2017

PCI BIG BEAM COMPETITION

SAINT MARTIN'S UNIVERSITY: KRAKEN AGAIN

Student Members

Cameron Reece, William Miller, Paul Rumbles, Jarad Roschi, Joel Rogers, Clarinda Marion, David Rowland

PCI Producer Member

Concrete Technology Corporation

Faculty Advisor

Jill Walsh, PhD, PE

PCI BIG BEAM COMPETITION 2016-17

June 12, 2017
Date

Saint Martin's University	1	May 5, 2017
Student Team (school name)	Team Number	Date of Casting

Basic Information

1. Age of beam at testing (days) 28
2. Compressive cylinder tests*
   - Number tested 2
   - Size of cylinders 4 x 8
   - Average (psi) 13,505
3. Concrete properties
   - Unit weight of concrete (lb/ft^3) 153.5
   - Slump (in.) 7.00
   - Air content (%) 1.40
   - Tensile strength (psi) 1,670
   - Circle one: Split cylinder **[MOR beam]**
4. Pretest calculations
   a. Applied load (total) to cause cracking (kip) 26.37
   b. Maximum applied point load at midspan (kip) 34.61
   c. Maximum anticipated deflection due to applied load only (in.) 6.17

Pretest calculations MUST be completed before testing.

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

Judging Criteria

Teams MUST fill in these values.

1. Actual maximum applied load (kip) 34.88
2. Measured cracking load (kip)[†] 24.44
3. Cost (dollars) 168.54
4. Weight (lb) 1690
5. Largest measured deflection (in.) 5.44
6. Most accurate calculations
   a. Absolute value of (maximum applied load – calculated applied load)/calculated applied load) 0.073
   b. Absolute value of (maximum measured deflection – calculated deflection)/calculated deflection) 0.008
   c. Absolute value of (measured cracking load – calculated cracking load)/calculated cracking load) 0.119

Total of three absolute values (a + b + c) = 0.200

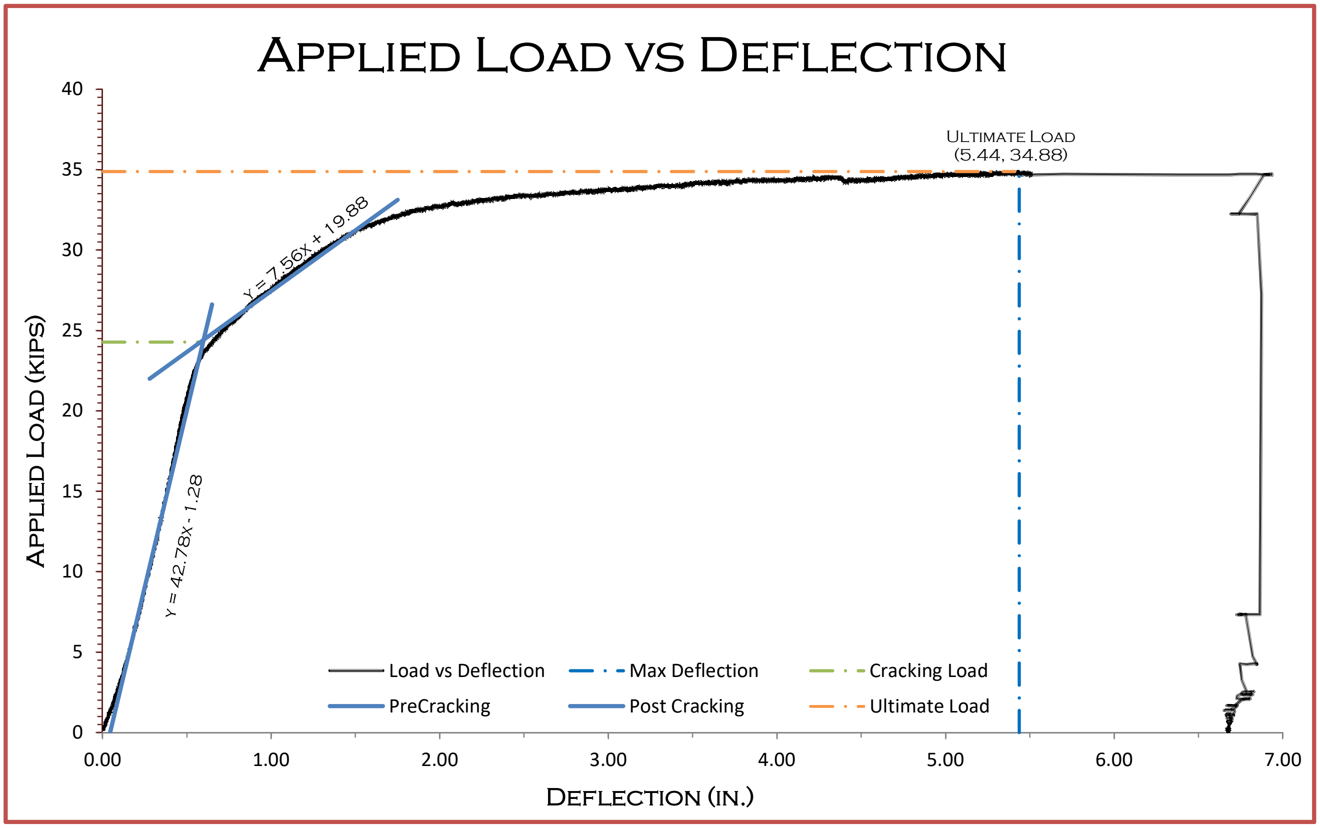
[†] Measured cracking load is found from the "bend-over" point in the load/deflection curve. Provide load/deflection curve in report.

