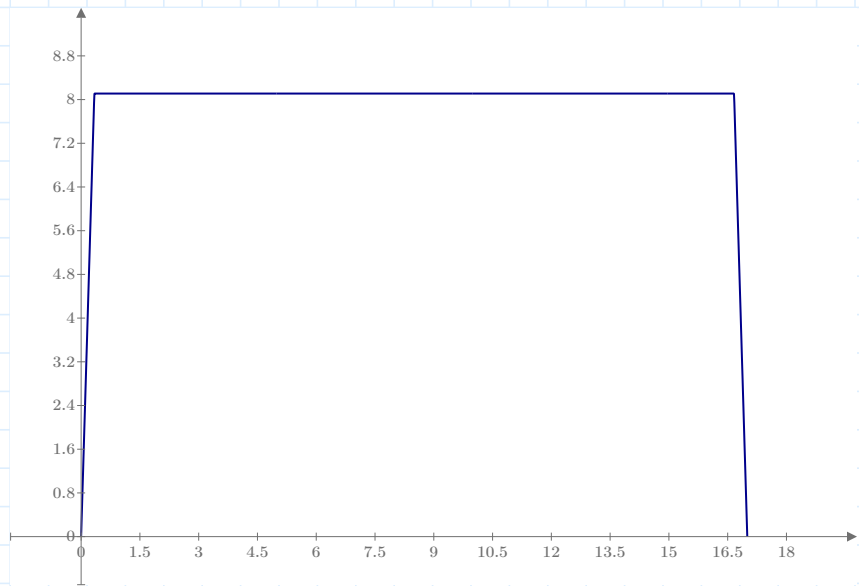
Transfer Length

$$P_{ic}(x) := \mathbf{if} \left(x \leq l_{tc}, \frac{x}{l_{tc}} \cdot P_{ic}, \mathbf{if} \left(l_{tc} < x < l_s - l_{tc}, P_{ic}, P_{ic} - \frac{P_{ic}}{l_{tc}} \cdot (x - (l_s - l_{tc})) \right) \right)$$

Prestress Force After Elastic Shortening Function (Short Term Losses)

Prestress Force After Elastic Shortening vs Beam Span Length

$$P_{ic}(x) \text{ (kip)}$$



$$x \text{ (ft)}$$

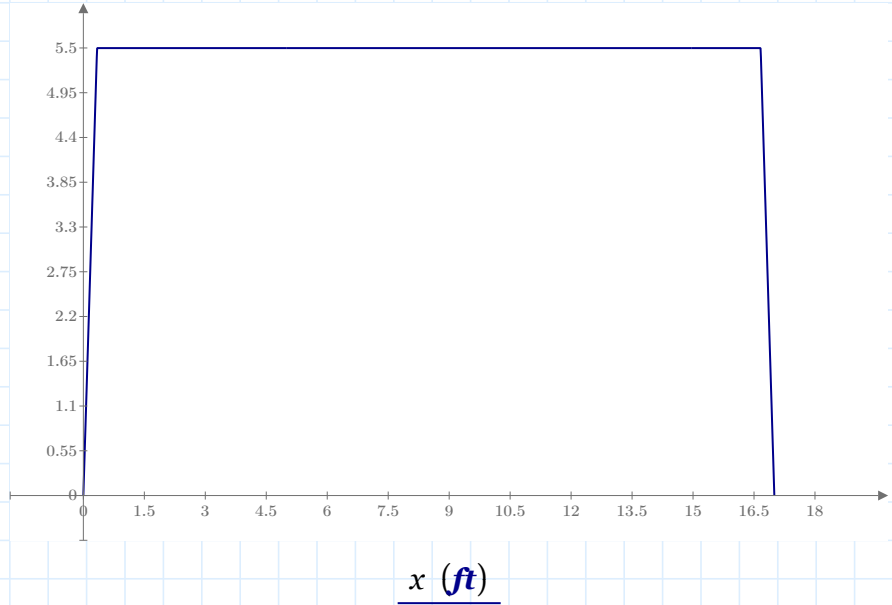
Top Strands Prestress Force Function After Creep, Shrinkage, and Steel Relaxation

$$P_{ed}(x) := \mathbf{if} \left(x \leq l_{tc}, \frac{x}{l_{tc}} \cdot P_{ec}, \mathbf{if} \left(l_{tc} < x < l_s - l_{tc}, P_{ec}, P_{ec} - \frac{P_{ec}}{l_{tc}} \cdot (x - (l_s - l_{tc})) \right) \right)$$

Prestress Force After Creep, Shrinkage, and Steel Relaxation Function (Long Term Losses)

Prestress Force After Creep, Shrinkage, and Steel Relaxation vs Beam Span Length

$P_{ec}(x)$ (kip)



Transfer and Development Length Factor

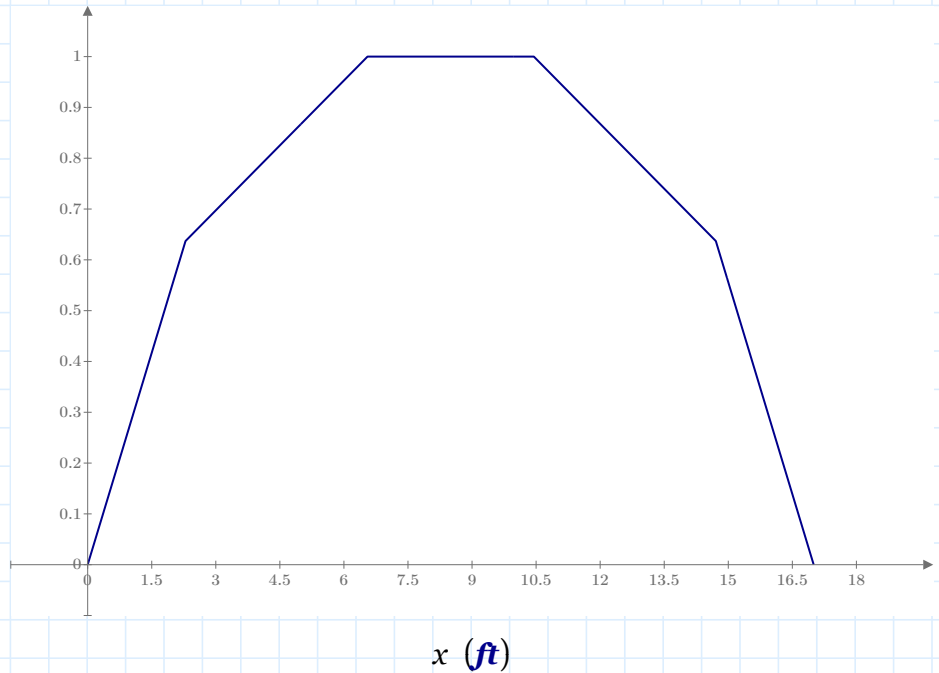
$l_d := l_t + \frac{(f_{ps2} - f_{pe})}{1 \text{ ksi}} d_{ps} = 6.552 \text{ ft}$

Development Length

$$k_{td}(x) := \text{if} \left(x < l_t, \frac{x}{l_t} \cdot \frac{f_{pe}}{f_{ps}}, \text{if} \left(l_t \leq x \leq l_d, \frac{x - l_t}{l_d - l_t} \cdot \left(1 - \frac{f_{pe}}{f_{ps}} \right) + \frac{f_{pe}}{f_{ps}}, \text{if} \left(l_d < x \leq l_s - l_d, 1, \text{if} \left(l_s - l_d < x \leq l_s - l_t, 1 - \frac{x - (l_s - l_d)}{l_d - l_t} \cdot \left(1 - \frac{f_{pe}}{f_{ps}} \right) + \frac{f_{pe}}{f_{ps}}, \frac{x - (l_s - l_t)}{l_t} \cdot \frac{f_{pe}}{f_{ps}} \right) \right) \right)$$

Development Length Factor vs Beam Span Length

$k_{td}(x)$



ALLOWABLE STRESSES

Transfer Stress Limits

$$f_{tTm} := 3 \cdot \sqrt{f'_{ci}} \cdot \sqrt{\text{psi}} = 238.759 \text{ psi}$$

