2025 PCI Big Beam Competition

May 6, 2025

Final Report

Northern Arizona University

Steve Sanghi College of Engineering

Flagstaff, AZ

Team Members:

Beam Dreamers; Payton Correia, Zachary Fukumoto, Isabella Velasco, Caitlin Yazzie

Faculty Advisor:

Dr. Ben Dymond

PCI Producer Sponsor:

Tpac
3052 S. 19th Avenue, Phoenix, AZ 85009

PCI Regional Director:

N/A

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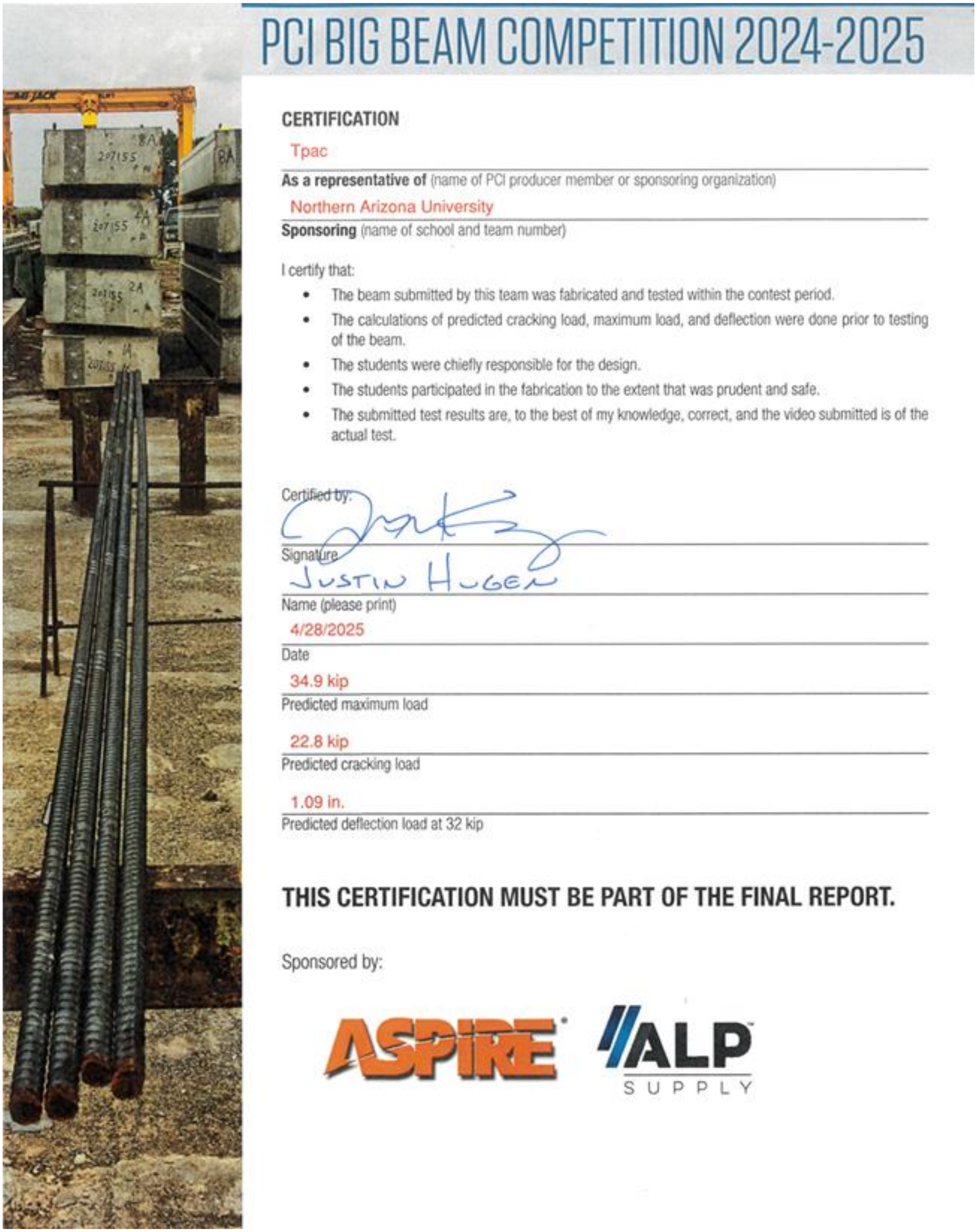


PCI BIG BEAM COMPETITION 2024-2025

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

JUSTIN HUGEN

Name (please print)

4/28/2025

Date

34.9 kip

Predicted maximum load

22.8 kip

Predicted cracking load

1.09 in.

Predicted deflection load at 32 kip

THIS CERTIFICATION MUST BE PART OF THE FINAL REPORT.

Sponsored by:

ASPIRE

ALP SUPPLY

List of Abbreviations

Variable/Abbreviation	Meaning
AZ	Arizona
ASTM	ASTM International, (formerly known as American Society for Testing and Materials)
CY	Cubic Yard
In	Inch
lbs	Pounds
PCI	Precast/Prestressed Concrete Institute
QAQC	Quality Assurance/Quality Control
Tpac	Precast/prestressed concrete manufacturing company located in Phoenix, Arizona; an EnCon United Company

Acknowledgments

We would like to express our sincere gratitude to everyone who has contributed to the success of our PCI Big Beam Competition project.

First and foremost, we extend our appreciation to Tpac, the precast/prestressed concrete producer, for their support and expertise in fabricating our beam. Tpac is in Phoenix, Arizona and is an EnCon United Company. Thank you to the following who contributed to the manufacturing process of the NAU team's beam and allowing us the opportunity to learn from you all.

Table 1: Individuals who contributed to the fabrication of NAU's beam

Individual	Position	Individual	Position
Jason Lien	Tpac/Encon Staff	**Jose Aragon**	Production
Marc Davis	Tpac/Encon Staff	**Jason Aragon**	Production
Elias Fink	Tpac/Encon Staff	**Rodrigo Gutierrez**	Production
Paul Kramer	Tpac/Encon Staff	**Justin Hugen**	Quality Control/Quality Assurance Manager
Paul Press	Tpac/Encon Staff	**Terell Straughter**	Mix Testing
Dane Lind	Tpac/Encon Staff	**Jayce Murillo**	Mix Testing
McKenzie Brooks	Tpac/Encon Staff	**Tim Capaul**	Pre-Inspection
Joshua Tourville	Production Superintendent	**Earl Damper**	Strength Testing
Frank Lujan	Production	**Alec Contreras**	Post Inspection

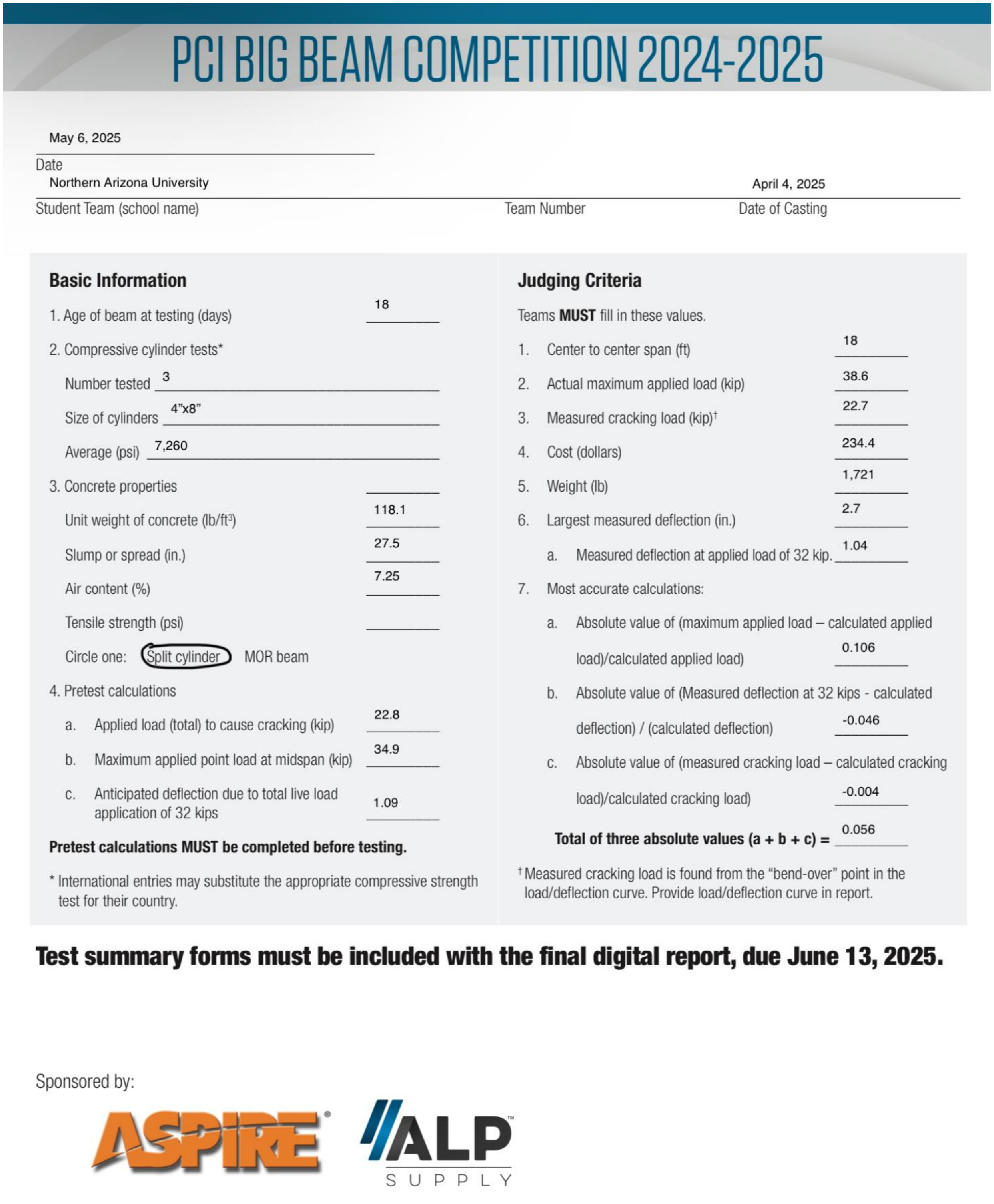
We are also deeply grateful to our technical advisor, Dr. Benjamin Dymond, for the mentorship and technical insights throughout the project. His expertise has been instrumental in helping us navigate the complexities of prestressed concrete design and analysis.

Additionally, we would like to thank Northern Arizona University's Department of Civil and Environmental Engineering for providing the necessary resources and facilities to develop and test our beam. Their support has been essential in bridging the gap between theoretical knowledge and practical application.

Finally, we extend our appreciation to the Precast/Prestressed Concrete Institute (PCI) for organizing this competition and giving us the opportunity to gain hands-on experience in structural engineering and prestressed concrete applications.

This project would not be possible without the collaboration and support of these individuals and organizations. Thank you for your contributions to our learning and success.

1.0 Judging Form



PCI BIG BEAM COMPETITION 2024-2025

Date: May 6, 2025

Student Team (school name): Northern Arizona University

Team Number:

Date of Casting: April 4, 2025

Basic Information

1. Age of beam at testing (days): 18

2. Compressive cylinder tests*

Number tested: 3

Size of cylinders: 4”x8”

Average (psi): 7,260

3. Concrete properties

Unit weight of concrete (lb/ft³): 118.1

Slump or spread (in.): 27.5

Air content (%): 7.25

Tensile strength (psi):

Circle one: [✓ Split cylinder] MOR beam

4. Pretest calculations

a. Applied load (total) to cause cracking (kip): 22.8

b. Maximum applied point load at midspan (kip): 34.9

c. Anticipated deflection due to total live load application of 32 kips: 1.09

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

2. Actual maximum applied load (kip): 38.6

3. Measured cracking load (kip)†: 22.7

4. Cost (dollars): 234.4

5. Weight (lb): 1,721

6. Largest measured deflection (in.): 2.7

a. Measured deflection at applied load of 32 kip.: 1.04

7. Most accurate calculations:

a. Absolute value of (maximum applied load – calculated applied load)/calculated applied load): 0.106

b. Absolute value of (Measured deflection at 32 kips - calculated deflection) / (calculated deflection): -0.046

c. Absolute value of (measured cracking load – calculated cracking load)/calculated cracking load): -0.004

Total of three absolute values (a + b + c) = 0.056

† 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 13, 2025.

Sponsored by:

Figure 1: Completed Judging Form

2.0 Load-Deflection Graph

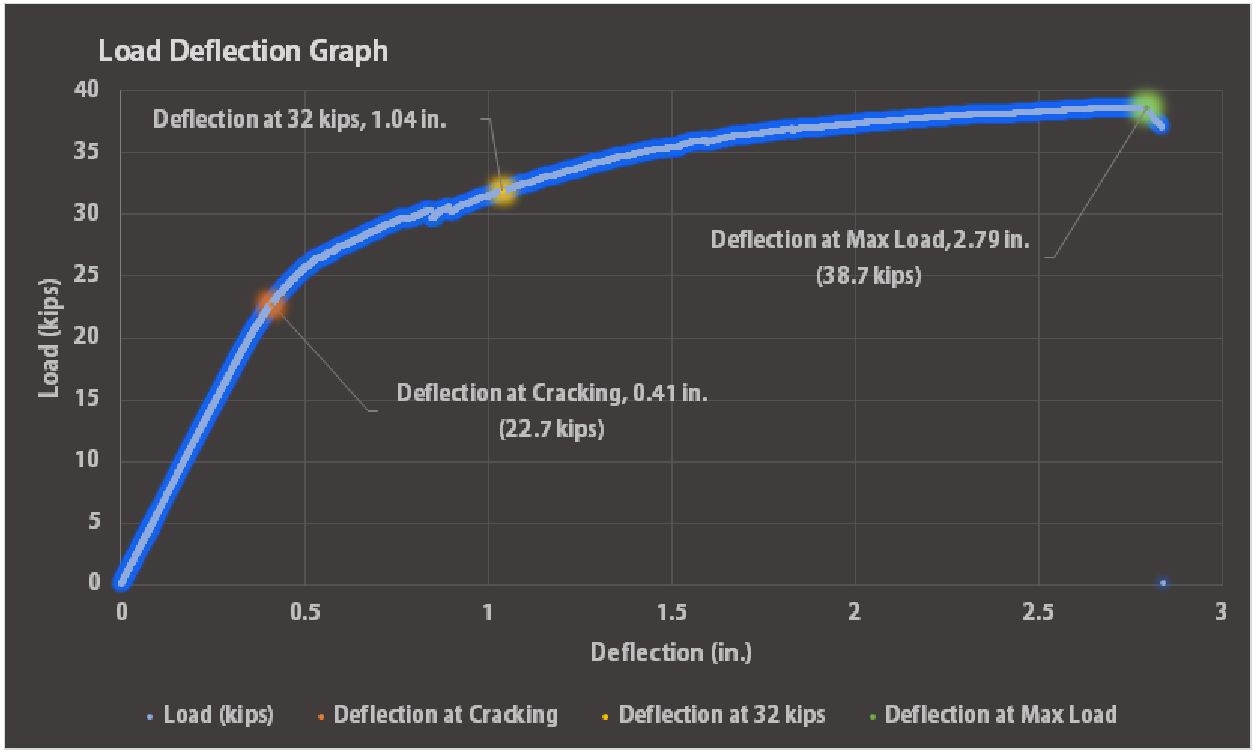
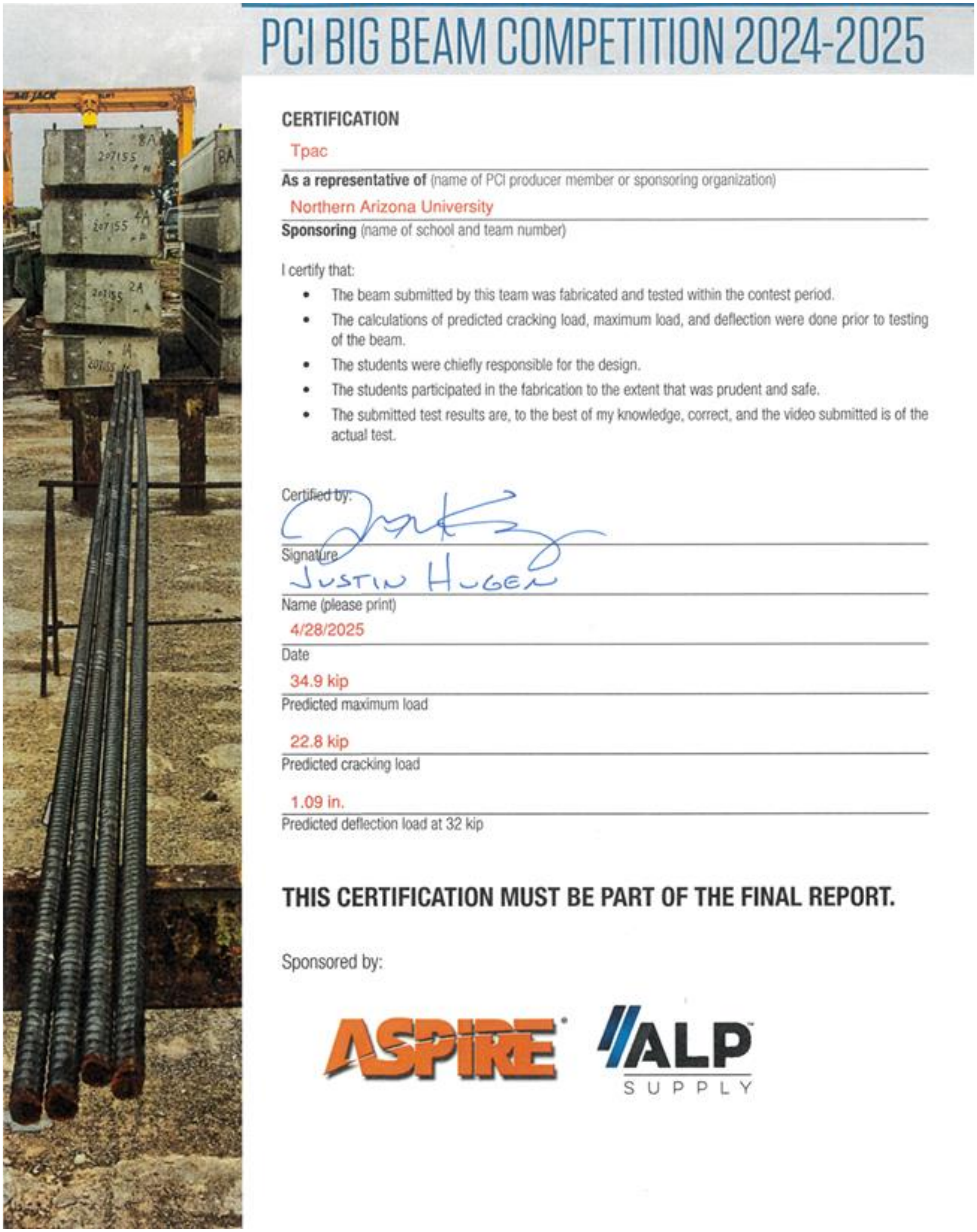


Figure 2: Deflection vs. Loading Graph

3.0 Certification Form



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1.09 in.