Test summary forms must be included with the final report, due June 16, 2017.

Sponsored by:

AUTODESK's SOLUTION ASSOCIATE FOR PRECAST
EDGE^REVIT
PTAC Consulting Engineers, Inc.
BUILDING TRUST
Sika
ASPIRE
The Concrete Bridge Magazine

Results



$P_{Cr.\ (Theoretical)}$ =	26.37	kips	7.30	% Error
$P_{Cr.\ (Actual)}$ =	24.44	kips		
$P_{u\ (Theoretical)}$ =	34.61	kips	0.79	% Error
$P_{u\ (Actual)}$ =	34.88	kips		
$\Delta_{(Theoretical)}$ =	6.17	in.	11.89	% Error
$\Delta_{(Actual)}$ =	5.44	in.		
Total % Error =			19.99	

PCI BIG BEAM COMPETITION 2016-17

CERTIFICATION

CONCRETE TECHNOLOGY CORPORATION

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

SAINT MARTIN'S UNIVERSITY, TEAM 1

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

AUSTIN MAUE, P.E.

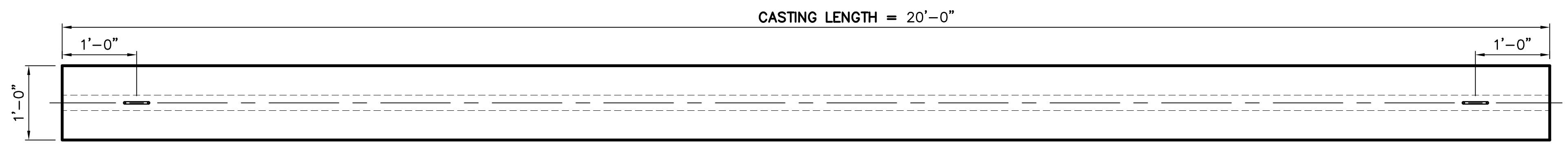
Name (please print)