Transfer Tensile Limit at Midspan

$$f_{tTe} := 6 \cdot \sqrt{f'_{ci}} \cdot \sqrt{\text{psi}} = 477.519 \text{ psi}$$

Transfer Tensile Limit at Ends

$$f_{tPCI}(x) := \text{if}(x < 0.25 \cdot l_s, -0.7 \cdot f'_{ci}, \text{if}(0.25 \cdot l_s < x < 0.75 \cdot l_s, -0.6 \cdot f'_{ci}, -0.7 \cdot f'_{ci}))$$

PCI Tension Limit Function

$$f_{tCe} := -0.7 \cdot f'_{ci} = -4433.8 \text{ psi}$$

Transfer Compression Limit at Ends

$$f_{tCm} := -0.6 \cdot f'_{ci} = -3800.4 \text{ psi}$$

Transfer Compression Limit at Midspan

$$f_{tCPCI}(x) := \text{if}(x < 0.25 \cdot l_s, 6 \cdot \sqrt{f'_{ci}} \cdot \sqrt{\text{psi}}, \text{if}(0.25 \cdot l_s < x < 0.75 \cdot l_s, 3 \cdot \sqrt{f'_{ci}} \cdot \sqrt{\text{psi}}, 6 \cdot \sqrt{f'_{ci}} \cdot \sqrt{\text{psi}}))$$

PCI Compression Limit Function

Transfer Applied Stress

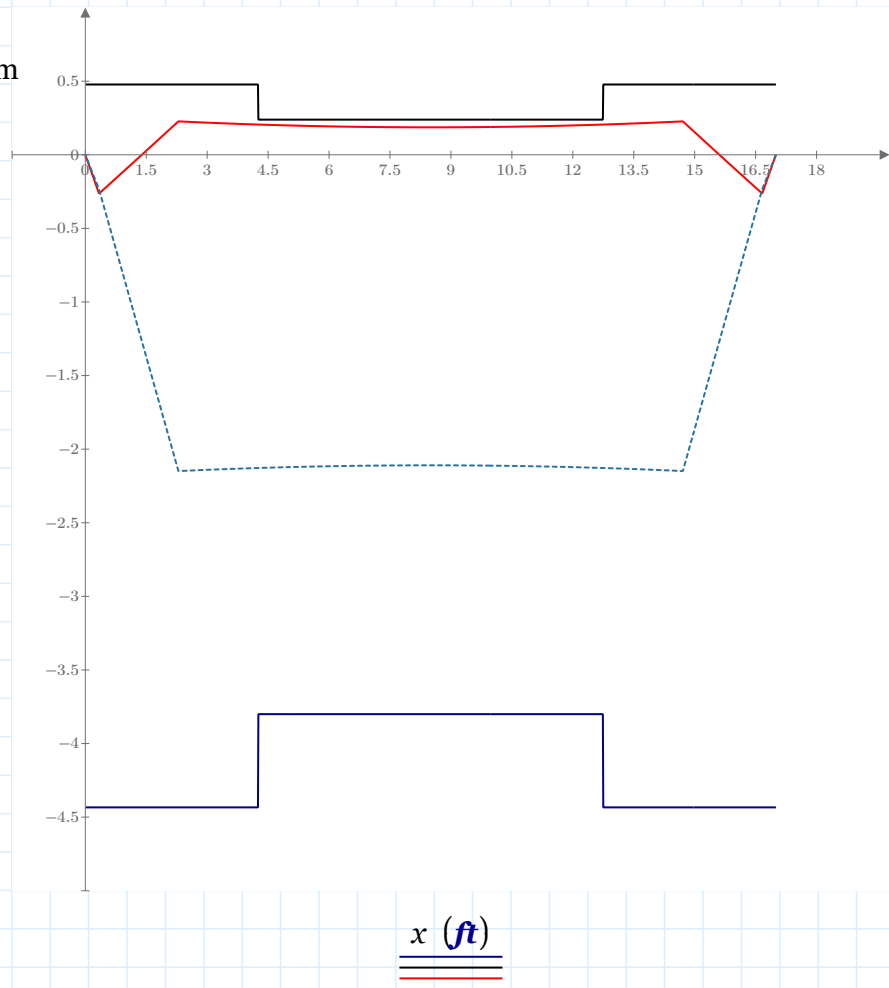
$$f_{tt}(x) := -\frac{P_i(x)}{A_{total}} + \frac{P_i(x) \cdot e \cdot y_{bmtop}}{I_{total}} - \frac{M_{sw}(x) \cdot y_{bmtop}}{I_{total}} - \frac{P_{ic}(x)}{A_{total}} + \frac{P_{ic}(x) \cdot e_c \cdot y_{bmtop}}{I_{total}}$$

Stress at Transfer
Top of Beam

$$f_{tb}(x) := -\frac{P_i(x)}{A_{total}} - \frac{P_i(x) \cdot e \cdot y_{bmbot}}{I_{total}} + \frac{M_{sw}(x) \cdot y_{bmbot}}{I_{total}} - \frac{P_{ic}(x)}{A_{total}} - \frac{P_{ic}(x) \cdot e_c \cdot y_{bmbot}}{I_{total}}$$

Stress at Transfer
Bottom of Beam

Transfer Stress Limits and
Transfer Applied Stress vs Beam
Span Length



Service Stress Limits

$$f_{sT.PCI} := 7.5 \cdot \sqrt{f_c} \cdot \sqrt{\text{psi}} = 0.663 \text{ ksi}$$

Service Tensile Limit

$$f_{sC.PCI} := -0.6 \cdot f_c = -4.685 \text{ ksi}$$

Service Compression Limit

Service Applied Stress

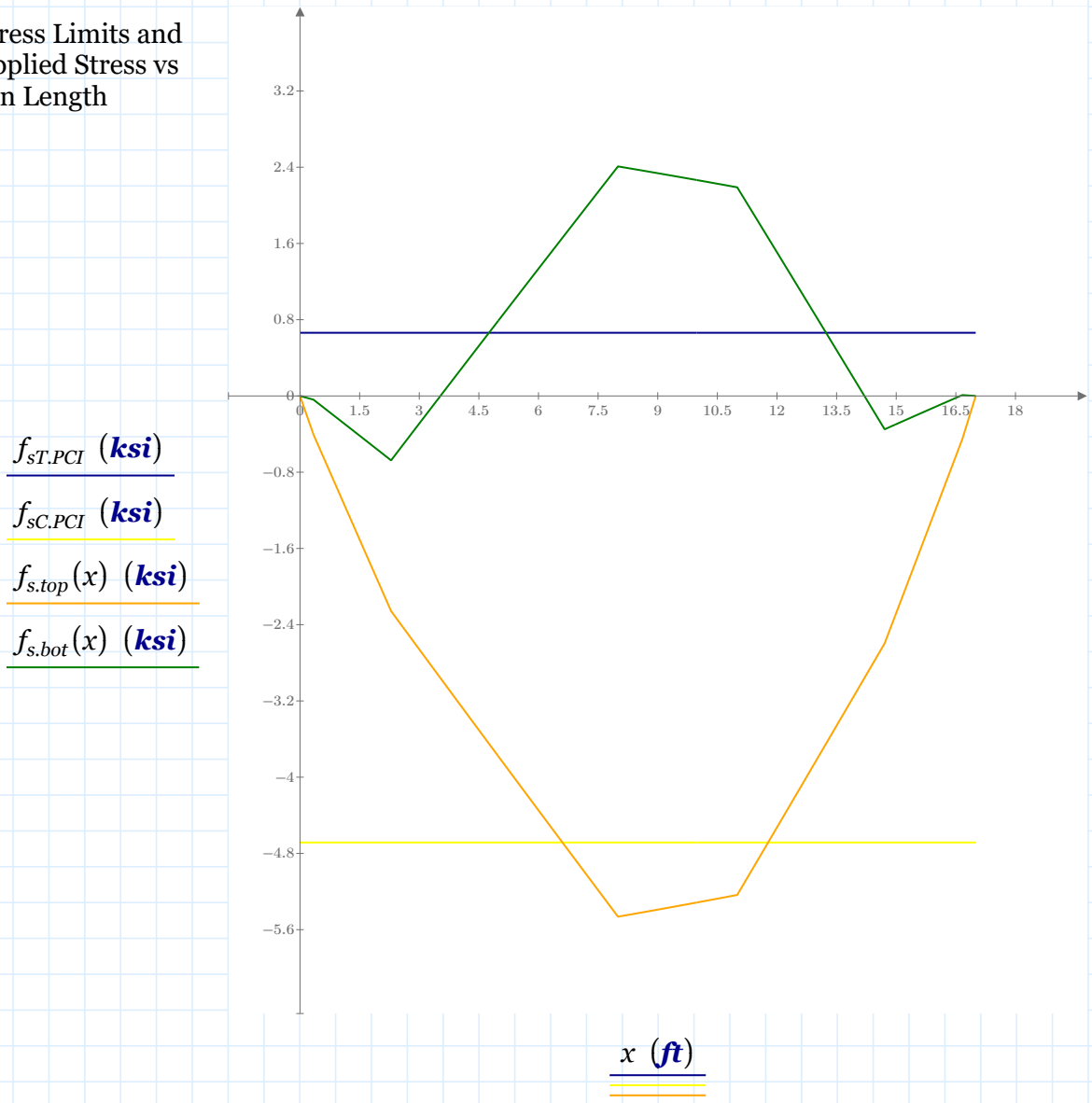
$$f_{s.top}(x) := -\frac{P_e(x)}{A_{total}} + \frac{P_e(x) \cdot e \cdot y_{bmtop}}{I_{total}} - \frac{M_{sw}(x) \cdot y_{bmtop}}{I_{total}} - \frac{M_{LL}(x) \cdot y_{bmtop}}{I_{total}} - \frac{P_{ec}(x)}{A_{total}} + \frac{P_e(x) \cdot e_c \cdot y_{bmtop}}{I_{total}}$$