Predicted deflection load at 32 kip

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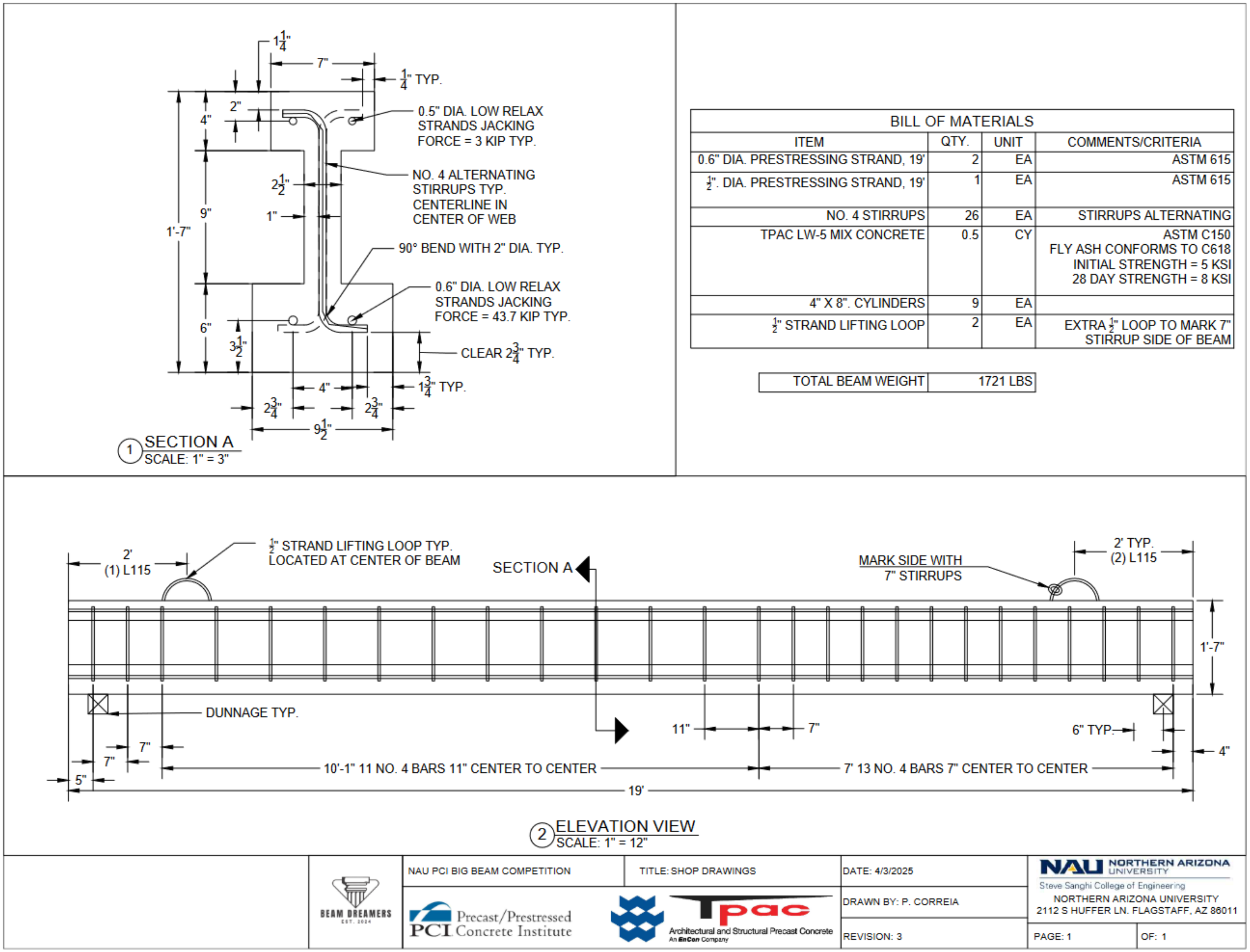
Sponsored by:

ASPIRE ALP SUPPLY

Figure 3: Completed Certification Form

4.0 Shop Drawings



BILL OF MATERIALS

ITEM	QTY.	UNIT	COMMENTS/CRITERIA
0.6" DIA. PRESTRESSING STRAND, 19'	2	EA	ASTM 615
$\frac{1}{2}$". DIA. PRESTRESSING STRAND, 19'	1	EA	ASTM 615
NO. 4 STIRRUPS	26	EA	STIRRUPS ALTERNATING
TPAC LW-5 MIX CONCRETE	0.5	CY	ASTM C150 FLY ASH CONFORMS TO C618 INITIAL STRENGTH = 5 KSI 28 DAY STRENGTH = 8 KSI
4" X 8". CYLINDERS	9	EA	
$\frac{1}{2}$" STRAND LIFTING LOOP	2	EA	EXTRA $\frac{1}{2}$" LOOP TO MARK 7" STIRRUP SIDE OF BEAM

TOTAL BEAM WEIGHT	1721 LBS

Figure 4: NAU Beam Shop Drawings (also located to scale in 0.1.1.1(a)Appendix H)

5.0 Concrete Mixture Analysis

5.1 Statistical Analysis of Mix

Although Tpac offered the team a lightweight and normal weight concrete mix to use for the fabrication of the NAU beam, the team decided to use the lightweight. The lightweight mix has a lower design strength than the normal weight, but the team found that the strength was sufficient to stay within competition requirements and had the benefit of making the beam lighter.

The team also opted to select a mix instead of designing one to take advantage of the higher certainty associated with a robust set of historical data. The full data set can be found in Appendix A. The following table shows a statistical analysis of Tpac’s lightweight mix.

Table 2: Statistical Analysis of Tpac's LW-5 mix (N=30) compared to NAU's test results

			Tpac LW-5 Test Results					
		NAU Test Results	Design Value	Mean	Median	Min	Max	Standard Deviation
Temperature	Air	69	--	72.8	70.0	50.0	93.0	12.4
	Concrete	67	--	96.48	75.0	63.0	91.0	7.92
Unit Weight (pcf)		118	122	125	126	120	130	2.2
Slump (in.)		27.5	27 ± 3 in	28.2	28.5	24.0	30.3	1.8
Air (%)		7.25	7.25	6.72	6.30	3.50	9.20	1.39
Age at Release		3	--	13	14	2	38	6.95
Compressive Strength	Release	5,080	5,000	5,400	5,370	4,160	7,690	896
	At Test	7,260	--	9,140	8,990	7,866	11,050	788

In Phoenix, Arizona, the temperatures can reach above 110 °F consistently, so the large range of concrete and air temperatures is not surprising. Curing temperatures lower than average may have delayed the setting time or reduced the strength, as the cement hydration reaction slows in lower temperatures; however, as the temperatures were not below freezing the effect would have been small.

Additionally, the air percentage is higher than average, and the unit weight is the lowest achieved with this mix; this led to an overall lighter beam. The average strength of this mixed design is higher than the design strength; extra strength will be helpful during the testing phase.

5.2 Mix Design

The above design elements are possible via the mix design data in Table 3 below.

The admixture data sheets for the lightweight mix can be found in Appendix B, and shows they meet ASTM C494 per the 2024-2025 PCI Big Beam rules [1]. Additionally, the records for the aggregates and pozzolans used in the concrete mix can be found in Appendix B and verify they meet ASTM standards per the rules.

Table 3: Lightweight mix design compared to actual mix

		Theoretical	Actual	Difference
Material	Type	lbs	lbs	
AZ Portland Cement	Type I-II-III/V	730	762.5	4.4%
Pozzolan Class	Class F (Fly Ash)	185	195	5.3%
Aggregate	WCS Maricopa	1286	1280	0.5%
	3/8" Expanded Shale (Utelite)	823	815	1.0%
Water	City Water	56 gal	56 gal	0%
Admixtures	Proprietary name	fl oz	fl oz	
Water Reducer	ADVA Cast 575	84	84	0%
Viscosity Modifier	V-MAR F-100	24	24	0%
Hydration stabilizer	RECOVER	20	19.5	2.5%
Rheology-Modifier	V-MAR 3	10	10	0%
Set Accelerator	Daraset 400	128	126	0%
Air Entrainer	Daravair 1000	15	15	0%

5.3 Concrete Cylinder Results

The team requested 9 test cylinders during the beam fabrication in order to attain accurate information on the specific concrete batch for the NAU beam, The compressive concrete strength was calculated using ASTM C39 [2], and the tensile strength was calculated using ASTM C496. The test cylinder data is shown in , and the test cylinder breaks are shown in Figure 5.

Table 4 below, and the test cylinder breaks are shown in Figure 5.

Figure 5: Cylinder Test Breaks with dates and labels corresponding to Table 5

Table 4: NAU Test Cylinder Results

	Test Date	**Compressive strength (PSI)**
1	4/22/25	7,000
2	4/28/25	7,120
3	4/28/25	7,390
Value used in predictions	--	7,260

5.4 Concrete Mixture Evaluation

Based on the statistical analysis in Section 5.1 Statistical Analysis of Mix and similarity of the NAU cylinder data to other mix's, the team decided on using the average of the second and third test cylinder results.

6.0 Structural Design Analysis

6.1 Preliminary Design

The loading configuration for the 2024-2025 Big Beam Competition is shown in Figure 6 with applied load, 2P, between the two-point loads [1].

The beam must crack with applied load, 2P, between 20 and 32 kips and fail between 32 and 40 kips. The goal is to produce a design to maximum deflection, minimize cost, and minimize weight while also meeting these constraints for cracking and failure capacity. The beams in the competition are assessed against one another for these categories by linear interpolation between the best and worst value [1]. The team is also awarded points based on the accuracy of calculation, report quality, and practicality, innovation, compliance with code, and display of good engineering judgement.

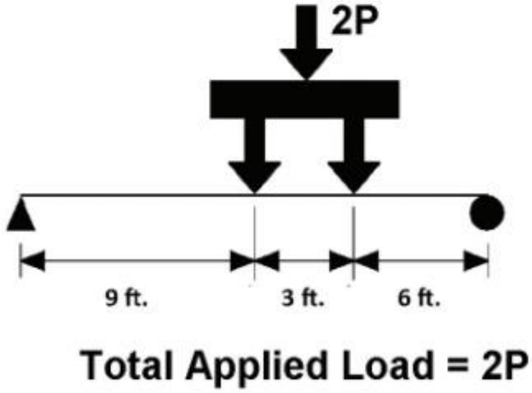


Figure 6: Loading Configuration

While both a lightweight and normal weight mix design were considered, the team also kept in mind that the beam would be judged on weight, so the final designs used lightweight concrete.

The design considerations are outlined in Appendix C. The calculations were completed in Mathcad [3] and are shown in Appendix D.

Deflection was calculated two ways; for the purposes of the decision matrix and ease of comparing multiple designs, the team calculated deflection using standard ACI 318-19 equations. Then, for the final predictions, deflection was verified using Response-2000 curvature and moment data and the method of virtual work for analysis.

6.2 Decision Matrix

An iterative design process was performed to create a variation of designs fitting the competition criteria, then ranked using a decision matrix to optimally select the best performing beam. Each design ranked is shown in Appendix E. From this the team refined these designs by choosing the attributes that preformed best and applying them when making new designs; for example, having the top flange have a width of seven inches. Design four and five are refined from the best three designs.

These four cross-sections, shown in Appendix E, were selected from an initial pool of nine cross-sections. Five were eliminated from that preliminary pool based on criteria such as predicted cracking and breaking loads being too close to competition limits, excessive self-weight, and higher predicted cost.

Below is the decision matrix with all five designs ranked based on the three categories.

Table 5: Decision Matrix Initial Score

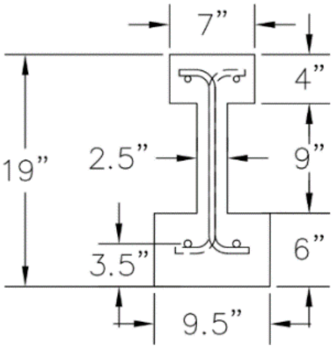
Design	**Criteria**						**Initial Score (max: 3)**
	Weight (lbs)		Deflection (in)		Cost ($)		
	Value	Score	Value	Score	Value	Score	
1	1759	0.74	0.113	0.56	236.3	0	1.30
2	1849	0.13	0.117	0.72	234.4	0.50	1.35
3	1721	1	0.099	0	234.4	0.50	1.50
4	1868	0	0.124	1	232.5	1	2
5	1721	1	0.117	0.72	234.4	0.50	2.22

To account for penalization if the beam cracks or breaks close to the specified limits, the team developed a performance multiplier system to encourage predictions that remained towards the middle of the cracking range (at 26 kips), and the breaking range (36 kips). This approach added a factor of safety to the designs, as even if the team's calculations were not accurate, the risk of further penalties was reduced. The scores altered by the performance multipliers are shown in Appendix E, and the process for selecting the performance multiplier for the cracking and breaking load is shown in

6.3 Design Selection

Shear spacing was not a factor on the teams' decision matrix because it would be roughly the same for all designs. Since one of the main design goals was to keep the beam as light as possible the web had room for only one stirrup leg.

The remaining four designs were refined through further analysis and comparison to improve structural efficiency and performance. Among all four designs, Design 4 had the lowest weight because it included only three prestressing strands, whereas the other designs used four.



When coordinating with Tpac regarding the shop drawings, the original stirrup design was not constructable as it had multiple different bend angles; additionally, the clear cover was excessive. Tpac helped the team better understand stirrup construction and detailing. As a result, the team decided to add another prestressing strand to hold the stirrup and reduced the height of the bottom flange. This led to design 5 (Figure 7).

Figure 7 (left): Design 5, chosen for production

7.0 Beam Fabrication & Testing

7.1 Certification of Materials

Per the competition rules, all materials must be fit to use per ASTM standards. The plant certification that the steel meets applicable ASTM codes is shown in Appendix A.

7.2 Fabrication

On March 4th, 2025, the team went to the Tpac plant in Phoenix, AZ, to oversee fabrication after communicating about the design via AutoCAD drawings.

Figure 8: Formwork with stirrups and prestressing strands

As seen in the photos below, the formwork dimensions, stirrup spacing, and all other measurements were verified to be accurate according to the shop drawings (shown in
Figure 4 and Appendix H).

Figure 9: Top flange

Figure 10: 11 in. stirrup spacing

Figure 11; 7 in. stirrup spacing

As seen in the shop drawings in Section 4.0, the stirrups were spaced differently to reduce the cost and amount of stirrups required, as the shear demand varies based on location. The stirrups have one leg extending the length of the web, with bends so that the stirrups are held in place by the prestressing strands throughout the concrete pour. A sample stirrup is shown in Figure 12.

Figure 12: Stirrup sample

Due to the difference in stirrup spacing, the team needed a way to ensure the beam was aligned properly to withstand the loading. To keep track of what side has the 7-inch stirrup spacing Tpac placed two lifting loops on the corresponding side, also putting a in house fabrication identifier on the same die.

Figure 13 (left): Double lifting loop identifying side with 7 in. stirrup spacing

Figure 14 (right): Single lifting loop identifying side with 11 in. stirrup spacing

After verification that the measurements were correct, Tpac's LW-5 concrete mix was made at a batch plant on site. Preliminary tests of were conducted to verify quality. The spread test (shown in Figure 15 below) tested the flowability of the concrete mix and determine whether the in-situ concrete mixture was consistent with the mixture design.

Figure 15 (left): Spread Test set up

Figure 16: Spread Test results

The spread test showed that the concrete batch was very workable as it had an even radius. Tpac also tested the percentage of air in the freshly mixed concrete to determine the unit weight. Figure 17 below shows the values of these tests and resulting unit weight of the concrete.

Table 6: Spread Test Results

Category	Test Results	Design Values
Spread	27.50 in	27 ± 3 in.
Estimated air	7.25%	3%
Unit weight	118.1 pcf	124.1 pcf

Once the tests were completed and concrete quality was verified, the concrete was ready to be poured. Nine concrete cylinders, labeled NAU (shown in Figure 17), were poured so that the team could test the concrete's compressive and tensile strength (results are shown in Section 5.3 Concrete Cylinder Results). The cylinders were poured from the same batch, cured in the same conditions, and tested before the Big Beam test to ensure accuracy of results.

Figure 17: Fabricated test cylinders in molds

Throughout the pour, Tpac production employees (Figure 18) ensured there were no air bubbles and that the concrete filled in the formwork completely.

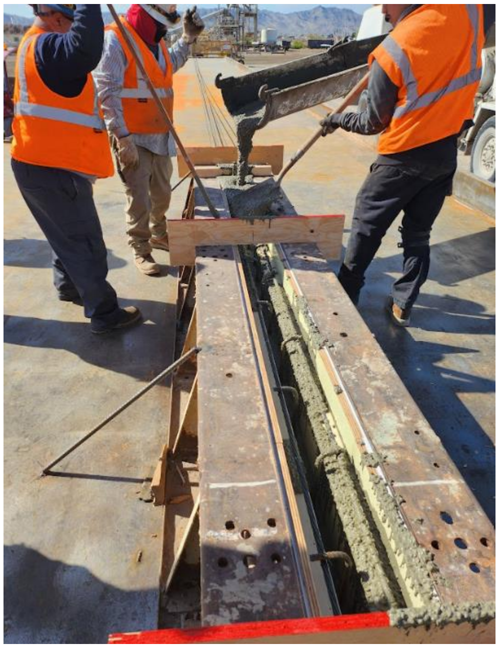


Figure 18: Concrete pour, with Tpac employees ensuring no gaps

To ensure the concrete would set evenly and have a nice look, the top was smoothed out. Tpac let the concrete cure for three days before verifying that the concrete strength was greater than the required 5,000 psi and cut the strands. The initial strength of the concrete at release was 5,077 psi on the third day.

Figure 19: Beam after concrete poured

Tpac shipped the beam to NAU on April 16th, 12 days after being fabricated. All reports from fabrication are shown in 0.

7.3 Test Set Up

Upon arrival, the beam was transported into the NAU concrete lab.

The team proceeded to position the beam properly according to the PCI Big Beam rules [1], as seen in Figure 20 below. The green steel support beams and load actuator were moved to position and load the beam correctly.

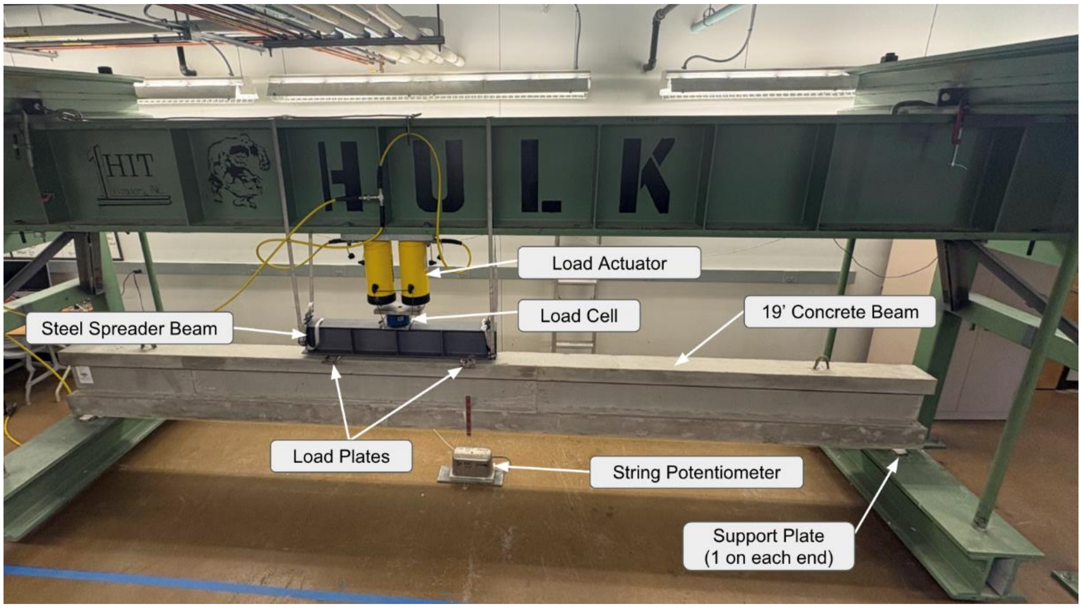


Figure 20: Overview of test set up

The beam was measured and marked at the support plate locations to ensure it was centered properly, the point load locations where load plates would transfer the load to the beam. Areas where steel load plates contacted the concrete beam were grouted to ensure full contact and load transfer.

The centers of the load plates were placed 6-inches from the end of the beam, creating an 18-foot span length. Once everything was in place, the team added the steel load plates, steel spreader beam, load cell to measure the load during testing, a transfer plate, and the load actuator, as shown above in Figure 20. The dimensions of the beam, support plates, load plates, and string potentiometer can be seen below in Figure 21.

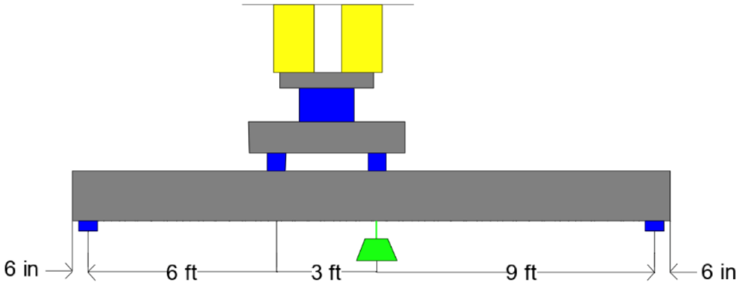


Figure 21: Detail of test set up with dimensions

Mason's string was placed spanning the entire length of the beam, with a ruler attached to the beam, behind the string, to visually show deflection during testing, as shown below in Figure 22 below.

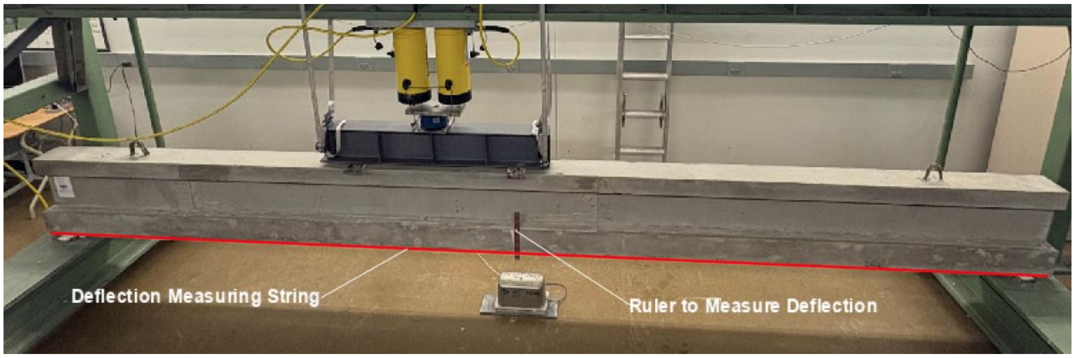


Figure 22: Testing set up showing how deflection is visually measured

7.4 Beam Test Results

The NAU Big Beam test was conducted on 4/28/2025 following the cylinder tests and certification of predictions. The test included plotting applied load and deflection calculated at midspan. The following graph contains the test data.