6/12/17

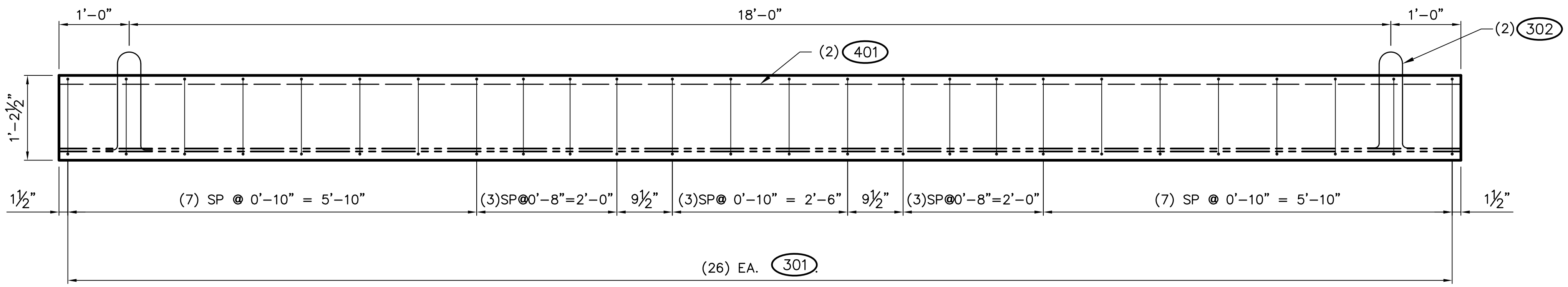
Date

THIS CERTIFICATION MUST BE PART OF THE FINAL REPORT

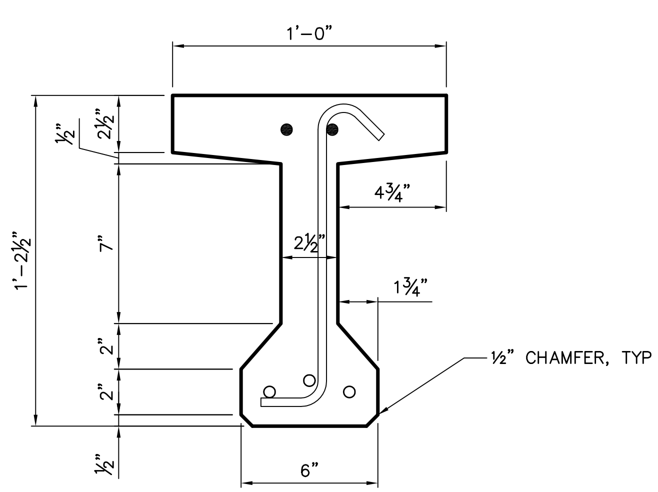
MARKED END



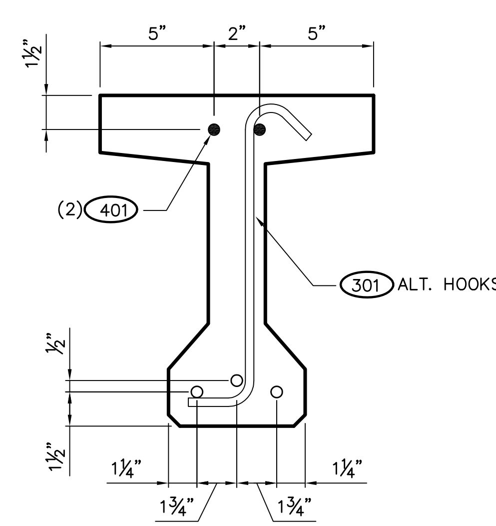
PLAN VIEW



ELEVATION VIEW



TYPICAL SECTION



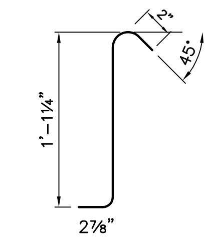
REINF. DETAIL

REINFORCEMENT SCHEDULE

GRADE	BAR MARK NUMBER	QUANTITY	STRAIGHT	NO. BENDS	CUTTING LENGTH
60	301	28		2	1'–6"
	302	2		3	3'–5½"
	401	2	X		20'–4"

REBAR TYPE — BAR SIZE — MARK NUMBER: X402

STIRRUP/TIE PIN ø (UNO)
#3 = 1½"
#4 = 2"
#5 = 2½"
#6 = 4½"
#7 = 5¼"
#8 = 6"



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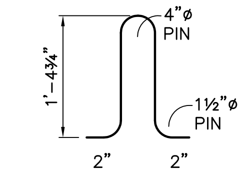


302

GENERAL NOTES

CONCRETE: STRENGTH @ RELEASE.... 7,000 P.S.I.
STRENGTH @ 28 DAYS.... 13,000 P.S.I.

PRESTRESS: 0.5"ø 270KSI, 7 WIRE UNCOATED LOW RELAXATION STRAND

STRAIGHT: (3) STRANDS JACKED TO 93 KIPS (31.0 K/STR.)