Applied Stress At Top of Beam

$$f_{s.bot}(x) := -\frac{P_e(x)}{A_{total}} - \frac{P_e(x) \cdot e \cdot y_{bmbot}}{I_{total}} + \frac{M_{sw}(x) \cdot y_{bmbot}}{I_{total}} + \frac{M_{LL}(x) \cdot y_{bmbot}}{I_{total}} - \frac{P_{ec}(x)}{A_{total}} - \frac{P_{ec}(x) \cdot e_c \cdot y_{bmtop}}{I_{total}}$$

Applied Stress At Bottom of Beam

Service Stress Limits and Service Applied Stress vs Beam Span Length



MOMENT CAPACITY

Cracking Moment

$$f_r := f_{sT.PCI} = 662.749 \text{ psi}$$

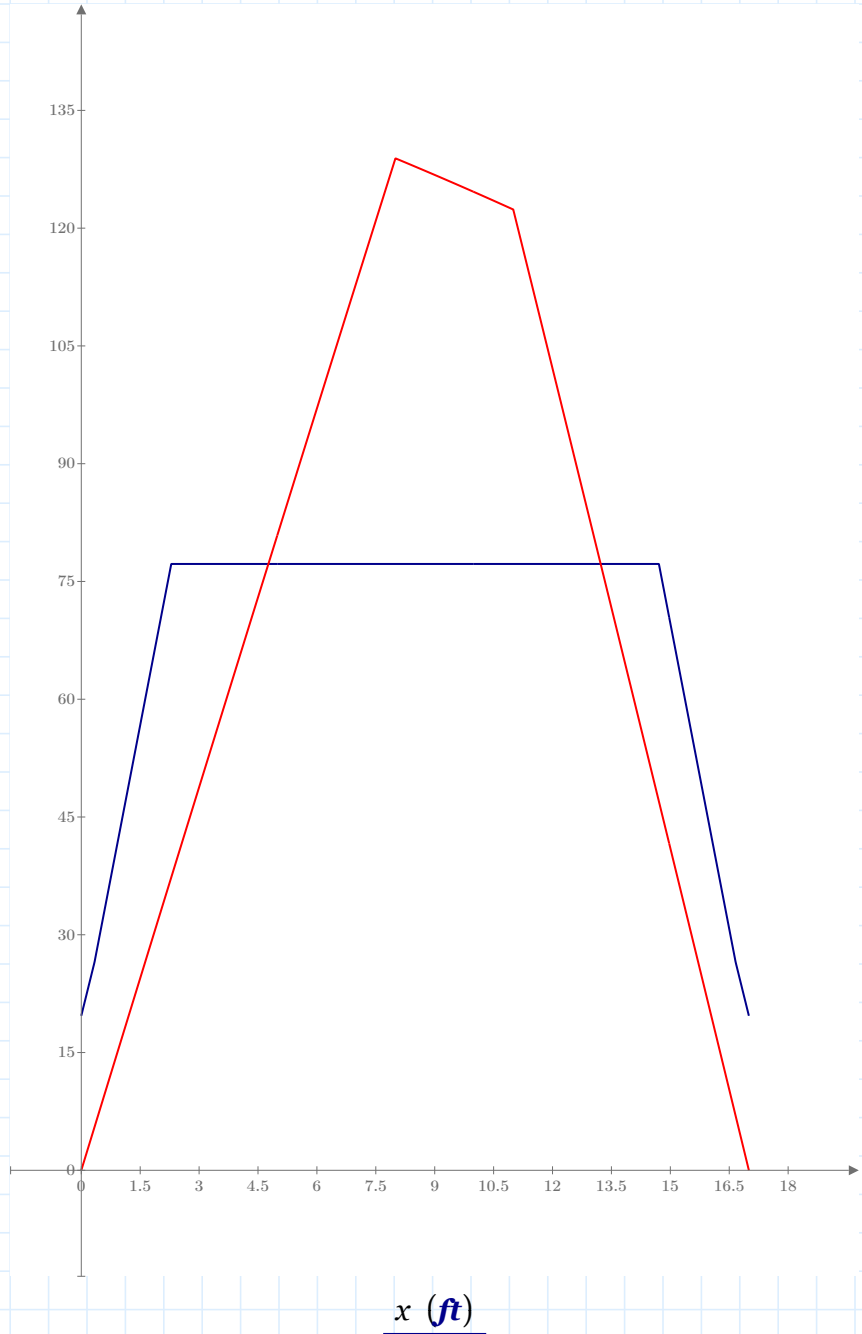
Modulus of Rupture, Based on Cylinder Tests

$$M_{cr}(x) := \left(f_r + \frac{P_e(x)}{A_{total}} + \frac{P_e(x) \cdot e \cdot y_{bmbot}}{I_{total}} \right) \cdot \frac{I_{total}}{y_{bmbot}} + \left(\frac{P_{ec}(x)}{A_{total}} + \frac{P_{ec}(x) \cdot e_c \cdot y_{bmbot}}{I_{total}} \right)$$

Moment to Cause Cracking

Moment to Cause Cracking and Unfactored Moment vs Beam Span Length

$M_{cr}(x)$ (kip·ft)
 $M(x)$ (kip·ft)