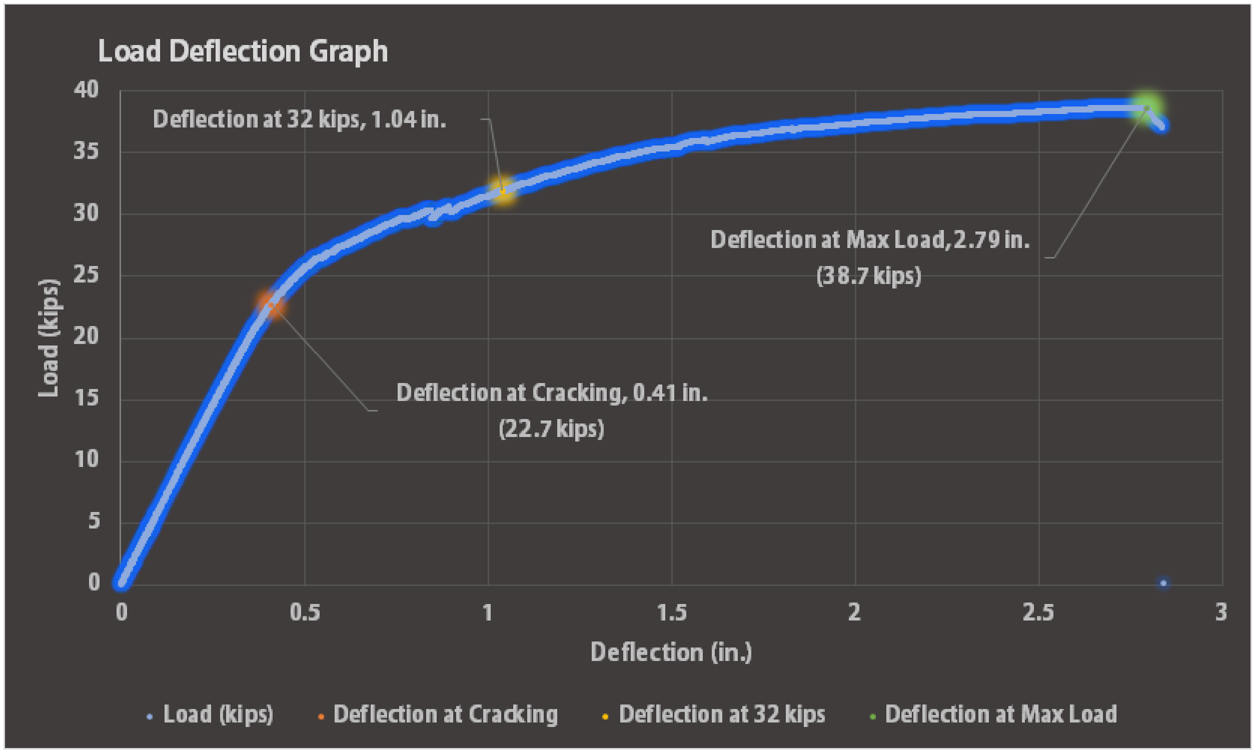


Figure 23: Deflection vs. Loading Graph

The following table shows how the predictions are compared to the actual results.

Table 7: Comparison of Results and Predictions

	Predicted Value	Actual Value	% Difference
Cracking	22.8 kips	22.7 kips	-0.4 %
Breaking Load	34.9 kips	38.6 kips	+11 %
Midspan Deflection (32 kips)	1.09 in	1.04 in	-4.7 %
Midspan Deflection (Max)	1.9 in	2.7 in	+50 %

Overall, our predictions are close to our actual values. Our breaking load prediction was likely of due to suboptimal cylinder test results. Ideal cylinder breaks show a cone shape. As seen in Figure 5, the cylinder breaks only have a chunk broken off. This likely led to our concrete strength being lower in our predictions than anticipated, leading to the concrete having higher strength and crushing with a higher load.

In the future, the team will conduct more cylinder tests to have a larger sample size in case of user error in using the testing equiptment.

8.0Team Statements

8.1 Payton Correia

This competition was incredible because it allowed me to apply what I've learned throughout my academic career to a tangible project. I really enjoyed challenging myself to learn the specifics of designing with prestressed concrete, the logistics of fabricating a beam, and communicate with a variety of professionals and learn from their experiences. Completing the design work with Isabella Velasco, one of my best friends, was a joy and I was thrilled to get the opportunity to challenge ourselves technically. I am extremely proud of the work we have put into this project, the skills we have learned, and our improved understanding of prestressed concrete design. I feel confident in my abilities to use precast/prestressed concrete in my career.

10931 East Bella Vista Drive Scottsdale, AZ 85259

Figure 24: Photo of Payton Correia

8.3 Isabella Velasco

This competition opened my eyes into the precast and prestressed concrete world. Our school curriculum only has a regular concrete class so when we got this project we met with our technical advisor, Dr. Dymond, weekly to learn about prestressed concrete. This whole experience was very fun and challenging to go through. We learned new software's to make calculations and predictions that I would have never learned if not in this project. I am considering a career now in prestressed and precast concrete because I really loved this project. It was overwhelming at first but once we started, I was able to dive in and put my all into it. This project was a full rounded project where we got to see the entire process it takes to make prestressed precast concrete. Payton Correia, who is one of my best friends, and I would always joke about how this project was our baby so much, so it wasn't a joke anymore. We even named out beam Stacy because we loved our beam and it was a visual representation of all the hard work we had put into designing her.

1492 S. Vine St. Gilbert, AZ 85233

Figure 25: Photo of Isabella Velasco

8.4 Caitlin Yazzie

The PCI Big Beam Competition has provided me with an invaluable, hands-on introduction to civil engineering that I would not have gained elsewhere. Through this project, I learned the fundamentals of concrete mix design and came to understand the principles of prestressed concrete, how it is intentionally compressed before loading to improve its structural performance. I was actively involved in the full process, from interpreting shop drawings and coordinating with our sponsor on material requirements to overseeing the concrete pour and witnessing firsthand how the beam was constructed and tested to failure. These experiences not only deepened my technical knowledge but also taught me the importance of communication and planning within a team, especially while balancing coursework and jobs. I am grateful for this opportunity, and the skills and insights I've gained will have a lasting impact on both my academic and professional journey.

PO Box 272, Rock Point, AZ 86545

Figure 26: Photo of Caitlin Yazzie

8.2 Zachary Fukumoto

Participating in the PCI Big Beam Competition was a great learning experience in my academic and professional journey. I gained a deeper understanding of structural behavior, specifically in prestressed concrete design and testing, through this competition. Being able to design our beam and then actually test it brought our engineering skills to life. This competition taught me the importance of teamwork, problem-solving, communication, and time management. I am grateful for my team members and being able to work on this project.

94-227 Kuhana Place, Waipahu, HI, 96797

Figure 27: Photo of Zachary Fukumoto

9.0 Conclusion

Designing a precast/prestressed beam for predicting the load and deflection requirements is the objective of this project. The PCI Big Beam competition asked student groups to design and fabricate a prestressed/precast concrete beam that cracked within 20 kips and 32 kips and failed between 32 kips and 40 kips. Further design considerations are shown in Appendix C.

The team did their calculations in Mathcad (Appendix D) and iterated to create designs that maximized the scoring criteria and were in the middle of the breaking and failure loads (Appendix E).

The team used a decision matrix (Appendix G), scoring the deflection, weight, and cost according to the competition rules. The decision matrix included a performance multiplier of 0.95 – 1.05 to increase or decrease the score according to how close the cracking and failure loads were to the middle of the range (**Error! Reference source not found.**).

The final design was chosen based on how well the design ranked in terms of cost, weight, and deflection. Shop drawings for the chosen design are shown in Appendix H. The NAU team designed an I-shaped beam with two prestressing strands in the bottom flange and two non-structural strands in the top flange to hold the stirrups. The stirrups are #4 bars spaced 7 inches apart on the side experiencing the point loads, and 11 inches apart on the other side.

Tpac fabricated and transported the beam to NAU as the PCI Producing member (Section **Error! Reference source not found.**). All material and fabrication reports are shown in Appendix A, Appendix B, Appendix I, and 0. Then, the team set up the beam test according to the competition rules (Section 7.3 Test Set Up).

Test cylinders were created alongside the NAU beam, and Tpac provided NAU with historical data on the concrete mix (Appendix I). These were used to finalize predictions.

The final predictions, actual values, and comparisons are shown in Table 8 below.

Table 8: Comparison of Results and Predictions

	Predicted Value	Actual Value	% Difference
Cracking	22.8 kips	22.7 kips	-0.4%
Breaking Load	34.9 kips	38.6 kips	+11 %
Midspan Deflection (32 kips)	1.09 in	1.04 in	-4.7 %
Midspan Deflection (Max)	1.8 in	2.7 in	+50 %

The midspan deflection-loading graph is shown in Section 2.0.

10.0 NAU Capstone Requirements

10.1 Project Introduction

The Precast/Prestressed Concrete Institute (PCI) Big Beam Competition involves student teams designing and overseeing the manufacturing of a precast and prestressed 18-foot concrete beam. Each entry will be evaluated in connection with other entries from the same country as part of the national competition that serves as the judging criteria. Our team must design the beam to carry a load of at least a total factored live load of 32 kips and its total peak applied load cannot exceed 40 kips. The beam must also not crack under the total applied service load of 20 kips.

The completed beam will be shipped to and tested at the NAU lab facility in the Engineering building. See Figure 9 below.

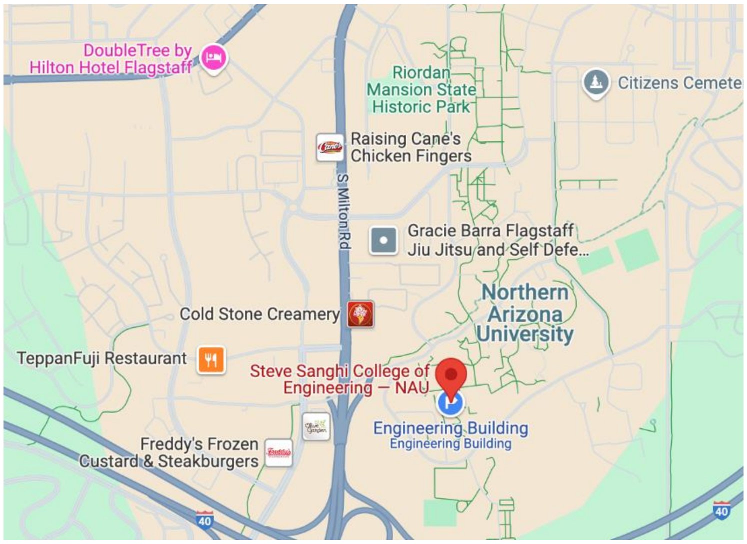


Figure 28: NAU Testing Lab Location

This project's focus is the design and analysis of the beam’s structural integrity. This will be done by testing the beam until failure to compare predicted failure to actual failure. The end goal of the project is to create the most accurate prediction, lightest weight, and largest deflection of the beam within the parameters provided by PCI.

The project constraints include staying within the constraints of the PCI Big Beam Rules and staying within our planned schedule. Time constraint is crucial for staying on track within our schedule and completing the project on time. Any delays in fabrication, transportation, or setup could push back the testing schedule. Abiding by the PCI Big Beam rules is also necessary since we will be judged on various aspects of categories pertaining to the competition.

The major objective of our project is to design the concrete mix, decide on a beam design that fits within the competition rules and project goals, create our shop drawings to send to TPAC, test the concrete cylinders tensile and compressive strengths, and finally test the beam and documenting its behaviors. The PCI Big Beam competition submittal includes a report and competition video per the PCI Big Beam Competition rules. The final report may need to be edited to meet the competition specifications. All tasks will be completed by the due date of May 9, 2025, which marks the end of the project.

10.2 Impacts

10.2.1 Economic Impacts

Long-term economic benefits of precast prestressed concrete include its superior quality, quick construction, and low maintenance requirements. Over the course of a project, cost savings may result from improved efficiency and a decrease in rework caused by controlled manufacturing. But because of the need for specific equipment, logistics for shipping, and access to plants, it usually entails higher upfront expenses. Cast-in-place concrete, on the other hand, is frequently more affordable initially and more readily available for remote or smaller-scale projects. However, the work and time required are more, which might raise the project's overall cost and susceptibility to delays. Since cast-in-place concrete is poured on-site, inclement weather may cause delays in the curing process.

10.2.2 Environmental Impacts

Precast concrete benefits the environment by using less material and producing less waste because its components are manufactured exactly in a factory. Over time, its durability also helps to reduce the carbon footprint. However, transportation-related pollutants and energy-intensive prestressing equipment are environmental drawbacks. Cast-in-place concrete, while reducing transportation-related emissions by using local materials, generally results in more waste due to on-site variability and less efficient material use. It may also have a shorter service life if not cured or constructed properly, leading to higher long-term environmental costs through repairs and replacements.

10.2.3 Social Impacts

Social benefits of prestressed/precast concrete include quicker installation, less time spent in construction zones, and improved quality control because it is produced off-site, all of which lessen dangers to the public and employees. Prestressed concrete also enhances public safety by offering fire-resistant and pest-resistant structural solutions, reducing the risk of property damage and personal harm. Additionally, it minimizes the risk of damage by requiring less work on-site. However, it entails moving bulky components and utilizing huge machinery, which limits installation flexibility and poses safety hazards. Contrarily, cast-in-place concrete permits on-site modifications and eliminates transportation dangers, but it necessitates more effort and longer building periods, raising the risks to workers and public safety. Additionally, it is weather-sensitive, which may have an impact on long-term safety and quality.

10.3 Summary of Engineering Cost

The total estimated cost of engineering services is $86,959. This includes personnel, travel expenses, supplies, and subcontracting fees. Personnel costs are calculated based on the total hours worked and the billing rate for each position throughout the project. Travel expenses include one day trip to Tpac in Phoenix, AZ to observe the pouring of the Big Beam. Supply costs are influenced by the lab equipment and software required for concrete analysis and creating shop drawings for the beam design. Specifically, the Materials Lab and the Concrete Lab will be utilized. Subcontracting fees reflect the work performed by Tpac to fabricate and ship the PCI Big Beam.

Table 6 shows a detailed breakdown and justification for personnel, travel, supplies, and subcontractor costs.

Table 9: Estimated Cost of Engineering Services

1.0 Personnel	**Classification**	**Rate/Hour ($)**		**Hours**	**Cost**
	SENG	247		109	$26,923
	INT	59		418	$24,662
	STE	130		145	$18,850
	LT	63		37	$2,331
	Total Personnel Cost				**$72,766**
2.0 Travel	**Classification**	**Billing Rate**	**Units**	**Miles**	**Cost**
	1-day Car Rental for Tpac Visit	77	$	--	$77
	Miles	0.4	$/mile	288	$115
	Total Travel Cost				**$192**
3.0 Supplies	**Classification**	**Rate/Day ($)**		**Days**	**Cost**
	Lab Rental	100		5	$500
	Total Supplies Cost				**$500**
4.0 Subcontractors	**Classification**	**Rate/Hour ($)**		**Hours**	**Cost**
	Beam Materials & Fabrication	--		--	$9,000
	Dr. Dymond Lessons and Advising	200		20	$4,000
	Total Subcontractors Cost				**$13,000**
Total Cost of Engineering Services					**$86,458**

References

[1] PCI, "2024-2025 Big Beam Rules," 2024-2025. [Online]. Available: https://www.pci.org/PCI/PCI/Education/Student_Competitions.aspx..

[2] ASTM International, "ASTM C39: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," *ASTM International,* 2021.

[3] PTC, *MathCAD Prime10*, PTC.

[4] J. Hugen, "Concrete Mix Design," 19 March 2025. [Online].

Appendices

Appendix A Material Reports

Appendix B Admixture Data Sheets

Appendix B.1 ADVA CAST 575

TECHNICAL DATA SHEET

Chryso Concrete Solutions

01/03/2025

ADVA® CAST 575

High Range Water Reducing Admixture

DESCRIPTION

ADVA® Cast 575 is a high efficiency, low addition rate polycarboxylate-based high-range water reducer designed for the production of a wide range of concrete mixes, from conventional to Self-Consolidating Concrete (SCC). It is designed to impart extreme workability without segregation to the concrete.

ADVA® Cast 575 is supplied as a ready-to-use liquid that weighs approximately 8.9 lbs/gal (1.1 kg/L). ADVA® Cast 575 does not contain intentionally added chlorides.

ADVANTAGES

- Excellent dosage efficiency, moisture control and air control
- Superior air entrainment control
- Enhanced concrete cohesiveness with low viscosity for rapid placement
- Superior finish on cast surfaces
- Enhanced strength development

FIELDS OF APPLICATION

- Formulated to impart improved workability to the concrete and to achieve high early compressive strength as required by the precast industry.

Method of Use

Dosage

- ADVA® Cast 575 is an easy to dispense liquid admixture. Dosage rates can be adjusted to meet a wide spectrum of concrete performance requirements. Addition rates for ADVA® Cast 575 can vary from 2 to 10 fl oz/100 lbs (130 to 650 mL/100 kg) with the type of application, but will typically range from 3 to 6 fl oz/100 lbs (200 to 390 mL/100 kg) of cementitious.
- Should conditions require using more than the recommended addition rate, please consult your representative.
- Mix proportions, cementitious content, aggregate gradations and ambient conditions will affect ADVA® Cast 575 dosage requirements. If materials or conditions require using more than the recommended addition rates, or when developing mix designs for Self-Consolidating Concrete please consult your representative for more information and assistance.

Additional Usage Recommandations

- ADVA® Cast 575 is a plant-added superplasticizer that is formulated to impart improved workability to the concrete and to achieve high early compressive strength as required by the precast industry. ADVA® Cast 575 can be used for the production of SelfConsolidating Concrete in precast/prestressed applications and may be used in conventional concrete production.
- ADVA® Cast 575 may be used in low water-cementitious ratio applications where concrete stability and improved tolerance to concrete material variability are required.
- ADVA® Cast 575 may be used to produce concrete with very low water/cementitious ratios while maintaining normal levels of workability.

Equipment

- A complete line of accurate, automatic dispensing equipment is available.

Complimentary Products

- ADVA® Cast 575 is compatible with most admixtures as long as they are added separately to the concrete mix. However, ADVA ® products

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TECHNICAL DATA SHEET

ADVA® CAST 575

High Range Water Reducing Admixture

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are not recommended for use in concrete containing naphthalene-based admixtures including DARACEM® 19 and DARACEM®100 and melamine-based admixtures including DARACEM® 65. In general, it is recommended that ADVA® Cast 575 be added to the concrete mix near the end of the batch sequence for optimum performance. Different sequencing may be used if local testing shows better performance. Please see Technical Bulletin TB-0110, *Admixture Dispenser Discharge Line Location and Sequencing for Concrete Batching Operations* for further recommendations.

- Pretesting of the concrete mix should be performed before use and as conditions and materials change in order to assure compatibility with other admixtures, and to optimize dosage rates, addition times in the batch sequencing and concrete performance. For concrete that requires air entrainment, the use of an ASTM C260 air-entraining agent (such as DARAVAIR® or DAREX® product lines) is recommended to provide suitable air void parameters for freeze-thaw resistance. Please consult your representative for guidance.

CHARACTERISTICS

Product Nature	Liquid
Color	Blue green
Shelf life	12 months
Specific gravity (25°C) in g/ml	1,079
pH (25°C)	5,20

PRECAUTIONS

- ADVA® Cast 575 will freeze at approximately 32°F (0°C) but will return to full functionality after thawing and thorough mechanical agitation.

SAFETY

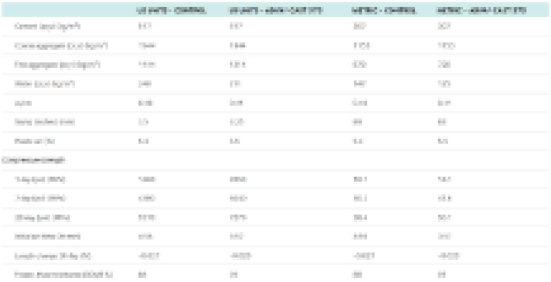
Prior to any use, please read carefully the Safety data Sheet.

PACKAGING

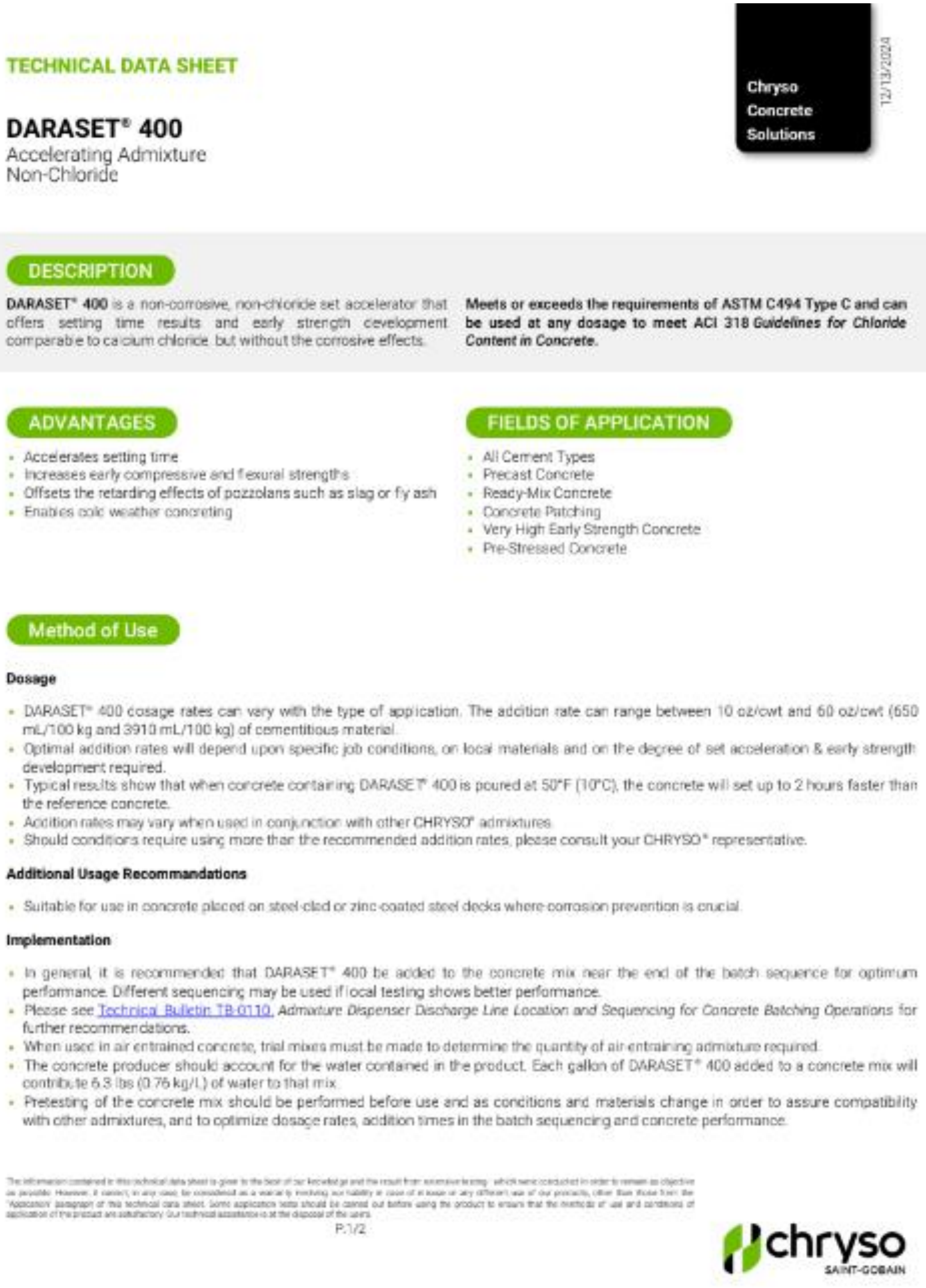
- Bulk
- 55 gallon drum
- 275 gallon tote

ADDITIONAL INFORMATION

ADVA® Cast 575 ASTM C494 Type F High-Range Water Reducer Test Data



Appendix B.2 DARASET 400



TECHNICAL DATA SHEET

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DARASET® 400

Accelerating Admixture
Non-Chloride

DESCRIPTION

DARASET® 400 is a non-corrosive, non-chloride set accelerator that offers setting time results and early strength development comparable to calcium chloride but without the corrosive effects.

Meets or exceeds the requirements of ASTM C494 Type C and can be used at any dosage to meet ACI 318 *Guidelines for Chloride Content in Concrete*.

ADVANTAGES

- Accelerates setting time
- Increases early compressive and flexural strengths
- Offsets the retarding effects of pozzolans such as slag or fly ash
- Enables cold weather concreting

FIELDS OF APPLICATION

- All Cement Types
- Precast Concrete
- Ready-Mix Concrete
- Concrete Patching
- Very High Early Strength Concrete
- Pre-Stressed Concrete

Method of Use

Dosage

- DARASET® 400 dosage rates can vary with the type of application. The addition rate can range between 10 oz/cwt and 60 oz/cwt (650 mL/100 kg and 3910 mL/100 kg) of cementitious material.
- Optimal addition rates will depend upon specific job conditions, on local materials and on the degree of set acceleration & early strength development required.
- Typical results show that when concrete containing DARASET® 400 is poured at 50°F (10°C), the concrete will set up to 2 hours faster than the reference concrete.
- Addition rates may vary when used in conjunction with other CHRYSO® admixtures.
- Should conditions require using more than the recommended addition rates, please consult your CHRYSO® representative.

Additional Usage Recommandations

- Suitable for use in concrete placed on steel-clad or zinc-coated steel decks where corrosion prevention is crucial.

Implementation

- In general, it is recommended that DARASET® 400 be added to the concrete mix near the end of the batch sequence for optimum performance. Different sequencing may be used if local testing shows better performance.
- Please see Technical Bulletin TB-0110, *Admixture Dispenser Discharge Line Location and Sequencing for Concrete Batching Operations* for further recommendations.
- When used in air entrained concrete, trial mixes must be made to determine the quantity of air-entraining admixture required.
- The concrete producer should account for the water contained in the product. Each gallon of DARASET® 400 added to a concrete mix will contribute 6.3 lbs (0.76 kg/L) of water to that mix.
- Pretesting of the concrete mix should be performed before use and as conditions and materials change in order to assure compatibility with other admixtures, and to optimize dosage rates, addition times in the batch sequencing and concrete performance.

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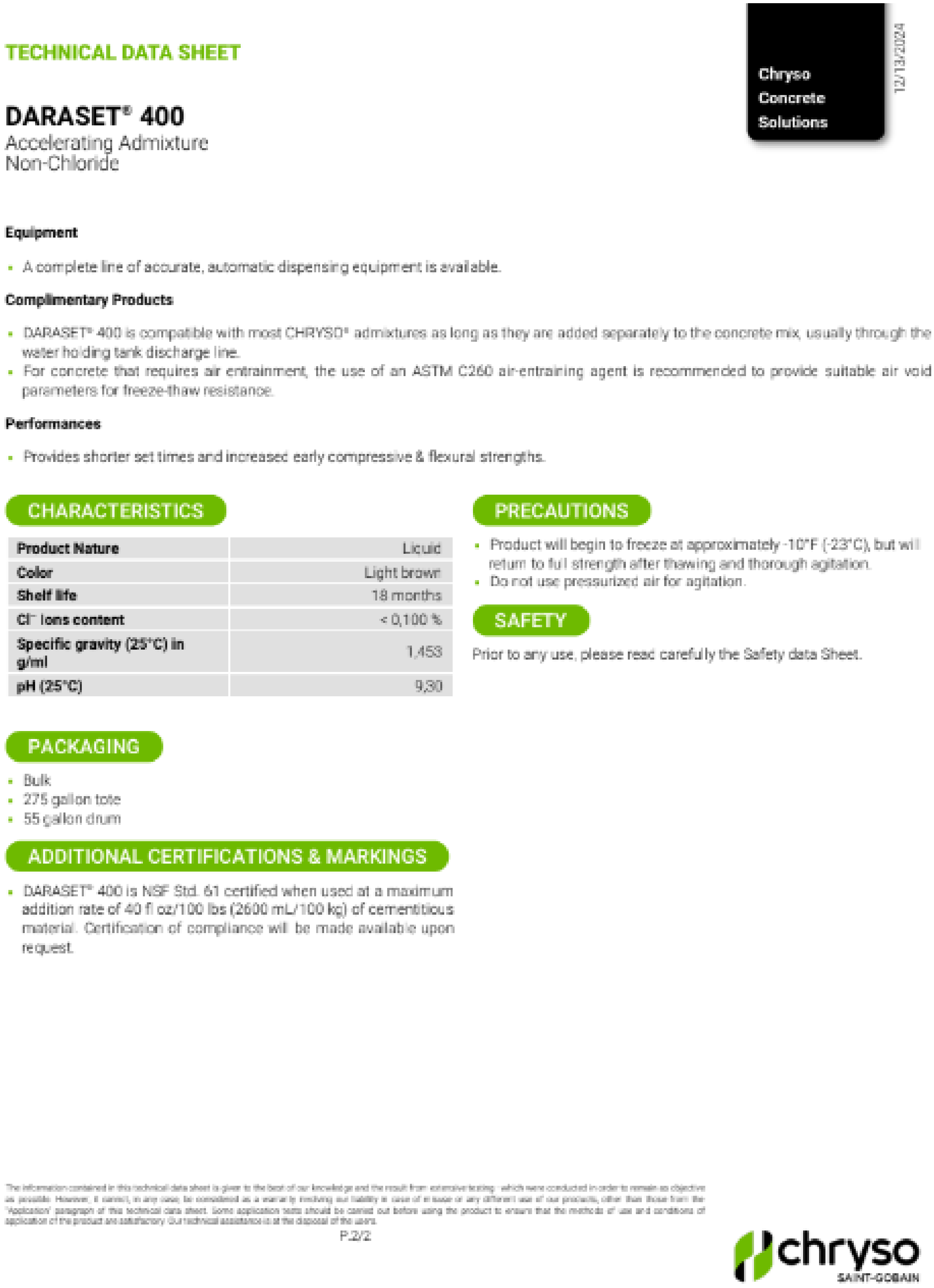

DARASET® 400

Accelerating Admixture
Non-Chloride

Equipment

- A complete line of accurate, automatic dispensing equipment is available.

Complimentary Products

- DARASET® 400 is compatible with most CHRYSO® admixtures as long as they are added separately to the concrete mix, usually through the water holding tank discharge line.
- For concrete that requires air entrainment, the use of an ASTM C260 air-entraining agent is recommended to provide suitable air void parameters for freeze-thaw resistance.

Performances

- Provides shorter set times and increased early compressive & flexural strengths.

CHARACTERISTICS

Product Nature	Liquid
Color	Light brown
Shelf life	18 months
Cl⁻ Ions content	< 0,100 %
Specific gravity (25°C) in g/ml	1,453
pH (25°C)	9,30

PRECAUTIONS

- Product will begin to freeze at approximately -10°F (-23°C), but will return to full strength after thawing and thorough agitation.
- Do not use pressurized air for agitation.

SAFETY

Prior to any use, please read carefully the Safety data Sheet.

PACKAGING

- Bulk
- 275 gallon tote
- 55 gallon drum

ADDITIONAL CERTIFICATIONS & MARKINGS

- DARASET® 400 is NSF Std. 61 certified when used at a maximum addition rate of 40 fl oz/100 lbs (2600 mL/100 kg) of cementitious material. Certification of compliance will be made available upon request.

Appendix B.3 DARAVAIR 1000

TECHNICAL DATA SHEET

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DARAVAIR® 1000

Air entraining admixture

DESCRIPTION

DARAVAIR® 1000 is a high-grade saponified rosin based air-entraining admixture that provides freeze-thaw resistance, yield control and finishability performance across the full range of concrete mix designs. Chemically similar to vinsol-based products, but with increased purity and supply dependability.

ADVANTAGES

- Produces rapid air build suitable for short mix cycles
- Performs reliably & consistently across a wide spectrum of mix designs
- Improves the durability of concrete to severe exposures

FIELDS OF APPLICATION

- All Cement Types
- Precast Concrete
- Post Tensioned & Prestressed Concrete
- Ready-Mix Concrete
- Concrete Exposed to Freeze-Thaw Cycles

Method of Use

Dosage

- DARAVAIR® 1000 dosage rates can vary with the type of application. The addition rate can range between 0.5 oz/cwt and 3 oz/cwt (30 mL/100 kg and 200 mL/100 kg) of cementitious material.
- Optimal addition rates will depend on temperature, cement, sand gradation, and the use of extra fine materials such as fly ash and microsilica.
- Dosage rates may vary when used in conjunction with other CHRYSO® admixtures. The air-entraining capacity of DARAVAIR® 1000 is usually increased when other concrete admixtures are contained in the concrete, particularly water-reducing admixtures and water-reducing retarders. This may allow up to [illegible] reduction in the amount of product required.
- Should conditions require using more than the recommended addition rates, please consult your CHRYSO® representative.

Additional Usage Recommandations

- Formulated to perform across the entire spectrum of production mixes, it generates specification quality, freeze-thaw resistant air systems in concrete.

Implementation

- In general, it is recommended that DARAVAIR® 1000 be added early in the batching sequence for optimum performance, preferably by "dribbling" on the sand.
- Product should not be added directly to heated water.
- Different sequencing may be used if local testing shows better performance.
- Please see Technical Bulletin TB-0110, *Admixture Dispenser Discharge Line Location and Sequencing for Concrete Batching Operations* for further recommendations.
- Pretesting of the concrete mix should be performed before use and as conditions and materials change in order to assure compatibility with other admixtures, and to optimize dosage rates, addition times in the batch sequencing, and concrete performance.

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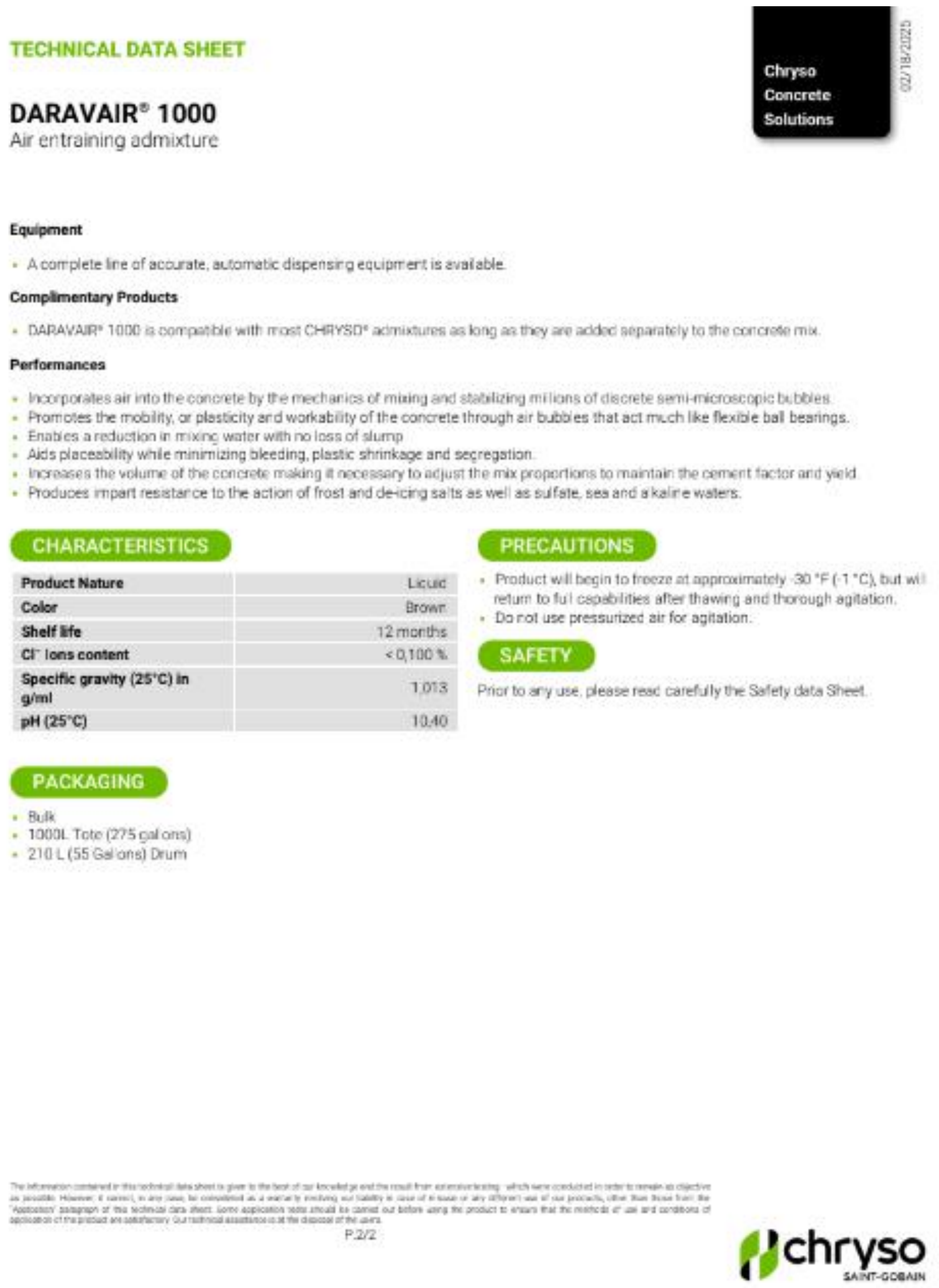

DARAVAIR® 1000

Air entraining admixture

Equipment

- A complete line of accurate, automatic dispensing equipment is available.

Complimentary Products

- DARAVAIR® 1000 is compatible with most CHRYSO® admixtures as long as they are added separately to the concrete mix.

Performances

- Incorporates air into the concrete by the mechanics of mixing and stabilizing millions of discrete semi-microscopic bubbles.
- Promotes the mobility, or plasticity and workability of the concrete through air bubbles that act much like flexible ball bearings.
- Enables a reduction in mixing water with no loss of slump.
- Aids placeability while minimizing bleeding, plastic shrinkage and segregation.
- Increases the volume of the concrete making it necessary to adjust the mix proportions to maintain the cement factor and yield.
- Produces impart resistance to the action of frost and de-icing salts as well as sulfate, sea and alkaline waters.

CHARACTERISTICS

Product Nature	Liquid
Color	Brown
Shelf life	12 months
Cl⁻ Ions content	< 0,100 %
Specific gravity (25°C) in g/ml	1,013
pH (25°C)	10,40

PRECAUTIONS

- Product will begin to freeze at approximately -30 °F (-1 °C), but will return to full capabilities after thawing and thorough agitation.
- Do not use pressurized air for agitation.

SAFETY

Prior to any use, please read carefully the Safety data Sheet.

PACKAGING

- Bulk
- 1000L Tote (275 gallons)
- 210 L (55 Gallons) Drum

Appendix B.4 RECOVER

TECHNICAL DATA SHEET

Chryso
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RECOVER®

Set retarding admixture

DESCRIPTION

RECOVER® is a ready-to-use aqueous solution of chemical compounds specifically designed to stabilize the hydration of Portland cement concretes.

Meets or exceeds the requirements of ASTM C494 Type B & D

ADVANTAGES

- Eliminates the need to discharge wash water from the mixer
- Prevents the waste of unused concrete
- Provides predictable extended set times
- Enables long hauls to remote sites

FIELDS OF APPLICATION

- All Cement Types
- Ready-Mix Concrete
- Precast Concrete
- Hot Weather Concreting
- Mass Concrete
- HPC & UHPC Concrete

Method of Use

Dosage

- RECOVER® addition rates can vary with the type of application. The addition rate can range between 6 fl. oz & 128 fl. oz (180 mL & 3800 mL) per treatment.
- Typical dosage rates are:
  - Returned or Lefover Concrete: 3 to 128 fl. oz/cwt (195 to 8350 mL/100 kg)
  - Set Time Extensions (+4 hours): 5 to 50 fl. oz/cwt (325 to 3260 mL/100 kg)
  - ASTM Type B or D Retarder: 2 to 6 fl. oz/cwt (130 to 390 mL/100 kg)
- Optimal addition rates will depend on the specific materials involved, mixer type and stabilization period.
- Dosage rates may vary when used in conjunction with other CHRYSO® admixtures.
- Should conditions require using more than the recommended addition rates, please consult your CHRYSO® representative.

Additional Usage Recommandations

- Designed to stabilize mixer wash water and returned or leftover concrete for extended periods, allowing for use of the materials when specified or allowed.
- Suitable for use where controlled extended set of concrete is needed. It is the concrete user's responsibility to determine if leftover, returned, or extended-set concrete is specified or allowed.
- Ideal for wash water applications, eliminating the need to discharge wash water from the mixer. This allows the wash water to be used as mix water in the next batch of concrete produced and prevents the residual plastic concrete from hardening.
- Used to prevent plastic concrete from reaching initial set for returned or leftover concrete. This allows the concrete to be stored in a plastic state and then used when specified or allowed. The use of this concrete may require the addition of freshly batched concrete and/or an accelerator.
- Recommended in situations where a controlled set time extension is required, such as extended hauls, large continuous pours, or pre-batching of concrete for later use.

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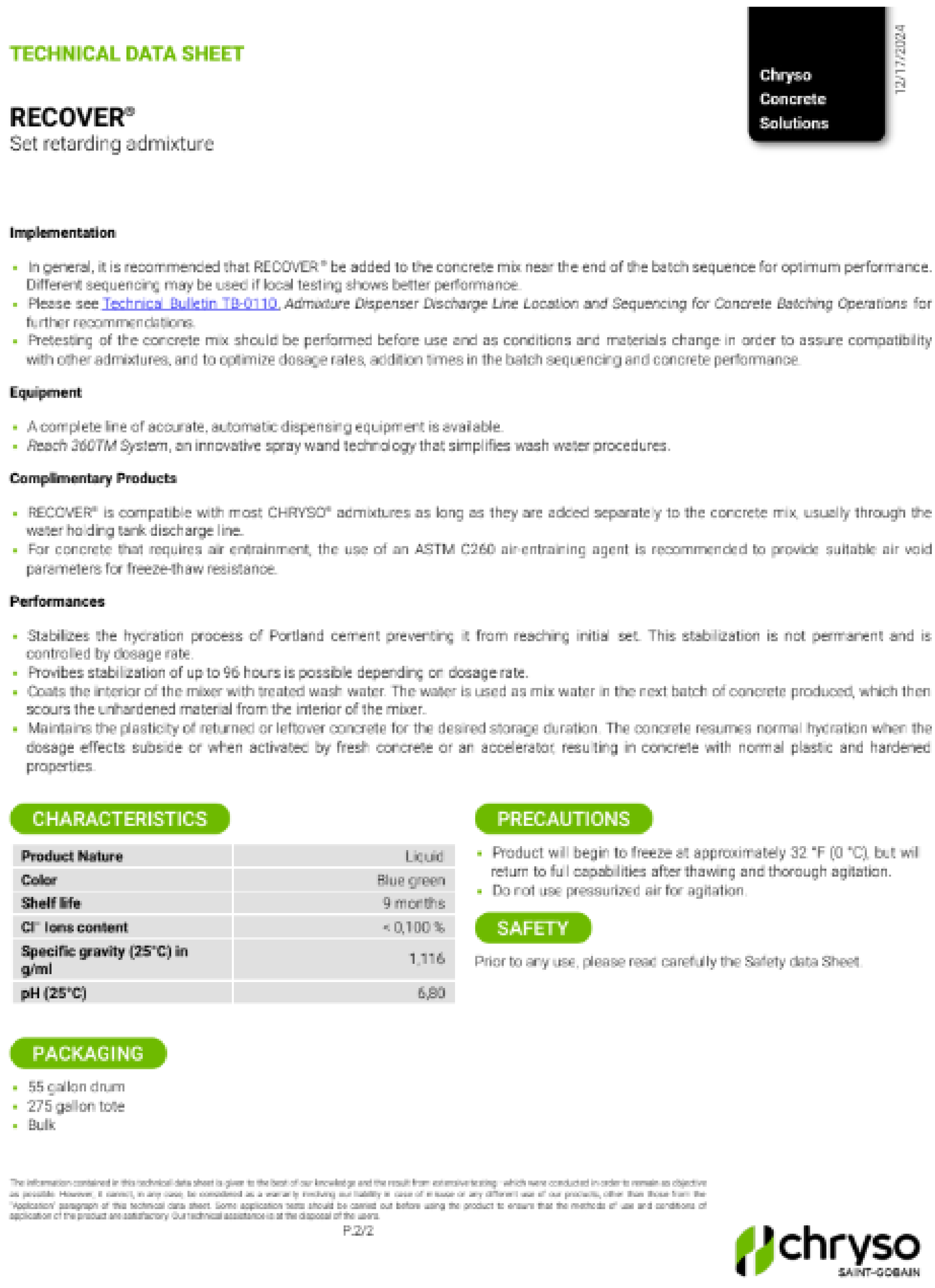

TECHNICAL DATA SHEET

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RECOVER®

Set retarding admixture

Implementation

- In general, it is recommended that RECOVER® be added to the concrete mix near the end of the batch sequence for optimum performance. Different sequencing may be used if local testing shows better performance.
- Please see Technical Bulletin TB-0110, *Admixture Dispenser Discharge Line Location and Sequencing for Concrete Batching Operations* for further recommendations.
- Pretesting of the concrete mix should be performed before use and as conditions and materials change in order to assure compatibility with other admixtures, and to optimize dosage rates, addition times in the batch sequencing and concrete performance.