`check := if (M(AB) > M_cr(AB), "Crack", "No Crack") = "Crack"`

Check To See If Beam Will Crack When the Unfactored Moment is Applied

Unreduced Nominal Flexural Capacity

$$\Phi := 1$$

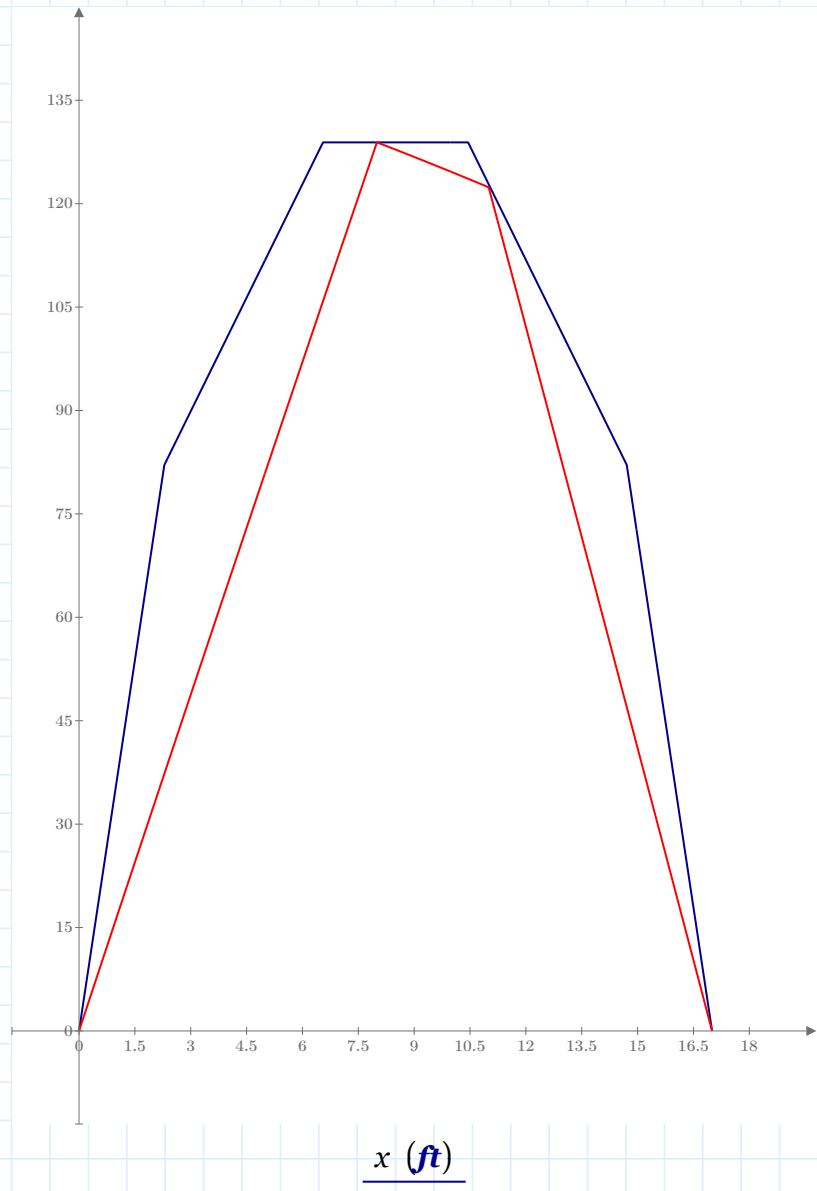
$$\Phi M_n(x) := \Phi \cdot k_{td}(x) \cdot M_n$$

Unreduced Safety Factor

Unreduced Factorized Nominal Flexural Capacity

Unreduced Nominal Flexural Capacity and Unfactored Moment vs Beam Span Length

$$\frac{\Phi M_n(x) \text{ (kip} \cdot \text{ft)}}{M(x) \text{ (kip} \cdot \text{ft)}}$$



Demand Compared to Nominal Flexural Capacity

$$M(AB) = 128.892 \text{ kip} \cdot \text{ft}$$

Critical Unfactored Service Moment

$$\Phi M_n(AB) = 128.893 \text{ kip} \cdot \text{ft}$$

Critical Unreduced Factorized Nominal Flexural Capacity

$$\text{check} := \text{if}(M(AB) \geq \Phi M_n(AB), \text{"Fails"}, \text{"Doesn't Fail"}) = \text{"Doesn't Fail"}$$

Check To See If Beam Will Crack When the Unfactored Moment is Applied

SHEAR CAPACITY

Simplified Shear Method

$$\text{check} := \text{if} (A_{ps} \cdot f_{ps} > 0.4 \cdot A_{ps} \cdot f_{pu}, \text{"OK"}, \text{"NG, Fix"}) = \text{"OK"}$$

$$\Phi := 1$$

$$l_{psdl} := 50 \cdot d_{ps} = 2.083 \text{ ft}$$

Verify Method Validity

Unreduced Safety Factor

Prestressing Strand Development Length

$$\text{check} := \text{if} (V_u(h) \leq 2 \cdot \lambda \cdot \sqrt{f'_c} \cdot \text{psi} \cdot w_w \cdot h + 8 \cdot \sqrt{f'_c} \cdot \text{psi} \cdot w_w \cdot h, \text{"OK"}, \text{"NG"}) = \text{"OK"}$$

Check Section Size Adequacy

$$V_{cstr}(x) := \left(0.6 \lambda \cdot \sqrt{f'_c} \cdot \text{psi} + 700 \cdot \text{psi} \cdot \min \left(\frac{|V_u(x)| \cdot h_{barc}}{|M(x)|}, 1 \right) \right) \cdot w_w \cdot \max (h_{barc}, 0.8 \cdot h)$$

Concrete Shear Strength

$$V_{cmin} := 2 \cdot \lambda \cdot \sqrt{f'_c} \cdot \text{psi} \cdot w_w \cdot h_{barc} = 5.302 \text{ kip}$$

Minimum Concrete Contribution

$$V_{cmax} := 5 \cdot \lambda \cdot \sqrt{f'_c} \cdot \text{psi} \cdot w_w \cdot h_{barc} = 13.255 \text{ kip}$$

Maximum Concrete Contribution

$$V_c(x) := \max (\min (V_{cmax}, V_{cstr}(x)), V_{cmin})$$

Concrete Shear Capacity

Spacing Calculations

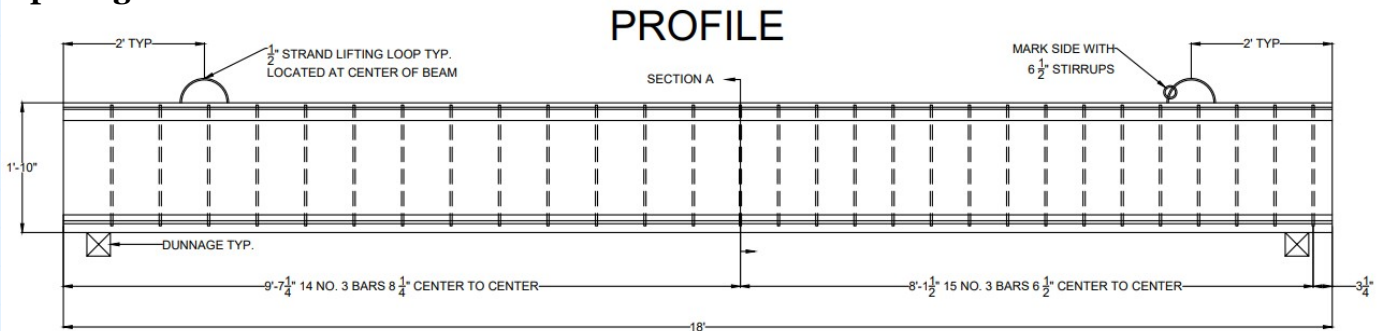


Figure 3: Stirrup Pattern Outlined in Shop Drawings

$$s_1 := 8.25 \text{ in}$$

$$s_2 := 8.25 \text{ in}$$

$$s_3 := 6.5 \text{ in}$$

$$l_{\Delta s1} := s_1 \cdot 11 = 90.75 \text{ in}$$

$$l_{\Delta s2} := l_{\Delta s1} + s_2 \cdot 3 = 115.5 \text{ in}$$

$$l_{\Delta s3} := l - l_{\Delta s2} = 100.5 \text{ in}$$

$$V_{s1} := \frac{A_{stir} \cdot n_{legs} \cdot f_y \cdot h_{barc}}{s_1} = 16 \text{ kip}$$

Steel Shear Strength at Spacing Interval 1

$$V_{s2} := \frac{A_{stir} \cdot n_{legs} \cdot f_y \cdot h_{barc}}{s_2} = 16 \text{ kip}$$

Steel Shear Strength at Spacing Interval 2

$$V_{s3} := \frac{A_{stir} \cdot n_{legs} \cdot f_y \cdot h_{barc}}{s_3} = 20.308 \text{ kip}$$