Equipment

- A complete line of accurate, automatic dispensing equipment is available.
- *Reach 360TM System*, an innovative spray wand technology that simplifies wash water procedures.

Complimentary Products

- RECOVER® is compatible with most CHRYSO® admixtures as long as they are added separately to the concrete mix, usually through the water holding tank discharge line.
- For concrete that requires air entrainment, the use of an ASTM C260 air-entraining agent is recommended to provide suitable air void parameters for freeze-thaw resistance.

Performances

- Stabilizes the hydration process of Portland cement preventing it from reaching initial set. This stabilization is not permanent and is controlled by dosage rate.
- Provibes stabilization of up to 96 hours is possible depending on dosage rate.
- Coats the interior of the mixer with treated wash water. The water is used as mix water in the next batch of concrete produced, which then scours the unhardened material from the interior of the mixer.
- Maintains the plasticity of returned or leftover concrete for the desired storage duration. The concrete resumes normal hydration when the dosage effects subside or when activated by fresh concrete or an accelerator, resulting in concrete with normal plastic and hardened properties.

CHARACTERISTICS

Product Nature	Liquid
Color	Blue green
Shelf life	9 months
Cl^- Ions content	< 0,100 %
Specific gravity (25°C) in g/ml	1,116
pH (25°C)	6,80

PRECAUTIONS

- Product will begin to freeze at approximately 32 °F (0 °C), but will return to full capabilities after thawing and thorough agitation.
- Do not use pressurized air for agitation.

SAFETY

Prior to any use, please read carefully the Safety data Sheet.

PACKAGING

- 55 gallon drum
- 275 gallon tote
- Bulk

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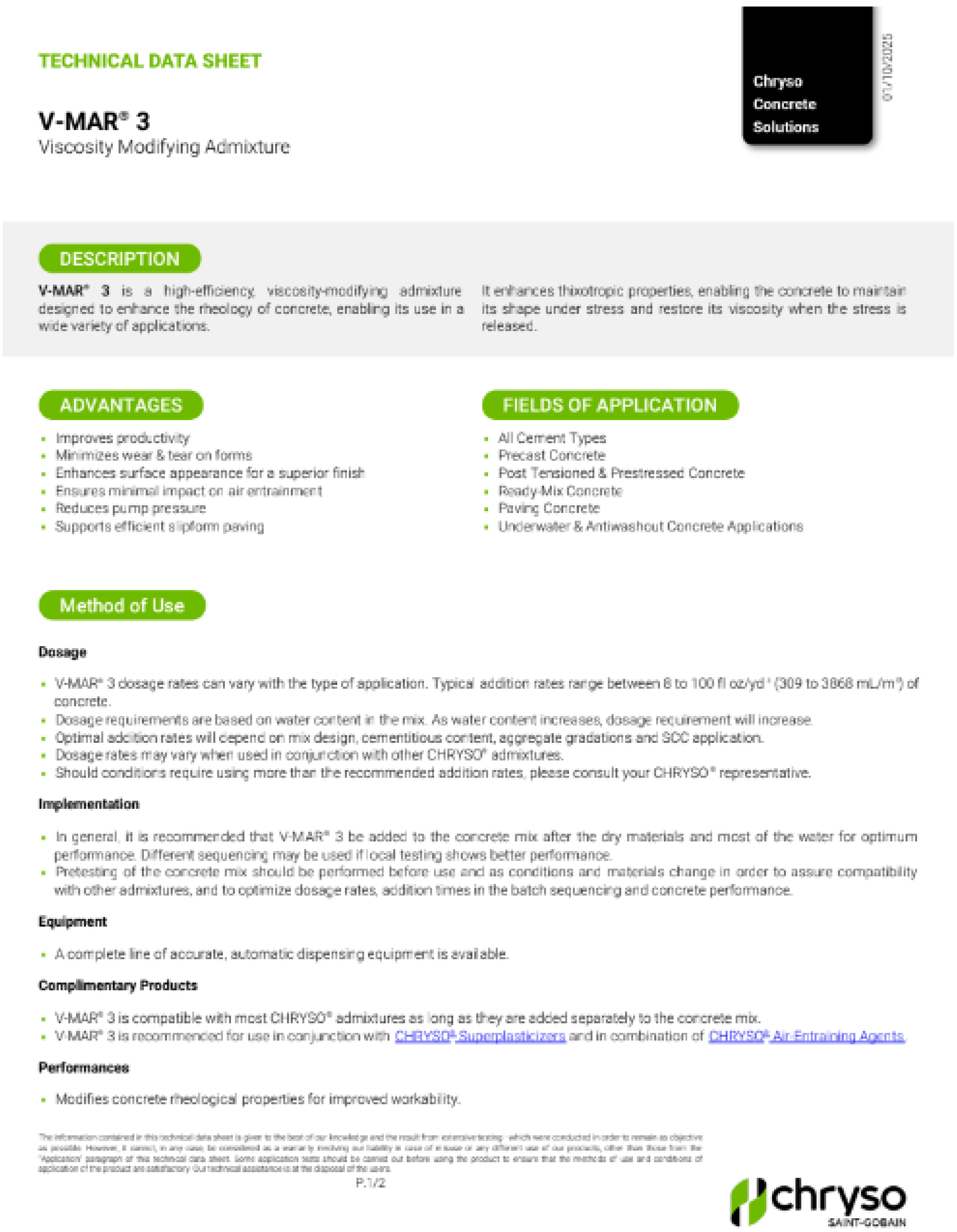
V-MAR 3



TECHNICAL DATA SHEET

V-MAR® 3

Viscosity Modifying Admixture

Chryso
Concrete
Solutions

01/10/2025

DESCRIPTION

V-MAR® 3 is a high-efficiency, viscosity-modifying admixture designed to enhance the rheology of concrete, enabling its use in a wide variety of applications. It enhances thixotropic properties, enabling the concrete to maintain its shape under stress and restore its viscosity when the stress is released.

ADVANTAGES

- Improves productivity
- Minimizes wear & tear on forms
- Enhances surface appearance for a superior finish
- Ensures minimal impact on air entrainment
- Reduces pump pressure
- Supports efficient slipform paving

FIELDS OF APPLICATION

- All Cement Types
- Precast Concrete
- Post Tensioned & Prestressed Concrete
- Ready-Mix Concrete
- Paving Concrete
- Underwater & Antiwashout Concrete Applications

Method of Use

Dosage

- V-MAR® 3 dosage rates can vary with the type of application. Typical addition rates range between 8 to 100 fl oz/yd^3 (309 to 3868 mL/m^3) of concrete.
- Dosage requirements are based on water content in the mix. As water content increases, dosage requirement will increase.
- Optimal addition rates will depend on mix design, cementitious content, aggregate gradations and SCC application.
- Dosage rates may vary when used in conjunction with other CHRYSO® admixtures.
- Should conditions require using more than the recommended addition rates, please consult your CHRYSO® representative.

Implementation

- In general, it is recommended that V-MAR® 3 be added to the concrete mix after the dry materials and most of the water for optimum performance. Different sequencing may be used if local testing shows better performance.
- Pretesting of the concrete mix should be performed before use and as conditions and materials change in order to assure compatibility with other admixtures, and to optimize dosage rates, addition times in the batch sequencing and concrete performance.

Equipment

- A complete line of accurate, automatic dispensing equipment is available.

Complimentary Products

- V-MAR® 3 is compatible with most CHRYSO® admixtures as long as they are added separately to the concrete mix.
- V-MAR® 3 is recommended for use in conjunction with CHRYSO® Superplasticizers and in combination of CHRYSO® Air-Entraining Agents.

Performances

- Modifies concrete rheological properties for improved workability.

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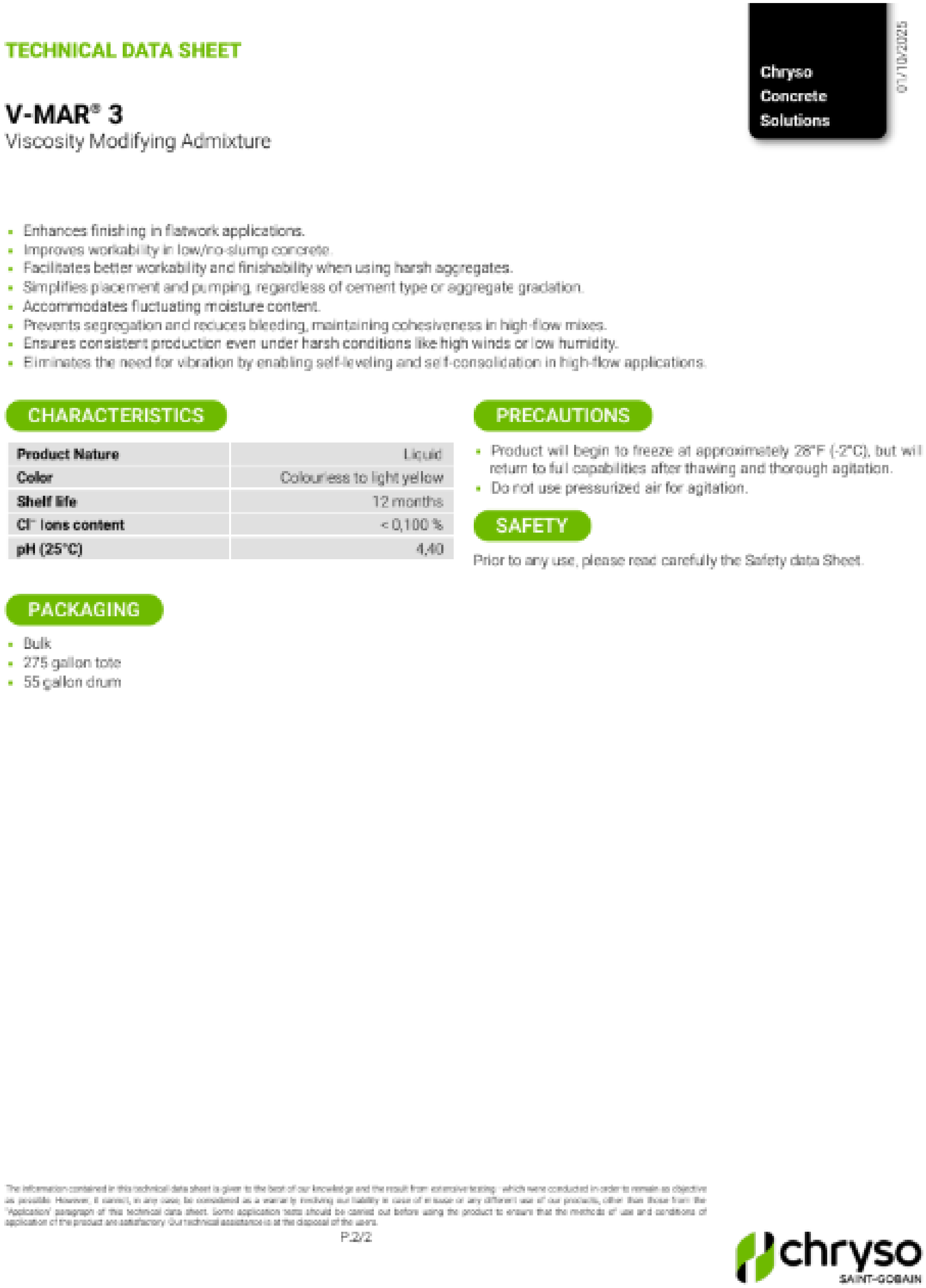

TECHNICAL DATA SHEET

V-MAR® 3

Viscosity Modifying Admixture

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Solutions

01/10/2025

- Enhances finishing in flatwork applications.
- Improves workability in low/no-slump concrete.
- Facilitates better workability and finishability when using harsh aggregates.
- Simplifies placement and pumping, regardless of cement type or aggregate gradation.
- Accommodates fluctuating moisture content.
- Prevents segregation and reduces bleeding, maintaining cohesiveness in high-flow mixes.
- Ensures consistent production even under harsh conditions like high winds or low humidity.
- Eliminates the need for vibration by enabling self-leveling and self-consolidation in high-flow applications.

CHARACTERISTICS

Product Nature	Liquid
Color	Colourless to light yellow
Shelf life	12 months
Cl⁻ Ions content	< 0,100 %
pH (25°C)	4,40

PRECAUTIONS

- Product will begin to freeze at approximately 28°F (-2°C), but will return to full capabilities after thawing and thorough agitation.
- Do not use pressurized air for agitation.

SAFETY

Prior to any use, please read carefully the Safety data Sheet.

PACKAGING

- Bulk
- 275 gallon tote
- 55 gallon drum

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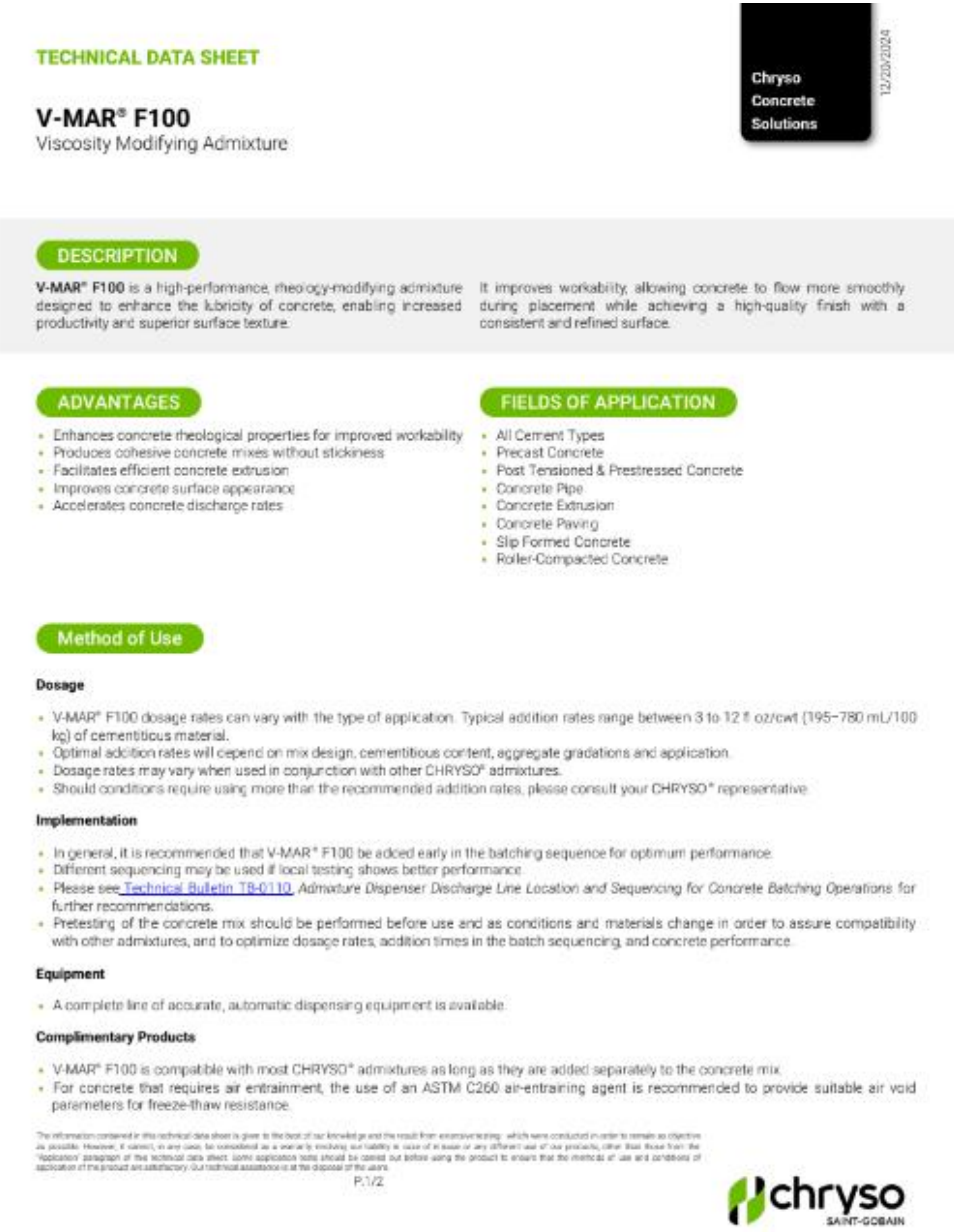
Appendix B.5 V-MAR F100



TECHNICAL DATA SHEET

Chryso
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Solutions

12/20/2024

V-MAR® F100

Viscosity Modifying Admixture

DESCRIPTION

V-MAR® F100 is a high-performance, rheology-modifying admixture designed to enhance the lubricity of concrete, enabling increased productivity and superior surface texture. It improves workability, allowing concrete to flow more smoothly during placement while achieving a high-quality finish with a consistent and refined surface.

ADVANTAGES

- Enhances concrete rheological properties for improved workability
- Produces cohesive concrete mixes without stickiness
- Facilitates efficient concrete extrusion
- Improves concrete surface appearance
- Accelerates concrete discharge rates

FIELDS OF APPLICATION

- All Cement Types
- Precast Concrete
- Post Tensioned & Prestressed Concrete
- Concrete Pipe
- Concrete Extrusion
- Concrete Paving
- Slip Formed Concrete
- Roller-Compacted Concrete

Method of Use

Dosage

- V-MAR® F100 dosage rates can vary with the type of application. Typical addition rates range between 3 to 12 fl oz/cwt (195–780 mL/100 kg) of cementitious material.
- Optimal addition rates will depend on mix design, cementitious content, aggregate gradations and application.
- Dosage rates may vary when used in conjunction with other CHRYSO® admixtures.
- Should conditions require using more than the recommended addition rates, please consult your CHRYSO® representative.

Implementation

- In general, it is recommended that V-MAR® F100 be added early in the batching sequence for optimum performance.
- Different sequencing may be used if local testing shows better performance.
- Please see Technical Bulletin TB-0110, *Admixture Dispenser Discharge Line Location and Sequencing for Concrete Batching Operations* for further recommendations.
- Pretesting of the concrete mix should be performed before use and as conditions and materials change in order to assure compatibility with other admixtures, and to optimize dosage rates, addition times in the batch sequencing, and concrete performance.

Equipment

- A complete line of accurate, automatic dispensing equipment is available.

Complimentary Products

- V-MAR® F100 is compatible with most CHRYSO® admixtures as long as they are added separately to the concrete mix.
- For concrete that requires air entrainment, the use of an ASTM C260 air-entraining agent is recommended to provide suitable air void parameters for freeze-thaw resistance.

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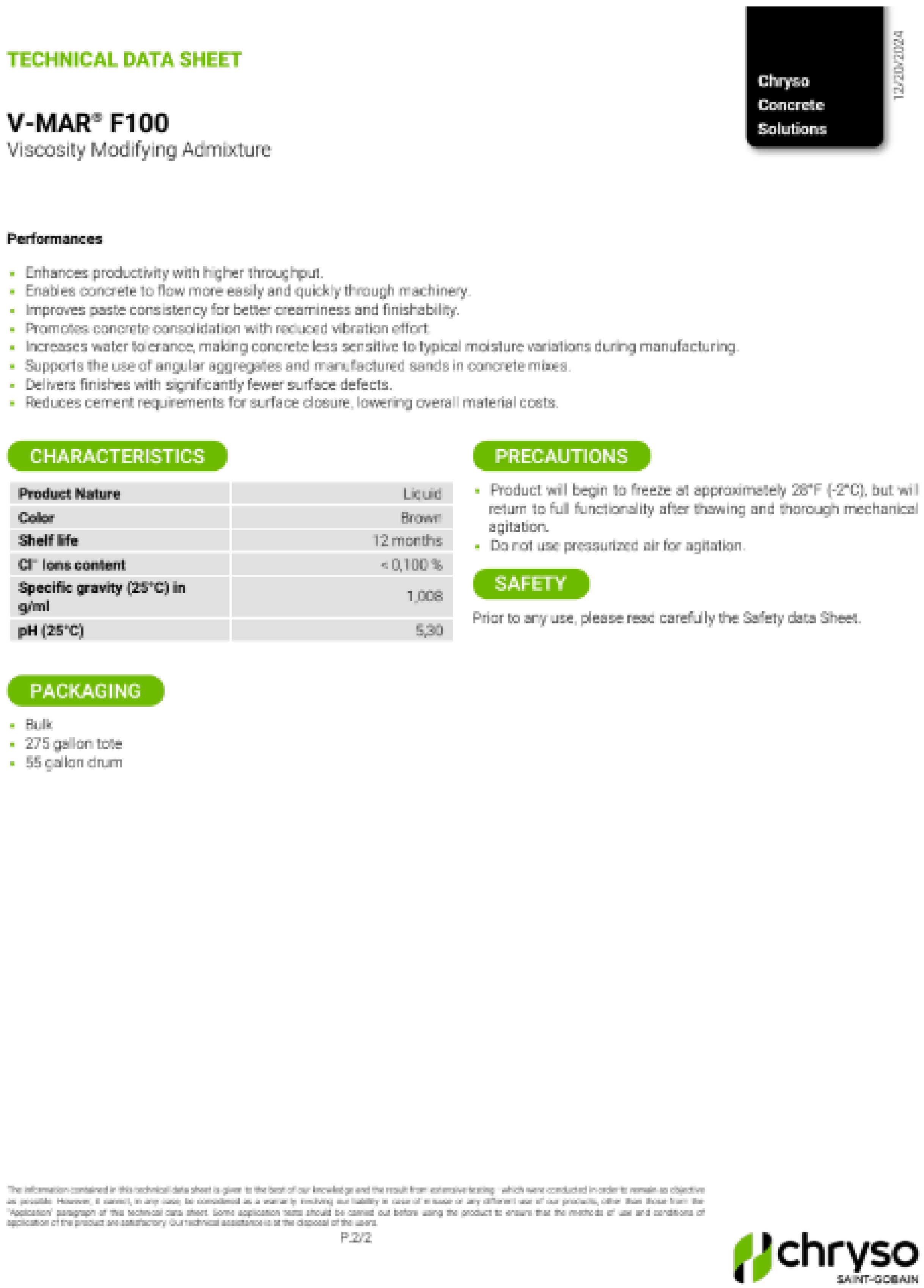

TECHNICAL DATA SHEET

Chryso
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V-MAR® F100

Viscosity Modifying Admixture

Performances

- Enhances productivity with higher throughput.
- Enables concrete to flow more easily and quickly through machinery.
- Improves paste consistency for better creaminess and finishability.
- Promotes concrete consolidation with reduced vibration effort.
- Increases water tolerance, making concrete less sensitive to typical moisture variations during manufacturing.
- Supports the use of angular aggregates and manufactured sands in concrete mixes.
- Delivers finishes with significantly fewer surface defects.
- Reduces cement requirements for surface closure, lowering overall material costs.

CHARACTERISTICS

Product Nature	Liquid
Color	Brown
Shelf life	12 months
Cl⁻ Ions content	< 0,100 %
Specific gravity (25°C) in g/ml	1,008
pH (25°C)	5,30

PRECAUTIONS

- Product will begin to freeze at approximately 28°F (-2°C), but will return to full functionality after thawing and thorough mechanical agitation.
- Do not use pressurized air for agitation.

SAFETY

Prior to any use, please read carefully the Safety data Sheet.

PACKAGING

- Bulk
- 275 gallon tote
- 55 gallon drum

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Appendix C Design Considerations

Table 10: Design Considerations

Process	Evaluation of…
Cross section properties	centroids, moment of inertia, and weight
Free-body, shear, and moment diagrams	applied loads, shear capacity, and moment capacity to inform calculation of cracking and failure loads.
Losses	short-term losses (elastic shortening), and long-term losses (creep, shrinkage, and steel relaxation)
Flexural analysis	nominal moment in order to ensure that the steel yields before the concrete crushes (to ensure a safer method of failure)
Transfer and development lengths	the required length needed to anchor the strand and fully develop the transfer of its compressive force.
Stresses	stresses at transfer and test, compared to allowable stress limits
Prediction of failure load	When cracking moment exceeds applied moment, leading to cracks forming in the concrete
Prediction of cracking and failure loads	When the ultimate moment exceeds applied moment, leading to the beam's failure
Shear analysis	Whether shear capacity exceeds shear demand (forcing the beam to fail in flexure)
Calculation of deflection	Prediction of the beam's maximum deflection when the maximum loading is applied.
Cost	Evaluation of cost per the PCI Big Beam 2024-2025 rules [1].

Appendix D Design Calculations

CROSS SECTION PROPERTIES

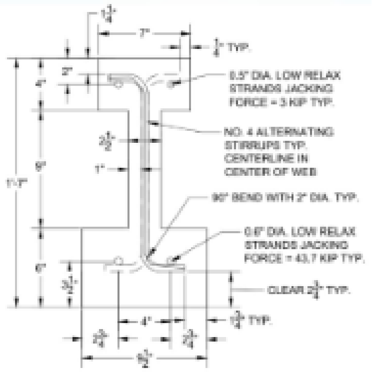


Figure 1: cross section design from shop drawings

$L_{tot} := 19\ ft$ beam length

$L := 18\ ft$ $x := 0\ ft, 0.1\ ft..L$ span length

$t_{tf} := 3.5\ in$ thickness of top flange

$t_{bf} := 6\ in$ thickness of bottom flange

$h_w := 9\ in$ height of web

$b_{tf} := 9\ in$ width of top flange

$b_{bf} := 9.5\ in$ width of bottom flange

$b_w := 2.5\ in$ width of web

$h := t_{tf} + t_{bf} + h_w = 18.5\ in$ beam height

$L_{p.xs} := 2 \cdot (t_{tf} + t_{bf} + h_w) + b_{tf} + b_{bf} + (b_{tf} - b_w) + (b_{bf} - b_w) = 69\ in$
perimeter of cross section

LOADING

$P_{tot} := 34.9\ kip$ total applied actuator load

Predictions

Cracking Load: 22.8 kips
Breaking Load: 34.9 kips

$P := 0.5\ P_{tot} = 17.5\ kip$ half of actuator load to each point load

Test Results

Cracking Load: 22.7 kip
Breaking Load: 38.6 kip

MATERIAL PROPERTIES

$\rho := 124.1\ pcf$ concrete density (normalweight)

$E_{ps} := 28500\ ksi$ prestressing strand modulus of elasticity

$E_s := 29000\ ksi$ steel reinforcement modulus of elasticity

$f_{pu} := 270\ ksi$ strength of prestressing strands

Concrete Properties

Section updated based on cylinder test data

$f'_{ci.req} := 5000\ psi$ required strength of concrete to cut strands

$f'_{ci} := 5077.5\ psi$ initial concrete strength (when strands cut)

$f'_{c.req} := 8000\ psi$ required strength of concrete to test

$f'_c := 7260\ psi$ strength of concrete (based on ASTM C78)

$d_{agr} := 0.5\ in$ diameter of aggregate

$E_{ci} := 33 \cdot (\rho \div pcf)^{1.5} \cdot \sqrt[2]{f'_{ci} \cdot psi} = 3251\ ksi$ initial concrete modulus of elasticity

$E_c := 33 \cdot (\rho \div pcf)^{1.5} \cdot \sqrt[2]{f'_c \cdot psi} = 3887\ ksi$ concrete modulus of elasticity

$\lambda := 0.75$ Lightweight factor = 1 normalweight, 0.75 lightweight

$RH := 75$ relative humidity, (%)

STRAND & REINFORCEMENT

Prestressing Strands (7-wire) (bottom)

$d_{ps} := 0.6\ in$ diameter

$A_{ps1} := 0.217\ in^2$ nominal area

$y_{ps1} := 3.5\ in$ height of prestressing strand 1, from bottom

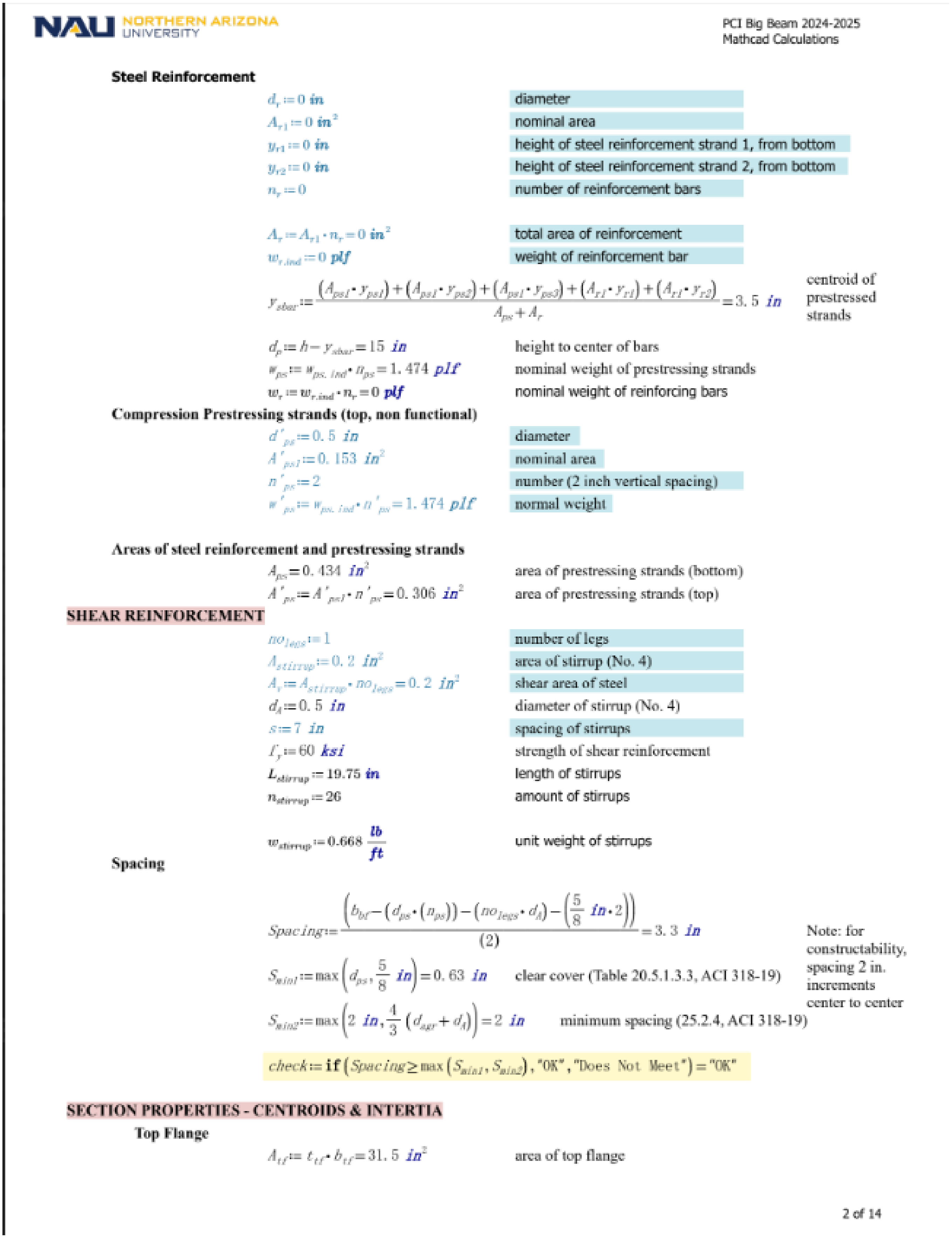
$y_{ps2} := 3.5\ in$ height of prestressing strand 2, from bottom

$y_{ps3} := 0\ in$ height of prestressing strand 3, from bottom

$n_{ps} := 2$ number prestressing strands

$A_{ps} := A_{ps1} \cdot n_{ps} = 0.434\ in^2$ total area of prestressing strands

$w_{ps.ind} := 0.737\ plf$



Steel Reinforcement

$d_r := 0\ in$ diameter

$A_{r1} := 0\ in^2$ nominal area

$y_{r1} := 0\ in$ height of steel reinforcement strand 1, from bottom

$y_{r2} := 0\ in$ height of steel reinforcement strand 2, from bottom

$n_r := 0$ number of reinforcement bars

$A_r := A_{r1} \cdot n_r = 0\ in^2$ total area of reinforcement

$w_{r.ind} := 0\ plf$ weight of reinforcement bar

$$y_{sbar} := \frac{(A_{ps1} \cdot y_{ps1}) + (A_{ps1} \cdot y_{ps2}) + (A_{ps1} \cdot y_{ps3}) + (A_{r1} \cdot y_{r1}) + (A_{r1} \cdot y_{r2})}{A_{ps} + A_r} = 3.5\ in$$

centroid of prestressed strands

$d_p := h - y_{sbar} = 15\ in$ height to center of bars

$w_{ps} := w_{ps.ind} \cdot n_{ps} = 1.474\ plf$ nominal weight of prestressing strands

$w_r := w_{r.ind} \cdot n_r = 0\ plf$ nominal weight of reinforcing bars

Compression Prestressing strands (top, non functional)

$d'_{ps} := 0.5\ in$ diameter

$A'_{ps1} := 0.153\ in^2$ nominal area

$n'_{ps} := 2$ number (2 inch vertical spacing)

$w'_{ps} := w_{ps.ind} \cdot n'_{ps} = 1.474\ plf$ normal weight

Areas of steel reinforcement and prestressing strands

$A_{ps} = 0.434\ in^2$ area of prestressing strands (bottom)

$A'_{ps} := A'_{ps1} \cdot n'_{ps} = 0.306\ in^2$ area of prestressing strands (top)

SHEAR REINFORCEMENT

$no_{legs} := 1$ number of legs

$A_{stirrup} := 0.2\ in^2$ area of stirrup (No. 4)

$A_v := A_{stirrup} \cdot no_{legs} = 0.2\ in^2$ shear area of steel

$d_A := 0.5\ in$ diameter of stirrup (No. 4)

$s := 7\ in$ spacing of stirrups

$f_y := 60\ ksi$ strength of shear reinforcement

$L_{stirrup} := 19.75\ in$ length of stirrups

$n_{stirrup} := 26$ amount of stirrups

$w_{stirrup} := 0.668\ \frac{lb}{ft}$ unit weight of stirrups

Spacing

$$Spacing := \frac{\left(b_{bf} - (d_{ps} \cdot (n_{ps})) - (no_{legs} \cdot d_A) - \left(\frac{5}{8}\ in \cdot 2\right)\right)}{(2)} = 3.3\ in$$

$S_{min1} := \max\left(d_{ps}, \frac{5}{8}\ in\right) = 0.63\ in$ clear cover (Table 20.5.1.3.3, ACI 318-19)

$S_{min2} := \max\left(2\ in, \frac{4}{3}\left(d_{agr} + d_A\right)\right) = 2\ in$ minimum spacing (25.2.4, ACI 318-19)

Note: for constructability, spacing 2 in. increments center to center

$check := \text{if}\left(Spacing \geq \max\left(S_{min1}, S_{min2}\right), \text{"OK"}, \text{"Does Not Meet"}\right) = \text{"OK"}$

SECTION PROPERTIES - CENTROIDS & INTERTIA

Top Flange

$A_{tf} := t_{tf} \cdot b_{tf} = 31.5\ in^2$ area of top flange

$y_{tf} := \frac{t_{tf}}{2} + h_w + t_{bf} = 16.75\ in$ centroid of top flange

Web

$A_w := b_w \cdot h_w = 22.5\ in^2$ area of web

$y_w := \frac{h_w}{2} + t_{bf} = 10.5\ in$ centroid of web

Bottom Flange

$A_{bf} := t_{bf} \cdot b_{bf} = 57\ in^2$ area of bottom flange

$y_{bf} := \frac{t_{bf}}{2} = 3\ in$ centroid of bottom flange

Beam

$y_{barbot} := \frac{(A_{tf} \cdot y_{tf}) + (A_w \cdot y_w) + (A_{bf} \cdot y_{bf})}{A_{tf} + A_w + A_{bf}} = 8.422\ in$ centroid of beam, from bottom

$y_{bartop} := h - y_{barbot} = 10.078\ in$ centroid of beam, from top

$A_g := A_{tf} + A_w + A_{bf} = 111\ in^2$ gross area of concrete

$V_g := A_g \cdot L = 0.51\ yd^3$ gross volume of concrete, CY

$e := d_p - y_{bartop} = 4.922\ in$ eccentricity

Moment of Inertia

$I_{tf} := \frac{1}{12}\ b_{tf} \cdot t_{tf}^3 + A_{tf} \cdot (y_{tf} - y_{barbot})^2 = 2216.701\ in^4$ inertia top flange

$I_w := \frac{1}{12}\ b_w \cdot (h - t_{tf} - t_{bf})^3 + A_w \cdot (y_w - y_{barbot})^2 = 249.004\ in^4$ inertia web

$I_{bf} := \frac{1}{12}\ b_{bf} \cdot t_{bf}^3 + A_{bf} \cdot (y_{bf} - y_{barbot})^2 = 1846.875\ in^4$ inertia bottom flange

$I_g := I_{tf} + I_w + I_{bf} = 4312.58\ in^4$ total inertia

$EI := E_c \cdot I_g = 116416.51\ ft^2 \cdot kip$ EI check

APPLIED LOADS, SHEAR, AND MOMENT

Selfweight

$w_{swc} := A_g \cdot \rho = 95.7\ plf$ concrete selfweight, distributed load

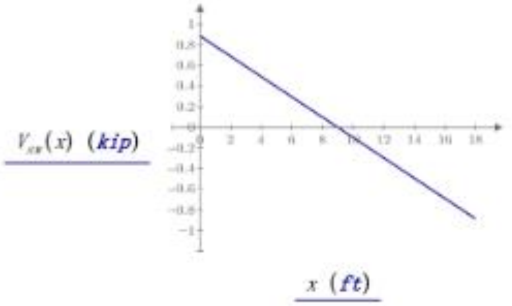
$w_{sw} := w_{swc} + w'_{ps} + w_{ps} = 98.6\ plf$ total self weight, distributed load

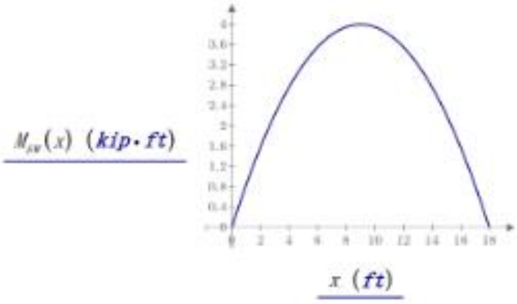
$W_{swt.p} := w_{sw} \cdot L = 1775\ lbf$ weight, for shipping & handling

$check := \text{if}\left(W_{swt.p} < 2000\ lbf, \text{"OK"}, \text{"Make Lighter"}\right) = \text{"OK"}$

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

$V_{sw}(x) := w_{sw} \cdot (0.5 \cdot L - x)$ selfweight shear





Live Load

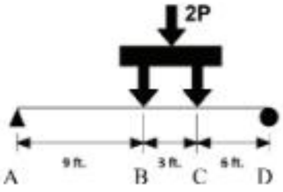


Figure 2: Loading Diagram i

$AB := 9\ ft$ $CD := 6\ ft$ $BC := L - AB - CD = 3\ ft$

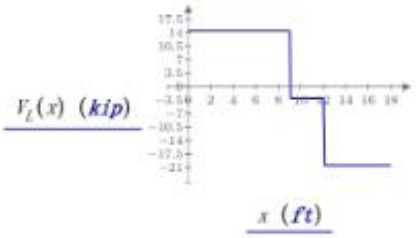
$L_{ab} := AB = 9\ ft$ $L_{ac} := AB + BC = 12\ ft$ $L_{ad} := L = 18\ ft$

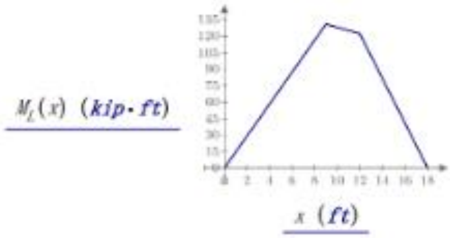
$R_A := P \div L \cdot (L - AB + CD) = 14.54\ kip$

$R_D := P \div L \cdot (L - CD + AB) = 20.36\ kip$

$$V_L(x) := \mathbf{if}\left(x \le L_{ab}, R_A, \mathbf{if}\left(L_{ab} < x \le L_{ac}, P \div L \cdot (CD - AB), -R_D\right)\right)$$

$$M_L(x) := \mathbf{if}\left(x \le L_{ab}, R_A \cdot x, \mathbf{if}\left(L_{ab} < x < L_{ac}, R_A \cdot x - P \cdot (x - AB), R_D \cdot CD - R_D \cdot (x - L_{ac})\right)\right)$$





Total Loads

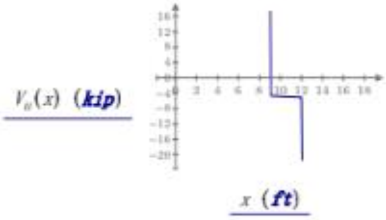
$V_{service}(x) := V_{sw}(x) + V_L(x)$ total unfactored service shear

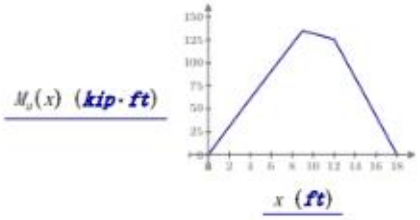
$M_{service}(x) := M_{sw}(x) + M_L(x)$ total unfactored service moment

$V_u(x) := 1.2 \cdot V_{sw}(x) + 1.6 \cdot V_L(x)$ total factored service shear

(load factors = 1.0 for accurate lab testing)

$M_u(x) := M_{sw}(x) + M_L(x)$ total factored service moment





LOSSES

$f_j := 0.75 \cdot f_{pu} = 202.5\ \mathbf{ksi}$ jacking stress

Elastic Shortening (ES)

$P_j := f_j \cdot A_{ps} = 87.9\ \mathbf{kip}$ jacking force

$P_{j.perstrand} := \dfrac{P_j}{n_{ps}} = 43.9\ \mathbf{kip}$ Jacking force per strand

$M_{sw\_mid} := \dfrac{w_{sw} \cdot L^2}{8} = 47.924\ \mathbf{kip \cdot in}$ max moment of beam (selfweight)