Steel Shear Strength at Spacing Interval 3

$$s_{cc} := \frac{3}{8} \text{ in}$$

Specified Concrete Cover (ACI 318-19, 20.5.1.3.3)

$$s_{max1} := \text{if} (V_{s1} > 4 \cdot \lambda \cdot \sqrt{f'_c} \cdot \text{psi} \cdot w_w \cdot h_{barc}, \min (0.375 \cdot h, 12 \text{ in}), \min (0.75 \cdot h, 24 \text{ in}))$$

$$s_{max1} = 8.25 \text{ in}$$

Maximum Spacing at Spacing Interval 1

$$s_{max2} := \text{if}(V_{s2} > 4 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} \cdot w_w \cdot h_{barc}, \min(0.375 \cdot h, 12 \text{ in}), \min(0.75 \cdot h, 24 \text{ in}))$$

$$s_{max2} = 8.25 \text{ in}$$

Maximum Spacing at Spacing Interval 2

$$s_{max3} := \text{if}(V_{s2} > 4 \cdot \lambda \cdot \sqrt{f'_c \cdot \text{psi}} \cdot w_w \cdot h_{barc}, \min(0.375 \cdot h, 12 \text{ in}), \min(0.75 \cdot h, 24 \text{ in}))$$

$$s_{max3} = 8.25 \text{ in}$$

Maximum Spacing at Spacing Interval 3

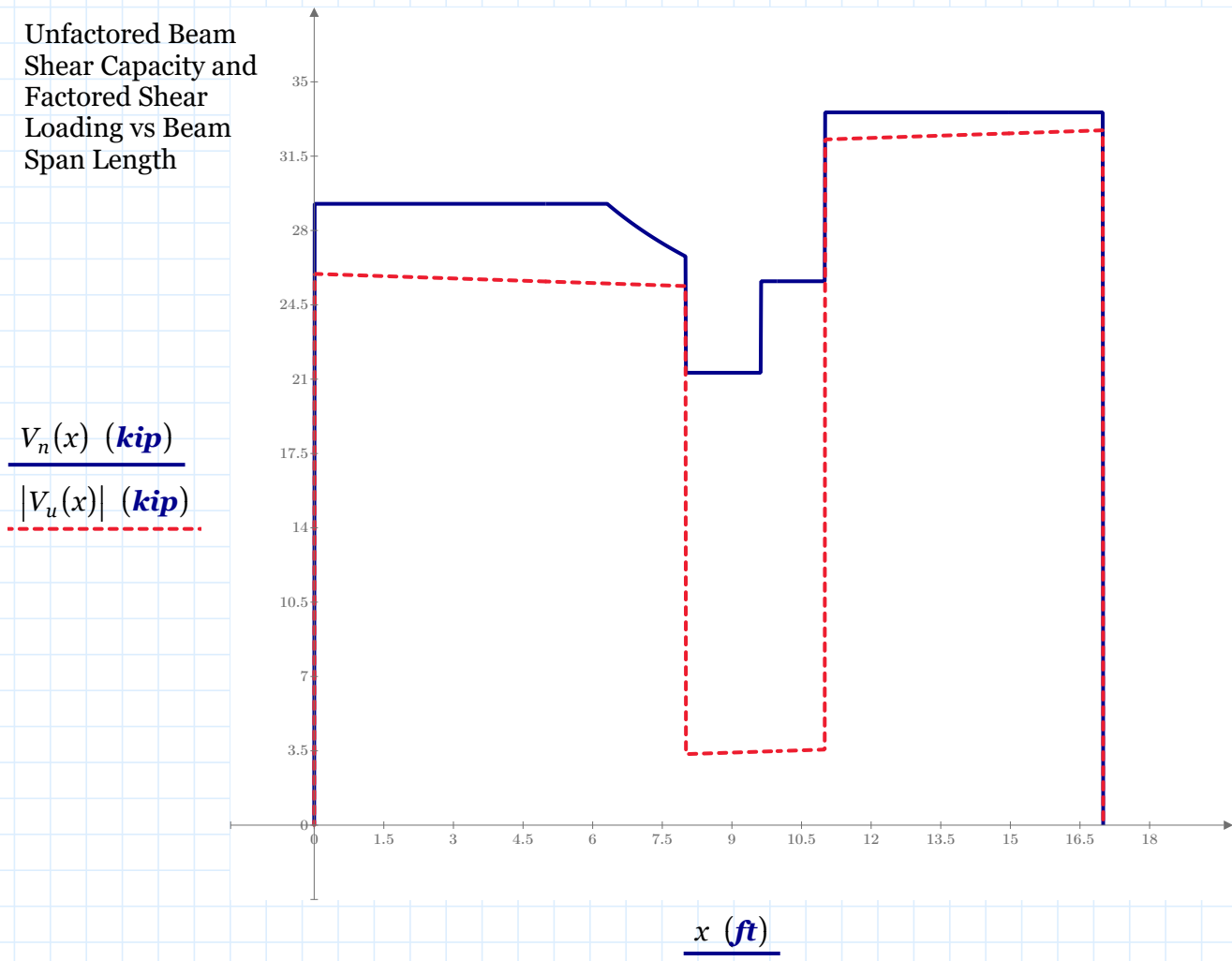
$$A_{vmin} := \min \left(\frac{A_{ps} \cdot n_{ps} \cdot f_{pu}}{80 \cdot f_y \cdot h_{barc}} \cdot \min(s_1, s_2, s_3) \cdot \sqrt{\frac{h_{barc}}{w_w}}, \max \left(0.75 \cdot \sqrt{f'_c \cdot \text{psi}} \cdot \frac{w_w}{f_y}, 50 \text{ psi} \cdot \frac{w_w}{f_y} \right) \cdot \min(s_1, s_2, s_3) \right) = 0.014 \text{ in}^2$$

Minimum Stirrup Area

$$V_n(x) := \text{if}(0 < x \leq l_{\Delta s1}, (V_c(x) + V_{s1}), \text{if}(l_{\Delta s1} < x \leq l_{\Delta s2}, (V_c(x) + V_{s2}), \text{if}(l_{\Delta s2} < x < l_s, (V_c(x) + V_{s3}), 0)))$$

Unfactored Beam Shear Capacity

Unfactored Beam Shear Capacity and Factored Shear Loading vs Beam Span Length



$$\text{check} := \text{if}(V_n(AC) > |V_u(AC)|, \text{"OK"}, \text{"NG"}) = \text{"OK"}$$

Final Maximum Shear Spacing Check

DEFLECTION

Superposition

$$\Delta_{cam} := \frac{-((A_{ps} \cdot n_{ps} \cdot f_{pi}) \cdot l^2 \cdot e)}{8 \cdot E_{ci} \cdot I_{total}} = -0.211 \text{ in}$$

Cambering Deflection

$$\Delta_{sw} := \frac{5 \cdot w_{ship} \cdot l^4}{384 \cdot E_c \cdot I_{total}} \cdot \left(\frac{1}{1 \text{ ft}}\right) = 0.164 \text{ in}$$

Selfweight Deflection

$$\Delta_{p8} := \frac{P \cdot (BC + CD)^2 \cdot AB^2}{3 \cdot E_c \cdot I_{total} \cdot l} = 0.192 \text{ in}$$

Point Load From 8 feet of the Pin Support's Deflection

$$\Delta_{p11} := \frac{P \cdot CD^2 \cdot AB^2}{3 \cdot E_c \cdot I_{total} \cdot l} = 0.085 \text{ in}$$

Point Load From 11 feet of the Pin Support's Deflection

$$\Delta_{tot} := \Delta_{cam} + \Delta_{sw} + \Delta_{p8} + \Delta_{p11} = 0.231 \text{ in}$$