$k_{ES} := 1.0$ kes constant - pretentioned members

$k_{cir} := 0.9$ kcir constant - pretentioned members

$f_{cir} := k_{cir} \cdot \left(\dfrac{P_j}{A_g} + \dfrac{P_j \cdot e^2}{I_g}\right) - \dfrac{M_{sw\_mid} \cdot e}{I_g} = 1.1\ \mathbf{ksi}$ strand stress at CGS

$ES := \dfrac{E_{ps}}{E_{ci}} \cdot k_{ES} \cdot f_{cir} = 9.7\ \mathbf{ksi}$ elastic shortening

Creep (CR)

$k_{cr} := \mathbf{if}\ (\lambda < 1, 1.6, 2) = 1.6$ creep strain amplifier

$CR := k_{cr} \cdot \dfrac{E_{ps}}{E_c} \cdot (f_{cir}) = 12.9\ \mathbf{ksi}$ creep

Shrinkage (SH)

$V_{div.S} := A_g \div L_{p.xs} = 1.609\ \mathbf{in}$

$k_{sh} := 1.0$ shrinkage constant

$SH := \left(\left(8.2 \cdot 10^{-6}\right) \cdot k_{sh} \cdot E_{ps} \cdot \dfrac{1}{\mathbf{ft}} \left(1\ \mathbf{ft} - \left(0.06 \cdot V_{div.S}\right)\right) (100 - RH)\right) = 5.8\ \mathbf{ksi}$

Steel relaxation (RE)

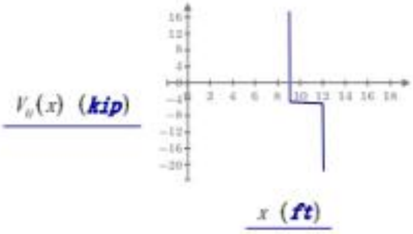
$k_{RE} := 5\ \mathbf{ksi}$ *[PT 5.8.1]*

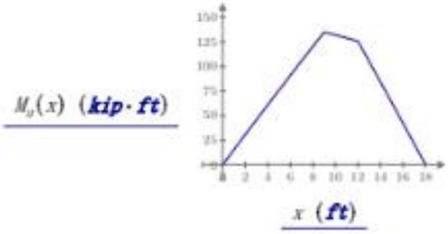
$J := 0.04$ *[PT 5.8.1]*

$C := 1.0$ *[PT 5.8.2]*

$ju_{ps} := \left(f_j - ES\right) \div f_{pu} = 0.714$

$C_{ps} := \mathbf{if}\left(ju_{ps} \ge 0.54, \dfrac{ju_{ps}}{0.21} \cdot \left(\dfrac{ju_{ps}}{0.9} - 0.55\right), \dfrac{ju_{ps}}{4.25}\right) = 0.828$ bottom strands





LOSSES

$f_j := 0.75 \cdot f_{pu} = 202.5\ \textbf{ksi}$ jacking stress

Elastic Shortening (ES)

$P_j := f_j \cdot A_{ps} = 87.9\ \textbf{kip}$ jacking force

$P_{j.perstrand} := \dfrac{P_j}{n_{ps}} = 43.9\ \textbf{kip}$ Jacking force per strand

$M_{sw\_mid} := \dfrac{w_{sw} \cdot L^2}{8} = 47.924\ \textbf{kip} \cdot \textbf{in}$ max moment of beam (selfweight)

$k_{ES} := 1.0$ kes constant - pretentioned members

$k_{cir} := 0.9$ kcir constant - pretentioned members

$f_{cir} := k_{cir} \cdot \left(\dfrac{P_j}{A_g} + \dfrac{P_j \cdot e^2}{I_g}\right) - \dfrac{M_{sw\_mid} \cdot e}{I_g} = 1.1\ \textbf{ksi}$ strand stress at CGS

$ES := \dfrac{E_{ps}}{E_{ci}} \cdot k_{ES} \cdot f_{cir} = 9.7\ \textbf{ksi}$ elastic shortening

Creep (CR)

$k_{cr} := \textbf{if}\ (\lambda < 1, 1.6, 2) = 1.6$ creep strain amplifier

$CR := k_{cr} \cdot \dfrac{E_{ps}}{E_c} \cdot (f_{cir}) = 12.9\ \textbf{ksi}$ creep

Shrinkage (SH)

$V_{div.S} := A_g \div L_{p.xs} = 1.609\ \textbf{in}$

$k_{sh} := 1.0$ shrinkage constant

$SH := \left(\left(8.2 \cdot 10^{-6}\right) \cdot k_{sh} \cdot E_{ps} \cdot \dfrac{1}{\textbf{ft}} \left(1\ \textbf{ft} - \left(0.06 \cdot V_{div.S}\right)\right) (100 - RH)\right) = 5.8\ \textbf{ksi}$

Steel relaxation (RE)

$k_{RE} := 5\ \textbf{ksi}$ *[PT 5.8.1]*

$J := 0.04$ *[PT 5.8.1]*

$C := 1.0$ *[PT 5.8.2]*

$ju_{ps} := \left(f_j - ES\right) \div f_{pu} = 0.714$

$C_{ps} := \textbf{if}\left(ju_{ps} \ge 0.54, \dfrac{ju_{ps}}{0.21} \cdot \left(\dfrac{ju_{ps}}{0.9} - 0.55\right), \dfrac{ju_{ps}}{4.25}\right) = 0.828$ bottom strands

$RE := \left(k_{RE} - J \cdot (SH + CR + ES)\right) \cdot C_{ps} = 3.2\ \mathbf{ksi}$ relaxation

STRESS AND FORCE AFTER LOSSES

$L_{sht} := ES = 9.7\ \mathbf{ksi}$ short term losses

$L_{lnt} := CR + SH + RE = 21.9\ \mathbf{ksi}$ long term losses

$TL := L_{sht} + L_{lnt} = 31.6\ \mathbf{ksi}$ total losses

$f_{pi} := f_j - ES = 192.8\ \mathbf{ksi}$ initial stress after ES

$P_i := A_{ps} \cdot f_{pi} = 83.7\ \mathbf{kip}$ prestress force after ES at transfer

$f_{se} := f_j - CR - SH - RE = 180.6\ \mathbf{ksi}$ final stress after all losses

$P_e := f_{se} \cdot A_{ps} = 78.4\ \mathbf{kip}$ prestress force after ES at transfer

FLEXURAL CAPACITY

Code Equations

$check := \mathbf{if}\left(f_{se} \ge 0.5\ f_{pu}, \text{"OK"}, \text{"Condition Not Met"}\right) = \text{"OK"}$

$$\rho_p := \frac{A_{ps}}{b_{tf} \cdot d_p} = 0.003$$

$\gamma_p := 0.28$ gamma factor for prestressing

$$\beta_1 := \max\left(0.65, min\left(0.85, 0.85 - 0.05 \cdot \left(\frac{\left(f'_c - 4000\ \mathbf{psi}\right)}{1000\ \mathbf{psi}}\right)\right)\right) = 0.687$$ beta strength factor

$$f_{ps} := f_{pu} \cdot \left(1 - \frac{\gamma_p}{\beta_1} \cdot \left(\rho_p \cdot \frac{f_{pu}}{f'_c}\right)\right) = 256.843\ \mathbf{ksi}$$ flexural strength

$$a := \frac{A_{ps} \cdot f_{ps}}{0.85 \cdot f'_c \cdot b_{tf}} = 2.007\ \mathbf{in}$$ depth of Whitney stress block

$$c := \frac{a}{\beta_1} = 2.921\ \mathbf{in}$$ depth to neutral axis

$c := 3.031\ \mathbf{in}$ refined guess at c

Refine with Strain Compatibility

$$\varepsilon_1 := \frac{f_{se}}{E_{ps}} = 6.3 \cdot 10^{-3}$$ strain due to Pe alone

$$\varepsilon_2 := \frac{P_e}{A_g \cdot E_c} \cdot \left(1 + \frac{e^2 \cdot A_g}{I_g}\right) = 2.9 \cdot 10^{-4}$$ increase in steel strain to decompress concrete at the steel

$\varepsilon_{cu} := 0.003$ ultimate strain in concrete

$$\varepsilon_3 := \varepsilon_{cu} \cdot \left(\frac{d_p - c}{c}\right) = 1.2 \cdot 10^{-2}$$ steel strain to failure, concrete crushing

$\varepsilon_{ps} := \varepsilon_1 + \varepsilon_2 + \varepsilon_3 = 1.8 \cdot 10^{-2}$ total steel strain at failure

$$f_{ps} := \mathbf{if}\left(\varepsilon_{ps} \le 0.0085, 28800\ \mathbf{ksi} \cdot \varepsilon_{ps}, 270\ \mathbf{ksi} - \frac{0.04}{\varepsilon_{ps} - 0.007} \cdot \mathbf{ksi}\right) = 266.5\ \mathbf{ksi}$$

$$c := \frac{A_{ps} \cdot f_{ps}}{0.85 \cdot f'_c \cdot \beta_1 \cdot b_{tf}} = 3.031\ \mathbf{in}$$ depth of neutral axis

$$a := \frac{A_{ps} \cdot f_{ps}}{0.85 \cdot f'_c \cdot b_{tf}} = 2.083\ \mathbf{in}$$

$check := \mathbf{if}\left(a < t_{tf}, \text{"OK"}, \text{"Condition Not Met"}\right) = \text{"OK"}$

$$M_n := \mathbf{if}\left(a > t_{tf}, \left(\left(0.85 \cdot f'_c \cdot t_{tf} \cdot (b_{bf} - b_w) \cdot \left(\frac{a}{2} - \frac{t_{tf}}{2}\right)\right) + A_{ps} \cdot f_{ps} \cdot \left(d_p - \frac{a}{2}\right)\right), A_{ps} \cdot f_{ps} \cdot \left(d_p - \frac{a}{2}\right)\right)$$

$M_n = 134.5\ \mathbf{kip \cdot ft}$ nominal moment

$\phi_{flexure} := 1.0$ use 1.0 to calculate lab capacity

$\phi M_n := \phi_{flexure} \cdot M_n = 134.5\ \mathbf{kip \cdot ft}$ factored nominal moment

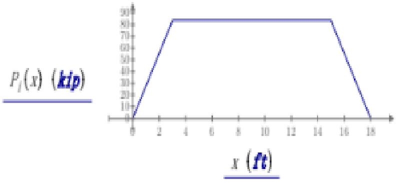
TRANSFER AND DEVELOPMENT LENGTH

$l_t := f_{se} \div (3\ \mathbf{ksi}) \cdot d_{ps} = 36.1\ \mathbf{in}$ $l_t = 3.01\ \mathbf{ft}$ transfer length

$l_d := l_t + \left(f_{ps} - f_{se}\right) \div (1\ \mathbf{ksi}) \cdot d_{ps} = 87.7\ \mathbf{in}$ $l_d = 7.31\ \mathbf{ft}$ development length

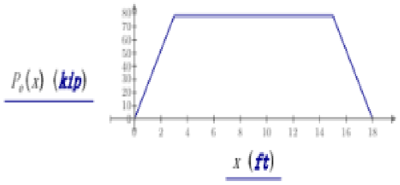
Force at Transfer

$$P_i(x) := \mathbf{if}\left(x \le l_t, \frac{x}{l_t} \cdot P_i, \mathbf{if}\left(l_t < x \le L - l_t, P_i, P_i - \frac{P_i}{l_t} \cdot (x - (L - l_t))\right)\right)$$



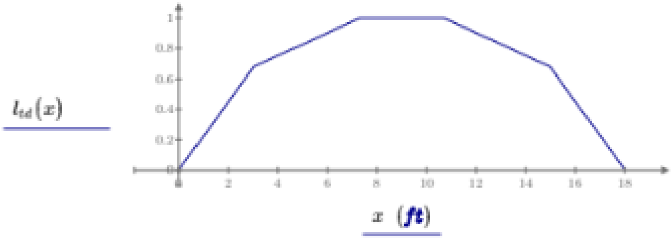
Force at Service

$$P_e(x) := \mathbf{if}\left(x \le l_t, \frac{x}{l_t} \cdot P_e, \mathbf{if}\left(l_t < x \le L - l_t, P_e, P_e - \frac{P_e}{l_t} \cdot (x - (L - l_t))\right)\right)$$



Transfer & Development Length Factor

$$l_{td}(x) := \mathbf{if}\left(x < l_t, \frac{x}{l_t}\cdot\frac{f_{se}}{f_{pu}}, \mathbf{if}\left(l_t \le x \le l_d, \frac{x-l_t}{l_d-l_t}\cdot\left(1-\frac{f_{se}}{f_{pu}}\right)+\frac{f_{se}}{f_{pu}}, \mathbf{if}\left(l_d < x \le L-l_d, 1, \mathbf{if}\left(L-l_d < x \le L-l_t, 1-\frac{x-(L-l_d)}{l_d-l_t}\cdot\left(1-\frac{f_{se}}{f_{pu}}\right), \frac{f_{se}}{f_{pu}}-\frac{x-(L-(l_t))}{l_t}\cdot\frac{f_{se}}{f_{pu}}\right)\right)\right)\right)$$



LLOWABLE STRESS VS. LIMITS

STRESSES AT TRANSFER

Stress Limits

$\sigma_{c.end} := -0.7 \cdot f'_{ci} = -3554.3\ psi$ allowable compressive stress at end

$\sigma_{c.mid} := -0.6 \cdot f'_{ci} = -3046.5\ psi$ allowable compressive stress at middle

$\sigma_{tc.PCI}(x) := \mathbf{if}\left(x < 0.25 \cdot L, -0.7 \cdot f'_{ci}, \mathbf{if}\left(0.25 \cdot L < x < 0.75 \cdot L, -0.6 \cdot f'_{ci}, -0.7 \cdot f'_{ci}\right)\right)$

$\sigma_{t.end} := 6 \cdot \sqrt{f'_{ci}} \cdot \sqrt{psi} = 428\ psi$ allowable tensile stress at end

$\sigma_{t.mid} := 3 \cdot \sqrt{f'_{ci}} \cdot \sqrt{psi} = 214\ psi$ allowable tensile stress at middle

$\sigma_{tt.PCI}(x) := \mathbf{if}\left(x < 0.25 \cdot L, 6 \cdot \sqrt{f'_{ci} \cdot psi}, \mathbf{if}\left(0.25 \cdot L < x < 0.75 \cdot L, 3 \cdot \sqrt{f'_{ci} \cdot psi}, 6 \cdot \sqrt{f'_{ci} \cdot psi}\right)\right)$

Applied Stress

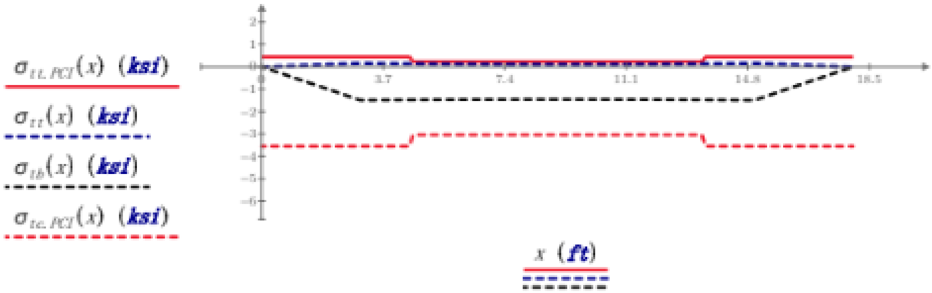
$\sigma_{tt}(x) := -\frac{P_i(x)}{A_g} + \frac{P_i(x) \cdot e \cdot y_{bartop}}{I_g} - \frac{M_{sw}(x) \cdot y_{bartop}}{I_g}$ applied stress at top

$\sigma_{tb}(x) := -\frac{P_i(x)}{A_g} - \frac{P_i(x) \cdot e \cdot y_{barbot}}{I_g} + \frac{M_{sw}(x) \cdot y_{barbot}}{I_g}$ applied stress at bottom

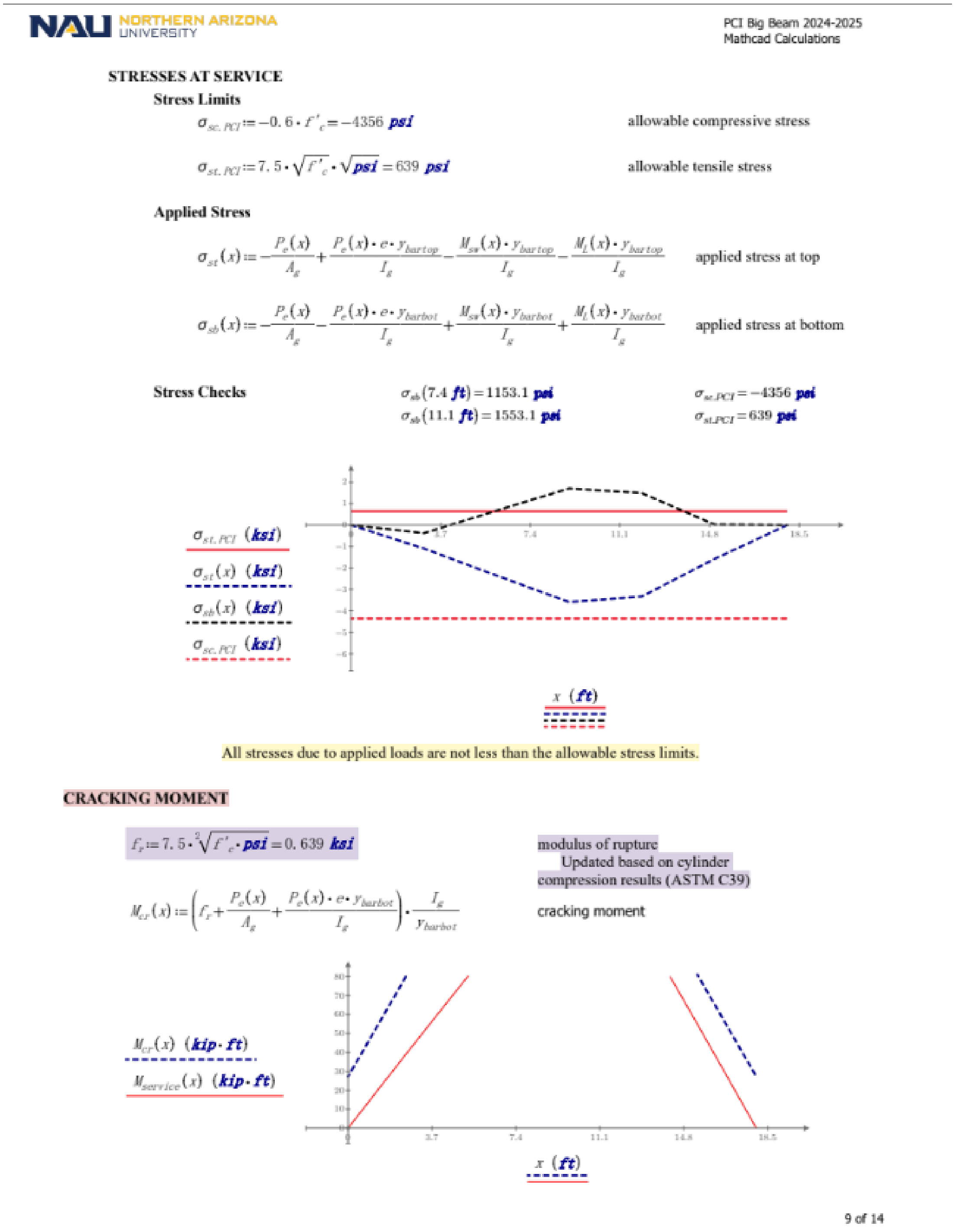
Stress Checks

$\sigma_{tt}(7.4\ ft) = 100.2\ psi$
$\sigma_{tt}(11.1\ ft) = 102.8\ psi$
$\sigma_{tb}(7.4\ ft) = -1467.9\ psi$

$\sigma_{tt.PCI}(7.4\ ft) = 213.8\ psi$
$\sigma_{tt.PCI}(11.1\ ft) = 213.8\ psi$
$\sigma_{tc.PCI}(7.4\ ft) = -3046.5\ psi$



All stresses due to applied loads are less than the allowable stress limits.



STRESSES AT SERVICE

Stress Limits

$\sigma_{sc.PCI} := -0.6 \cdot f'_c = -4356\ psi$ allowable compressive stress

$\sigma_{st.PCI} := 7.5 \cdot \sqrt{f'_c} \cdot \sqrt{psi} = 639\ psi$ allowable tensile stress

Applied Stress

$$\sigma_{st}(x) := -\frac{P_e(x)}{A_g} + \frac{P_e(x) \cdot e \cdot y_{bartop}}{I_g} - \frac{M_{sw}(x) \cdot y_{bartop}}{I_g} - \frac{M_L(x) \cdot y_{bartop}}{I_g}$$

applied stress at top

$$\sigma_{sb}(x) := -\frac{P_e(x)}{A_g} - \frac{P_e(x) \cdot e \cdot y_{barbot}}{I_g} + \frac{M_{sw}(x) \cdot y_{barbot}}{I_g} + \frac{M_L(x) \cdot y_{barbot}}{I_g}$$

applied stress at bottom

Stress Checks

$\sigma_{sb}(7.4\ ft) = 1153.1\ psi$

$\sigma_{sb}(11.1\ ft) = 1553.1\ psi$

$\sigma_{sc.PCI} = -4356\ psi$

$\sigma_{st.PCI} = 639\ psi$

All stresses due to applied loads are not less than the allowable stress limits.