Total Deflection of the Beam

Virtual Work

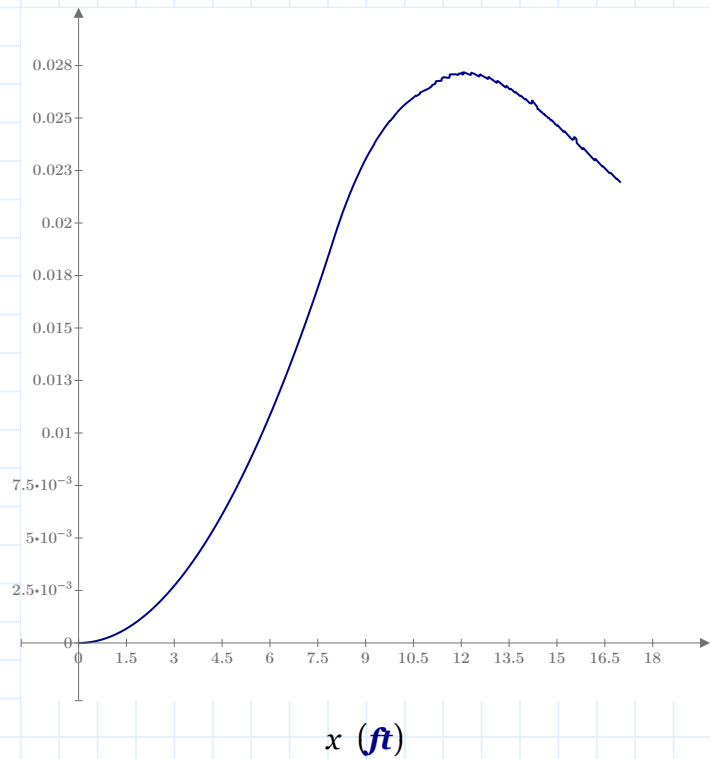
$$m(x) := \text{if}(x \leq AB, 0.5 \cdot x, \text{if}(AB < x < AC, 0.5 \cdot x - 1 \cdot (x - AB), 0.5 \cdot CD - 0.5 \cdot (x - AC)))$$

$$\Delta_{virt} := \int_0^l \frac{m(x) \cdot M(x)}{E_c \cdot I_{total}} dx = 0.374 \text{ in}$$

Total Deflection of the Beam Calculated Through Virtual Work During Service Loading

Deflection of the Beam Calculated Through Virtual Work vs Beam Span Length

$$\frac{\int_0^x \frac{m(x) \cdot M(x)}{E_c \cdot I_{total}} dx}{x} \left(\frac{\text{in}}{\text{ft}}\right)$$



Deflection $\equiv 0.58 \text{ in}$

*Deflection Will Be Calculated More Accurately With a Separate Software

ITERATION CHECKS

Cracking and Breaking Loads

$$M_{cr}(AB) = 77.23 \text{ kip} \cdot \text{ft}$$

Maximum Cracking Moment

$$M_{sw}(AB) = 2.16 \text{ kip} \cdot \text{ft}$$

Maximum Selfweight Moment

$$l_{maxcrack} := \left(\frac{\left(\frac{1}{l_s} (l_s - AB + CD) \right) AB}{2} \right) = 3.5294 \text{ ft}$$

Location of Maximum Cracking Moment

$$P_{crack} := \frac{M_{cr}(AB) - M_{sw}(AB)}{l_{maxcrack}} = 21.27 \text{ kip}$$

Load to Cause Failure in Flexure

$$\text{CrackingLoad} \equiv 21.27 \text{ kip}$$

$$P_{break} := \frac{\Phi M_n(AB) - M_{sw}(AB)}{l_{maxcrack}} = 35.908 \text{ kip}$$

Load to Cause Failure in Rupture

$$\text{BreakingLoad} \equiv 35.908 \text{ kip}$$

$$\frac{M_{cr}(AB)}{M(AB)} = 0.599$$

Unfactored Service Moment vs
Unreduced Nominal Capacity
(Cracking Method Validity Verification)

$$\frac{M(AB)}{\Phi M_n(AB)} = 1$$

Unfactored Service Moment vs
Unreduced Nominal Capacity (Breaking
Method Validity Verification)

COST

MATERIAL COSTS AND BEAM WEIGHT

The following unit cost shall be used to determine the beam cost. Concrete cost is based on actual strength, not design strength.

Material	Cost	Notes/Instructions
Concrete Cost (yd ³):	maximum (\$85 + \$10*(concrete strength, ksi), \$145) / cubic yard	Round concrete strength down to nearest ksi
Ultra-High-Performance Concrete	\$400/yd ³	
Prestressing Strand:		Use estimated lengths used in the beam
¾ in. diameter	\$0.27/ft	
½ in. diameter	\$0.30/ft	
½ in. special	\$0.33/ft	
0.6 in. diameter	\$0.42/ft	
0.7 in. diameter	\$0.55/ft	
Steel:		Use estimated lengths and nominal unit weights in this calculation as provided in the <i>PCI Design Handbook</i>
A615/A706	\$0.45/lb	
Welded Wire (deformed or smooth; for shear)	\$0.60/lb	
Epoxy Coated	\$0.50/lb	
A1035	\$0.70/lb	
Plate Steel	\$0.55/lb	
Forming	\$1.25/ft ² of formwork (include all contact surfaces)	

- There is no need to include cost of steel fabrication, concrete fabrication, curing, inserts, etc. Concrete cost is based on actual strength.
- The beam weight shall be estimated by using the measured unit weight of the concrete or by actually weighing the beam. If the beam weight is estimated, it is estimated based on the gross concrete cross section only, ignoring reinforcement, bearing plates, etc. * Special circumstances or special materials not addressed in these rules must be reviewed by the chair of the committee and/or PCI staff.

Figure 4: Material Costs and Beam Weight per PCI Big Beam Competition 2025-2026

Concrete

$$C_{conc} := \max \left(85 + \frac{10 \cdot \text{in}^2}{\text{kip}} \cdot f_c, \frac{145}{\text{yd}^3} \cdot V_{total} \right) = 163.09 \quad \text{Cost of Concrete in \$}$$

Formwork

$$C_{form} := (l_{perim} - t_{fw}) \cdot l \cdot \frac{1.25}{\text{ft}^2} + A_{total} \cdot \frac{1.25}{\text{ft}^2} = 106.18 \quad \text{Cost of Formwork in \$}$$

Prestressing Strand

$$Cd_{ps} := \text{if} (d_{ps} \geq 0.7 \text{ in}, 0.55, \text{if} (d_{ps} \geq 0.6 \text{ in}, 0.42, \text{if} (d_{ps} \geq 0.5 \text{ in}, 0.3, 0.27))) = 0.3$$

$$Cd_{psc} := \text{if} (d_{psc} \geq 0.7 \text{ in}, 0.55, \text{if} (d_{psc} \geq 0.6 \text{ in}, 0.42, \text{if} (d_{psc} \geq 0.5 \text{ in}, 0.3, 0.27))) = 0.27$$

$$C_{strand} := \frac{Cd_{ps}}{\text{ft}} \cdot l \cdot n_{ps} + \frac{Cd_{psc}}{\text{ft}} \cdot l \cdot n_{psc} = 20.52 \quad \text{Total Cost of Strand in \$}$$

Stirrups

A615/A706

Stirrup Material

$$C_{stir} := n_{stir} \cdot l_{stir} \cdot w_{stir} \cdot \frac{0.45}{\text{lb}} = 9.58 \quad \text{Total Cost of Stirrups in \$}$$

Total Cost

$$C_{total} := C_{conc} + C_{form} + C_{strand} + C_{stir} = 299.37$$

Total Cost of NAU PCI Big Beam 2025-2026's Beam in \$

DollarCost \equiv 299.37



Appendix B: Tpac Mix Designs



TPAC
Architectural and Structural Precast Concrete
An ENCON Company

CONCRETE MIX DESIGN

5-Aug-22

PROJECT NAME: **Various**

JOB #: **Various**

ADOT Project #:

MIX #: **ADOT-SCC-3-2R**

PRODUCT TYPE: **All**

DESIGN STRENGTH:

CONTRACTORS:

INITIAL f_{ci} = 6500-8500 PSI
28 DAY f_c = 9000 PSI

AGGREGATE SOURCE:

MAX. AGG. SIZE: 1/2"
Spread 27" + -3 Optimum 29"
W/C RATIO: 0.3095

FINE: **Maricopa Cemex Plant #41 (CM#0102)**
COARSE: **Salt River Cemex Plant # 11 (CM#0059)**

Self Consolidating Concrete

SSD Batch Weights per Yard			
MATERIAL PER CUBIC YARD	WEIGHT LBS	SP.GR.	VOL C.F.
CEMENT: Type I-II-III /V Arizona Portland Cement	730	3.15	3.71
Cal Portland Rilito 79.8%			
POZZOLAN, CLASS F(fly ash) 20.2%	185	2.20	1.35
Salt River Materials Group, 19th Ave. Phoenix			
AGGREGATE:			
1 WCS Maricopa	1268	2.61	7.79
2 1/2" #7 Coarse Aggregate	1488	2.65	9.00
3			
4			
WATER 34 GAL	283.22	1.00	4.54
EST. AIR 1.00%			0.27
ADMIXTURES: GCP			
1 Advacast 575 Note 1	96 oz 6.87 #	1.1	0.10
2 Recover	15 oz 1.13 #	1.15	0.02
3 Daraset 400	256 OZ. 19.16 #	1.40	0.22
6 Vmar 3 (Type S admixture)	8 oz 0.53 #	1.02	0.01
TOTAL	3981.905 lbs.		27.00 c.f.

Plastic Unit Weight= 147.49 pcf

Recycled Material

Note 1 **Advacast 575 or Glenium 3400 admixture Meets ASTM C 494 requirements for Type A, water reducing and type F, high range water reducer
**Advacast 575 or Glenium 3400 also meets ASTM C 1017 Type 1, Chemical Admixtures for use in producing Flowing Concrete

Submitted by:

Jeff S Grimsley, Quality Control Manager
Level III Prestressed Concrete Institute Certified Inspector # 1813007 Exp 10-23

3052 S. 19th Avenue, Phoenix, Arizona 85009-6926
Phone: 602-262-1360 Fax: 602-262-1374





CONCRETE MIX DESIGN

9-Dec-15

PROJECT NAME: **NAU Test Beam**

JOB #

CONTRACT #:
 PRODUCT TYPE: Beams
 CONTRACTOR:
 AGGREGATE SOURCE:
 FINE: Maricopa Cemex Plant #41 (CM#1312681)
 COARSE: Utelite, Salt Lake City Utah

MIX #: **LW-5**
 DESIGN STRENGTH:
 INITIAL **f_{ci}**= 5,000 psi 3 Day
 28 **f_c**= 8,000 psi
 MAX. AGG. SIZE: 1/2"
 Spread 27" + - 3"
 MAX. W/C RATIO: 0.346

Lightweight

Self Consolidating Concrete

MATERIAL PER CUBIC YARD	WEIGHT LBS	SP.GR.	VOL C.F.
CEMENT: Type II Arizona Portland Cement 70%	730	3.15	3.71
POZZOLAN, CLASS F(fly ash) 30% Salt River Materials, Cholla Power Plant	185	2.20	1.35
AGGREGATE:			
1 WCS Maricopa	1306	2.61	8.02
2 3/8" Expanded Shale (Utelite)	812	1.62	8.03
3			
4			
WATER 38 GAL	317	1.00	5.07
EST. AIR 3.00%			0.81
ADMIXTURES: WR GRACE			
1 Advacast 575**	63 oz.		
2 VmarF-100	24 oz.		
3 Recover	20 oz.		
4			
5 AE 90 Air	5 oz.		
6 Vmar3	10 oz.		
7			
9			
TOTAL	3349.5 lbs.		27.00 c.f.

Plastic Unit Weight= 124.1 pcf

Recycled Material

Pros:

1. Low Unit weight
2. Partially air entrained, reduces cracking with severe temperature changes
3. Good to above average 28 day compression strength for lightweight (6,500 psi anticipated)
4. Dry Unit weight @ 28 day probably between 120-122 pcf
5. Low water cement ratio assist with permeability
6. Easy to place concrete with maximum consolidation
7. Architectural Finish
8. High fire rating

Cons:

1. Low shear values @ transfer and 28 days
2. Specific gravity of lightweight material is unstable
3. Low transfer strengths if proper curing procedures are not used
4. Air entrainment is variable based on temperatures (air and Ambient)
5. Very Rocky Finish on the top, sometimes undesirable
6. Concrete has to be batched under strict supervision

NOTES: **Advacast 575 admixture Meets ASTM C 494 requirements for Type A, water reducing and type F, high range water reducing
 **Advacast 575 also meets ASTM C 1017 Type 1, Chemical Admixtures for use in producing Flowing Concrete



Submitted by:

Jeff S Grimsley, Quality Control Manager
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Appendix C: Software for Deflection Prediction

Geometric Properties

Gross Conc. Trans (n=6.40)

Area (in ²)	66.6	69.1
Inertia (in ⁴)	3823.9	4043.0
y _t (in)	11.2	11.3
y _b (in)	10.8	10.7
S _t (in ³)	341.0	358.1
S _b (in ³)	354.5	377.6

Full Member Properties

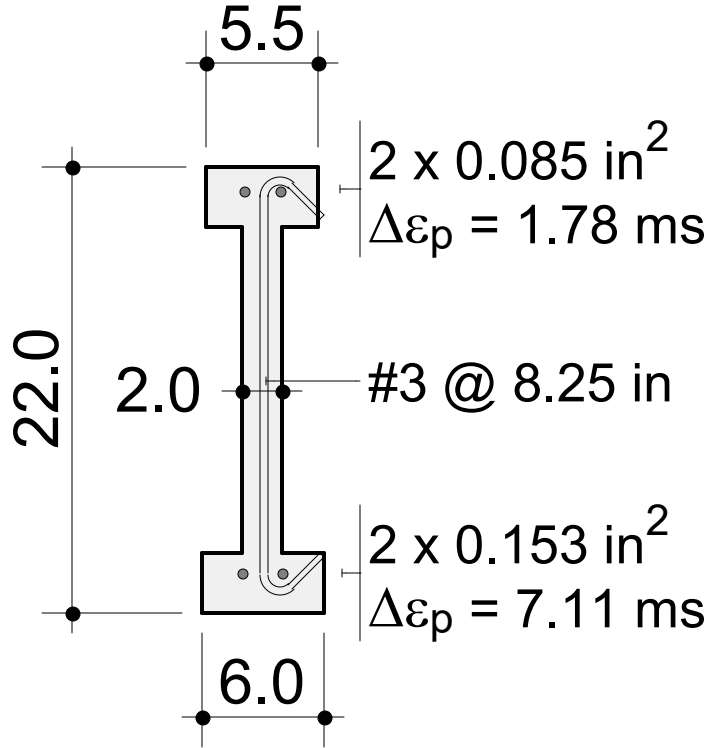
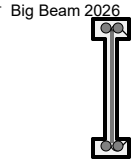
Length: 82.3 in with perfect anchorage

Roller @ 6.3 in (θ=0, Δy≠0) @ 82.3 in

3 Definitions for live load moment diagram

Element Catalog

Number of Elements: 1



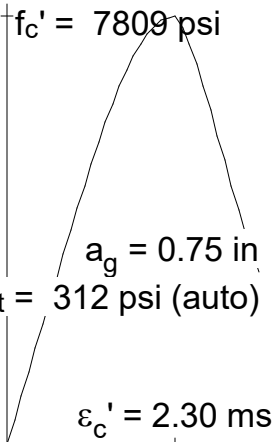
Crack Spacing

$2 \times \text{dist} + 0.1 d_b / \rho$

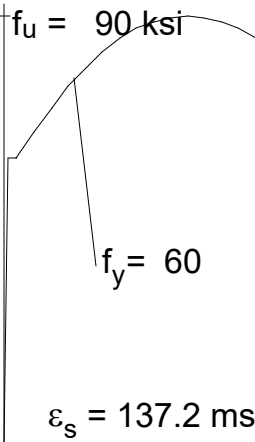
Loading (N,M,V + dN,dM,dV)