CRACKING MOMENT

$f_r := 7.5 \cdot \sqrt[2]{f'_c \cdot psi} = 0.639\ ksi$

modulus of rupture
Updated based on cylinder
compression results (ASTM C39)

$$M_{cr}(x) := \left(f_r + \frac{P_e(x)}{A_g} + \frac{P_e(x) \cdot e \cdot y_{barbot}}{I_g} \right) \cdot \frac{I_g}{y_{barbot}}$$

cracking moment

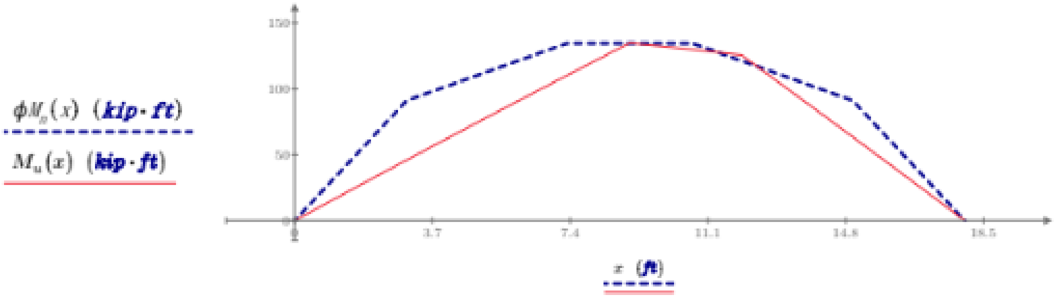
$check := \mathbf{if}\left(M_{service}(AB) > M_{cr}(AB), \text{"Crack"}, \text{"Not Crack"}\right) = \text{"Crack"}$

$M_{service}(AB) = 134.9\ \mathbf{kip \cdot ft}$ $M_{cr}(AB) = 89.5\ \mathbf{kip \cdot ft}$ $M_{ratio} := M_{service}(AB) \div M_{cr}(AB) = 1.51$

NOMINAL MOMENT CAPACITY VS. DEMAND

Modified Flexural Capacity

$\phi M_n(x) := \phi_{flexure} \cdot M_n \cdot I_{td}(x)$



$check := \mathbf{if}\left(M_u(AB) > \phi M_n(AB), \text{"Fail"}, \text{"Not Fail"}\right) = \text{"Fail"}$

$M_u(AB) = 134.9\ \mathbf{kip \cdot ft}$ $\phi M_n(AB) = 134.5\ \mathbf{kip \cdot ft}$ $M_u(AB) \div \phi M_n(AB) = 1.00$

SHEAR CAPACITY

$\phi_{shear} := 1.0$ resistance factor for shear

$L_{t,shear} := 50 \cdot d_{ps} = 2.5\ \mathbf{ft}$ $[A22.5.7.1]$

Checks to use simple method

$x_{crit} := \frac{h}{2} = 9.25\ \mathbf{in}$

$check := \mathbf{if}\left(A_{ps} \cdot f_{se} > 0.4\ A_{ps} \cdot f_{pu}, \text{"OK to use Simple Method"}, \text{"Recheck"}\right) = \text{"OK to use Simple Method"}$

$A_v = 0.2\ \mathbf{in}^2$ area of stirrups

$V_{c1}(x) := \left(0.6 \cdot \lambda \cdot \sqrt{f'_c \cdot \mathbf{psi}} + 700\ \mathbf{psi} \cdot min\left(\frac{|V_u(x)| \cdot d_p}{|M_u(x)|}, 1\right)\right) \cdot b_w \cdot \max\left(d_p, 0.8 \cdot h\right)$ concrete shear strength

$V_{c.min} := 2 \cdot \lambda \cdot \sqrt{f'_c \cdot \mathbf{psi}} \cdot b_w \cdot d_p = 4.8\ \mathbf{kip}$ min concrete contribution

$V_{c.max} := 5 \cdot \lambda \cdot \sqrt{f'_c \cdot \mathbf{psi}} \cdot b_w \cdot d_p = 12\ \mathbf{kip}$ max concrete contribution

$V_c(x) := \max\left(min\left(V_{c.max}, V_{c1}(x)\right), V_{c.min}\right)$

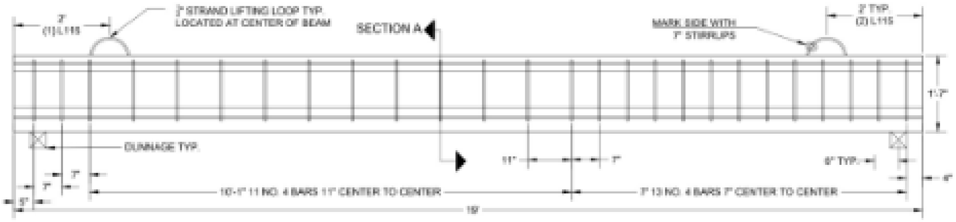


Figure 3: Stirrup Design from shop drawings

s_1 s_2 s_3

$s_1 := 7\ \mathbf{in}$ $s_2 := 11\ \mathbf{in}$ $s_3 := 7\ \mathbf{in}$ spacing

$V_{s1} := \frac{A_v \cdot f_y \cdot d_p}{s_1} = 25.714\ \mathbf{kip}$ $V_{s2} := \frac{A_v \cdot f_y \cdot d_p}{s_2} = 16.364\ \mathbf{kip}$ $V_{s3} := \frac{A_v \cdot f_y \cdot d_p}{s_3} = 25.714\ \mathbf{kip}$ steel shear strength

$s_{max1} := \mathbf{if}\left(V_{s1} > 4 \cdot \lambda \cdot \sqrt{f'_c \cdot \mathbf{psi}} \cdot b_w \cdot d_p, min\left(0.375 \cdot h, 12\ \mathbf{in}\right), min\left(0.75 \cdot h, 24\ \mathbf{in}\right)\right) = 6.9\ \mathbf{in}$ max stirrup spacing

$s_{max2} := \mathbf{if}\left(V_{s2} > 4 \cdot \lambda \cdot \sqrt{f'_c \cdot \mathbf{psi}} \cdot b_w \cdot d_p, min\left(0.375 \cdot h, 12\ \mathbf{in}\right), min\left(0.75 \cdot h, 24\ \mathbf{in}\right)\right) = 6.9\ \mathbf{in}$

$s_{max3} := \mathbf{if}\left(V_{s3} > 4 \cdot \lambda \cdot \sqrt{f'_c \cdot \mathbf{psi}} \cdot b_w \cdot d_p, min\left(0.375 \cdot h, 12\ \mathbf{in}\right), min\left(0.75 \cdot h, 24\ \mathbf{in}\right)\right) = 6.9\ \mathbf{in}$

$A_{v.min} := min\left(\frac{A_{ps} \cdot f_{pu} \cdot s}{80 \cdot f_y \cdot d_p} \cdot \sqrt{\frac{d_p}{b_w}}, \max\left(0.75 \cdot \sqrt{f'_c \cdot \mathbf{psi}} \cdot \frac{b_w \cdot s}{f_y}, 50\ \mathbf{psi} \cdot \frac{b_w \cdot s}{f_y}\right)\right) = 0.019\ \mathbf{in}^2$ min stirrup area

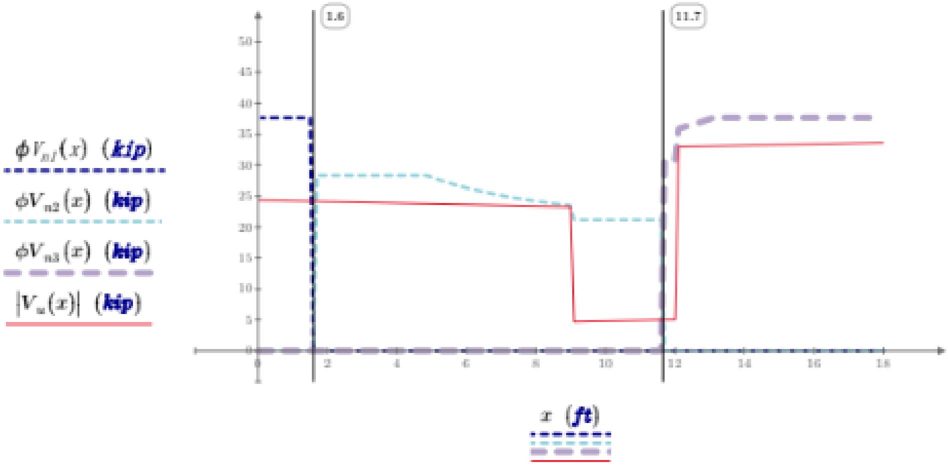
$\phi V_{n1}(x) := \mathbf{if}\left(x < 1.6\ \mathbf{ft}, \phi_{shear} \cdot \left(V_c(x) + V_{s1}\right), 0\right)$ Limits for plotting readability

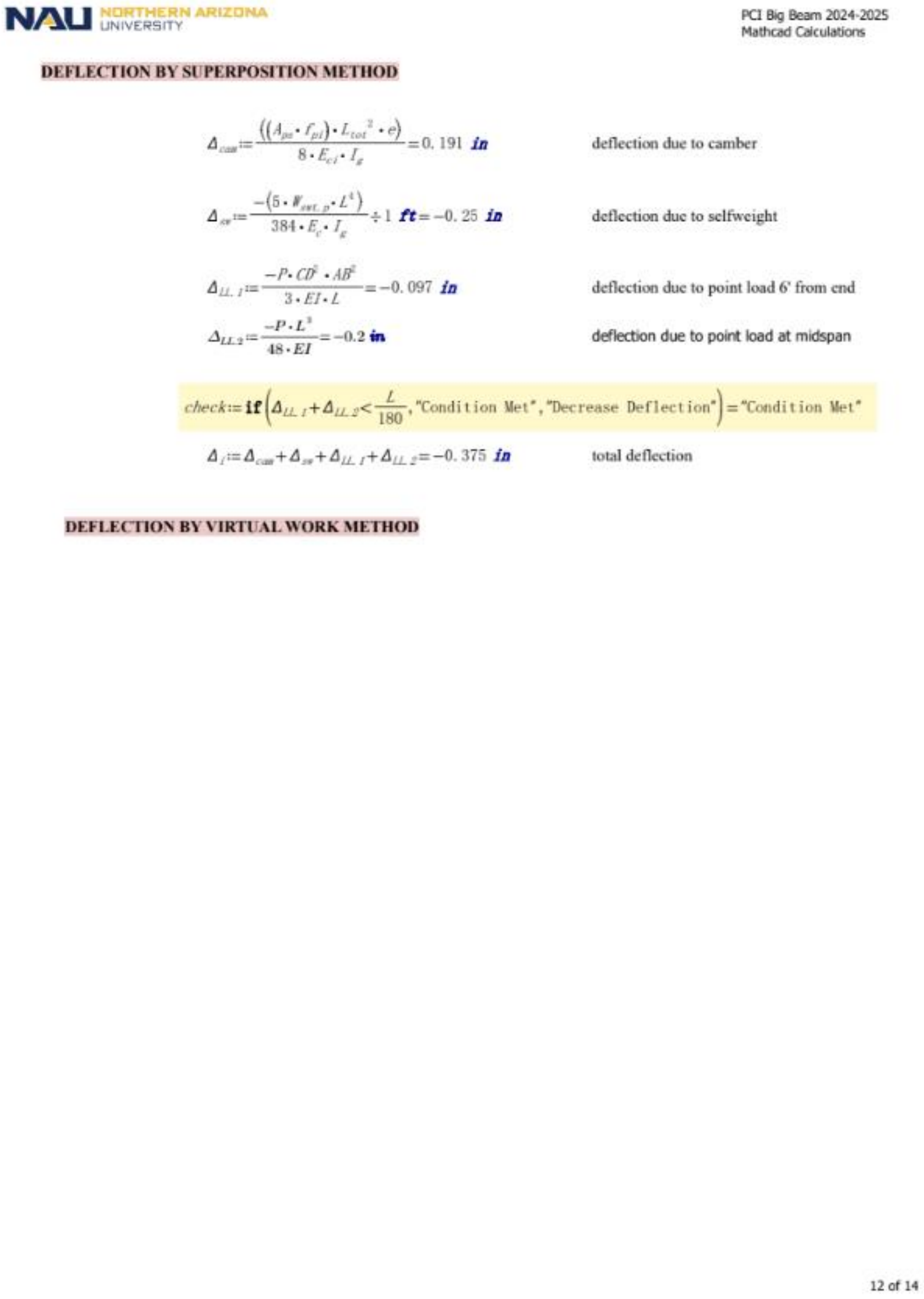
$\phi V_{n2}(x) := \mathbf{if}\left(1.6\ \mathbf{ft} < x < 11.7\ \mathbf{ft}, \phi_{shear} \cdot \left(V_c(x) + V_{s2}\right), 0\right)$

$\phi V_{n3}(x) := \mathbf{if}\left(x > 11.7\ \mathbf{ft}, \phi_{shear} \cdot \left(V_c(x) + V_{s3}\right), 0\right)$

$\left(V_u(x)\right)$ factored shear capacity

$\phi V_{n1}(x)$ $\phi V_{n2}(x)$ $\phi V_{n1}(x)$





NAU NORTHERN ARIZONA UNIVERSITY

PCI Big Beam 2024-2025
Mathcad Calculations

DEFLECTION BY SUPERPOSITION METHOD

$$\Delta_{cam} := \frac{\left(\left(A_{ps} \cdot f_{pi}\right) \cdot L_{tot}^{2} \cdot e\right)}{8 \cdot E_{ci} \cdot I_{g}} = 0.191\ in$$

deflection due to camber

$$\Delta_{sw} := \frac{-\left(5 \cdot W_{swt.p} \cdot L^{4}\right)}{384 \cdot E_{c} \cdot I_{g}} \div 1\ ft = -0.25\ in$$

deflection due to selfweight

$$\Delta_{LL.1} := \frac{-P \cdot CD^{2} \cdot AB^{2}}{3 \cdot EI \cdot L} = -0.097\ in$$

deflection due to point load 6' from end

$$\Delta_{LL2} := \frac{-P \cdot L^{3}}{48 \cdot EI} = -0.2\ in$$

deflection due to point load at midspan

$$check := \mathbf{if}\left(\Delta_{LL.1} + \Delta_{LL.2} < \frac{L}{180}, \text{"Condition Met"}, \text{"Decrease Deflection"}\right) = \text{"Condition Met"}$$

$$\Delta_{t} := \Delta_{cam} + \Delta_{sw} + \Delta_{LL.1} + \Delta_{LL.2} = -0.375\ in$$

total deflection

DEFLECTION BY VIRTUAL WORK METHOD

12 of 14

COST

Concrete

$f'_c = 7.26\ \boldsymbol{ksi}$ strength of concrete, at 28 days

$C_c := \left(20 + \left(\frac{10 \cdot \boldsymbol{in}^2}{\boldsymbol{kip}} \cdot f'_c\right)\right) = 92.6$ cost of concrete, $

Formwork

$L_{p.xs} = 5.8\ \boldsymbol{ft}$

$C_{fw} := \left(L_{p.xs} - b_{tf}\right) \cdot (L) \cdot \frac{1.25}{\boldsymbol{ft}^2} = 112.5$ cost of formwork, $

Prestressing Reinforcement

$d_{ps} = 0.6\ \boldsymbol{in}$ diameter of bottom prestressing strands

$C_{ps} := \frac{0.33}{\boldsymbol{ft}} \cdot L \cdot \left(n_{ps}\right) = 11.9$ cost of bottom prestressing strands, $

$d'_{ps} = 0.5\ \boldsymbol{in}$ diameter of top prestressing strands

$C'_{ps} := \frac{0.30}{\boldsymbol{ft}} \cdot L \cdot \left(n'_{ps}\right) = 10.8$ cost of top prestressing strands, $

Shear Reinforcement

$L_{stirrup} = 19.8\ \boldsymbol{in}$ length of stirrups
$n_{stirrup} = 26$ amount of stirrups

$w_{stirrup} = 0.7\ \frac{\boldsymbol{lb}}{\boldsymbol{ft}}$ unit weight of stirrups

$C_{stirrup} := w_{stirrup} \cdot L_{stirrup} \cdot n_{stirrup} \cdot \frac{0.45}{\boldsymbol{lb}} = 12.9$ cost of stirrups, $

Total Cost

$C_t := C_c + C_{fw} + C_{ps} + C'_{ps} + C_{stirrup} = 240.6$ total cost, $

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 (yd³)	$145/cubic yard (flat rate) ≤ $20 + $10 (concrete strength ksi) ≤ $200	Round concrete strength down to nearest ksi
Ultra-High-Performance Concrete	$400/yd³	
Prestressing Strand		Use estimated lengths used in the beam
⅜ 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 *PCI Design Handbook*
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	[illegible]	
Forming	$1.25/ft² 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.

Appendix E Alternate Designs

Table 11: Best of Initial Designs

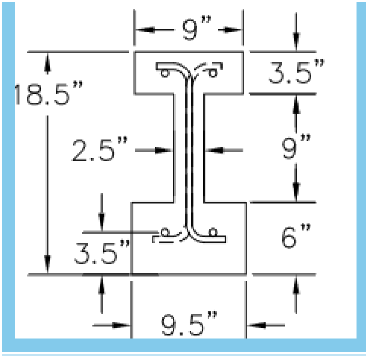
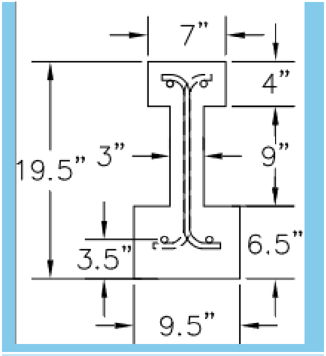
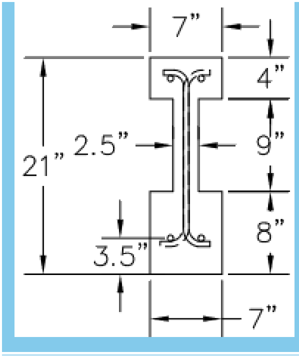
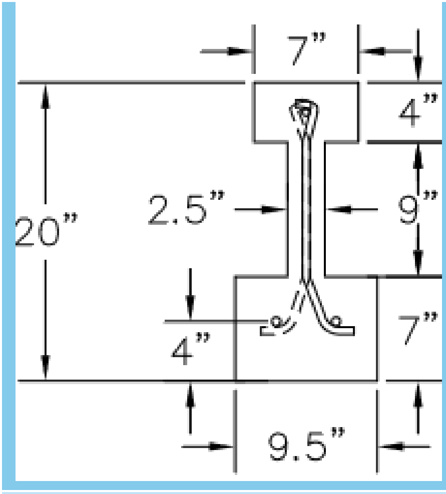
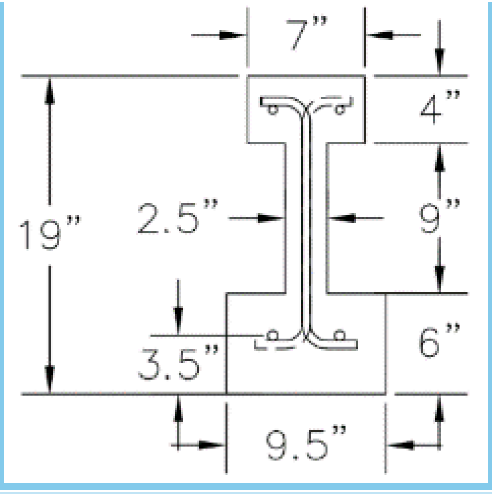
	Design 1	Design 2	Design 3
Design			
Change	Thinner top and bottom flange Small overall height	Narrow top flange and wider bottom flange and web	Top and bottom flanges same widths Tall beam
Result	Weight low Deflection high	High weight; Increased deflection	Low deflection Decreased weight

Table 12: Refined Designs

	Design 4	Design 5
Design		
Change	One strand at top to hold stirrup, higher deflection and failure load	Bottom flange reduced
Result	Clear cover excessive, high weight, stirrup design not constructable	Clear cover reduced; Decreased weight

Appendix F Performance Multiplier Scoring

Table 13: Performance Multiplier Scoring

Multiplier Scoring			
First Crack		Break	
Kip	Score	Kip	Score
20	0.95	32	0.95
21	0.96	33	0.97
22	0.98	34	1
23	1	35	1.03
24	1.02	36	1.05
25	1.03	37	1.03
26	1.05	38	1
27	1.03	39	0.97
28	1.02	40	0.95
29	1		
30	0.98		
31	0.96		

Appendix G Decision Matrix

The design numbers correspond with the designs shown in **Error! Reference source not found.** REF _Ref196341519 \p \h above. Design 5 is the final design, and the cross section is shown in Appendix H below. All weight, deflection, cost, first cracking, and breaking values are based on the MathCad calculations in **Error! Reference source not found.**.

Design	Criteria						Initial Score (max: 3)
	Weight (lbs)		Deflection (in)		Cost ($)		
	Value	Score	Value	Score	Value	Score	
1	1759	0.74	0.113	0.56	236.3	0	1.30
2	1849	0.13	0.117	0.72	234.4	0.50	1.35
3	1721	1	0.099	0	234.4	0.50	1.50
4	1868	0	0.124	1	232.5	1	2
5	1721	1	0.117	0.72	234.4	0.50	2.22

Performance multipliers were used to account for the constraints on the first crack being between 20 kips and 32 kips, and the beam's breaking between 32 kips and 40 kips. The scoring of the multipliers is shown **Error! Reference source not found.** in **Error! Reference source not found.**.

Design	Performance Multiplier					Adjusted Score (max: 3.31) **=A*B*C**
	Initial Score **A**	Theoretical Values (kips)		Multiplier (between 0.95-1.05)		
		First Crack	Break	First Crack **B**	Break **C**	
1	1.30	23.25	34.9	1	1	1.3
2	1.35	23.85	36.75	1	1.05	1.42
3	1.50	23.65	35.89	1	1.03	1.55
4	2	23.85	36.55	1.02	1.05	2.14
5	2.22	23.03	35.35	1	1.03	2.28

Appendix H Shop Drawings

Appendix I Test Cylinder Analysis of Concrete Mixture

Appendix I.1 Certified Mill Test Report

Appendix J Fabrication Reports