0.0 , 0.0 , 0.0 + 0.0 , 0.738 , 0.0

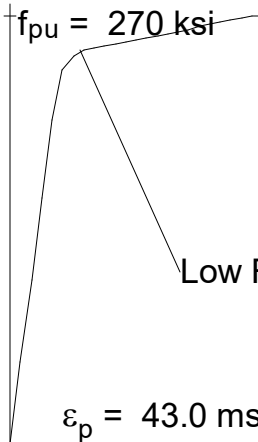
Concrete



Rebar



P-Steel



All dimensions in inches
Clear cover to reinforcement = 0.51 in



Big Beam 2026

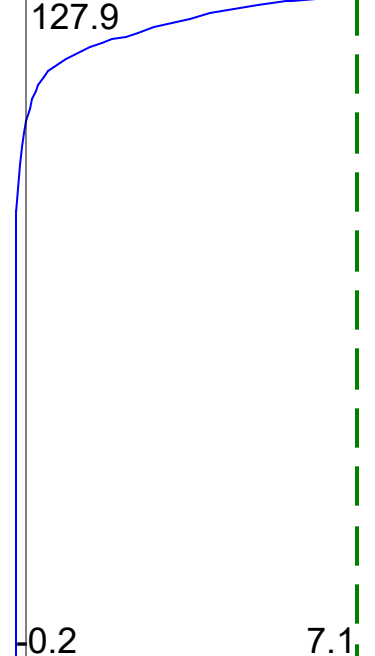
2026/03/20

Response v 1.9.6

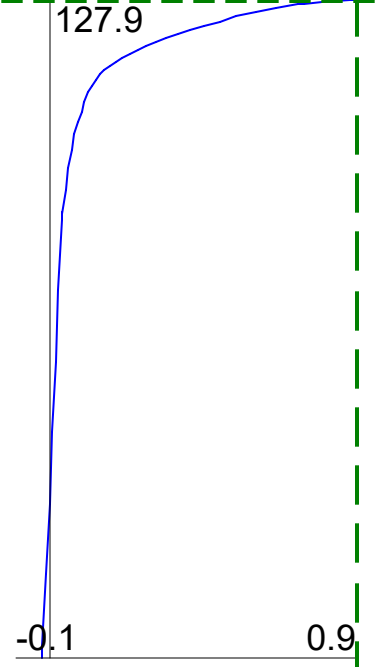
Big Beam 2026

2026/4/23 - 11:13 pm

Control : Moment - ϵ_x



Control : Moment - ϕ



$\epsilon_{x0} = 7.07$ ms

$\phi = 0.87$ rad/ 10^3 inch

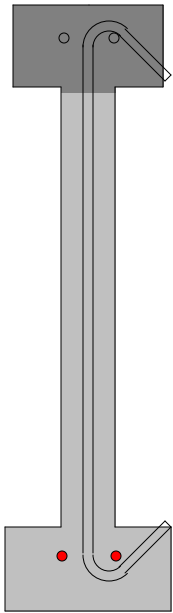
$\gamma_{xy}(avg) = 0.00$ ms

Axial Load = 0.0 kips

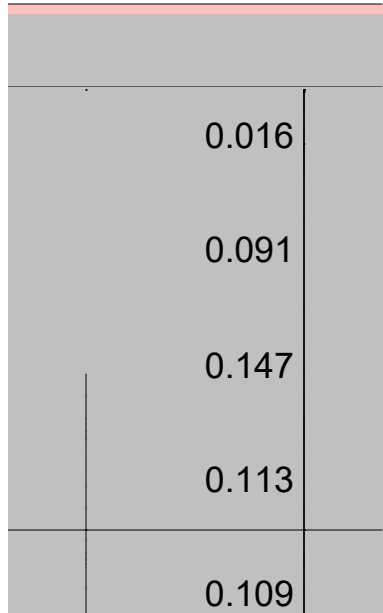
Moment:= 127.9 kip-ft

Shear = 0.0 kips

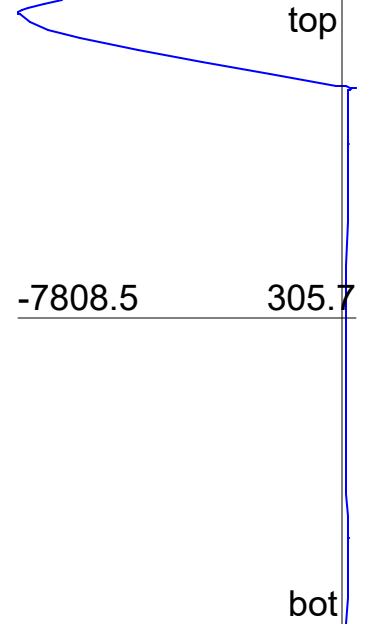
Cross Section



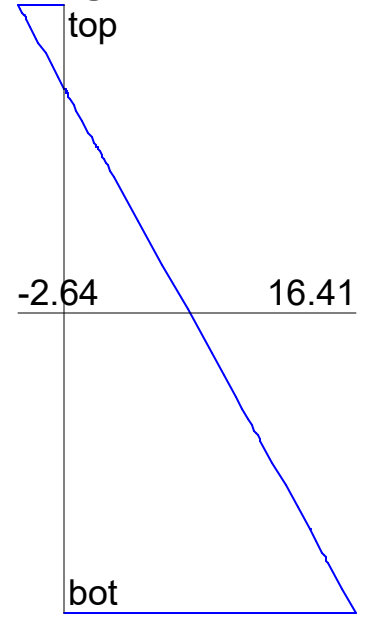
Crack Diagram



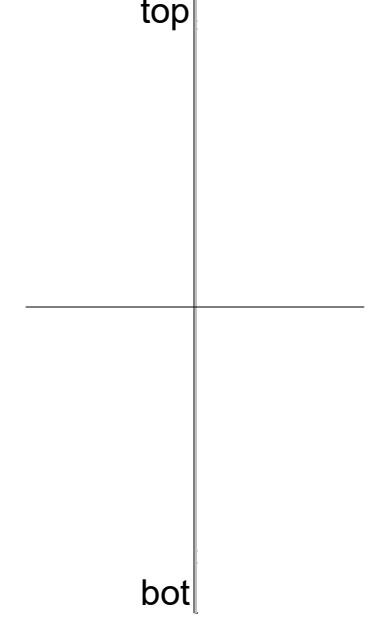
Longitudinal Concrete Stress



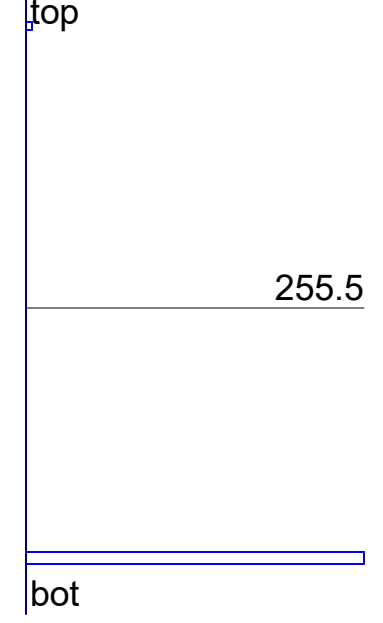
Longitudinal Strain



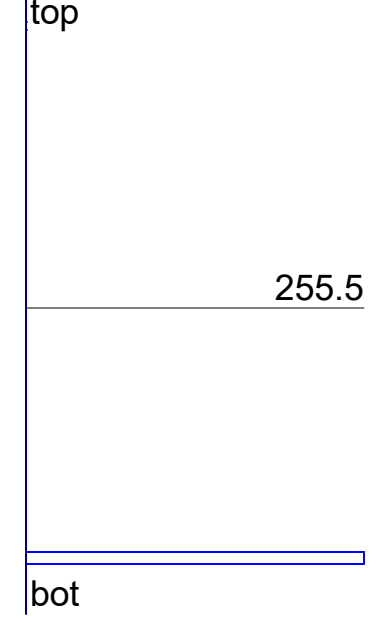
Shrinkage & Thermal Strain



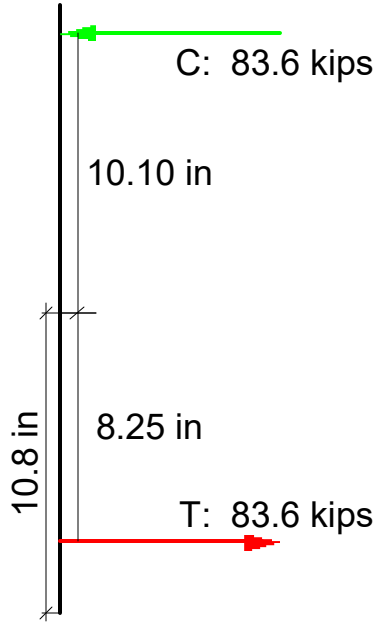
Long. Reinforcement Stress



Long. Reinf Stress at Crack



Internal Forces



N+M