FINISHES: TOP....... STEEL TROWEL
SIDES.... FORM FINISH
SOFFIT... FORM FINISH
ENDS..... FORM FINISH

YARD HAULING: SEE SHIPPING BUNKING
STORAGE BUNKING: 1'–0" FROM EACH END
SHIPPING BUNKING: 1'–0" FROM EACH END

INSERT & ASSEMBLY SCHEDULE

MARK	DESCRIPTION	PRIME	GALV.	QUANTITIES PER PIECE	QUANTITIES TOTAL

No.	Status	Revision	By	App'd	Date
1	FOR CONST.	STIRRUP SPACING	ADM	ADM	4/26/17
0	SUBMITTAL		ADM	ADM	4/21/17

CONTRACTOR :

Design ....
Drawn ADM
Checked ADM
Approved ....

DO NOT SCALE

CONCRETE TECHNOLOGY CORP.
MANUFACTURERS OF PRESTRESSED CONCRETE
1123 PORT OF TACOMA ROAD
TACOMA, WASHINGTON 98421

SAINT MARTIN'S UNIVERSITY
"BIG BEAM"
LACEY, WASHINGTON

PRODUCTION DRAWING
BEAMOTHR
MARK: BM2 QTY. 1 WT. 1.55 KIPS

Date APRIL 2017
Sh. No. ...... of ......
Dwg. No. BM–2 (1)
Job. No. 17X08A

TABLE OF CONTENTS

INTRODUCTION

In 2017, Saint Martin's University (SMU) entered its second Big Beam Competition under the supervision of faculty advisor Jill Walsh, PhD, PE. The tasks to achieve in the competition were to design, construct, and test a prestressed concrete beam according to the criteria laid out by Precast/Prestressed Concrete Institute (PCI) while meeting the American Society for Testing and Materials (ASTM) as well as the American Concrete Institute (ACI) standards.

The team's goal was to design a simple cross section that would behave as expected. The tested design was an I-shaped beam of constant depth and cross-section with normal weight, high-strength concrete, three prestressing strands, two longitudinal reinforcing steel bars, and alternating Z-shaped stirrups for shear reinforcement. Most of the design was done with a spreadsheet created by the 2016 Saint Martin's University' Big Beam team. The spreadsheet simultaneously calculates stresses in the concrete, strands, and rebar, employs a macro to find the equilibrium of internal forces, and generates the moment curvature of a cross section. The spreadsheet required a few coding adjustments as well as the inclusion of an additional calculations sheet to calculate release stresses. The team also added an automated section properties sheet to assist with efficiency in the design process. A detailed description of the beam is in the DESIGN PROCESS section. A comparison of predictions and actual results is shown below in TABLE 1.

TABLE 1. PREDICTIONS VERSUS RESULTS

	Prediction	Results
Ultimate Load (kips)	34.61	34.88
Deflection at Ultimate Load (in)	6.17	5.44
Cracking Load (kips)	26.37	24.44

While the ultimate load prediction was within 0.8% and the cracking load was within 7.3%, the deflection prediction was 11.9% lower than predicted. A detailed discussion about the possible causes of inaccuracies is in the RESULTS section.

ACKNOWLEDGEMENTS

Saint Martin's University' PCI Big Beam team is very thankful for the opportunity to participate in this unique competition. The team would not have been able to successfully design, build, and test the beam without the help of its advisor and sponsors.

Thank you to Dave Chapman, PE and Concrete Technology Corporation for choosing to sponsor Saint Martin's University's second competition entry. Additionally, thank you to the employees at CTC who donated their time and effort to help construct the beam.

The team is especially grateful to Austin Maue, PE for providing an incredible amount of advice throughout the competition.

Thank you Saint Martin's University for the support received during the course of this competition, and Jill Walsh, PhD, PE, this year's faculty advisor.

Finally, thank you to John Stanton, PhD, and the University of Washington for hosting the team and allowing the use such an impressive testing facility.

ASSUMPTIONS

- Strands are fully bonded with concrete. Strain changes in the steel and concrete are the same at strand release.
- Actual stress-strain relationships and materials are very similar to the constitutive models used.
- Strains are distributed linearly over the depth of the cross section.
- The ultimate moment is based on the strain which causes either concrete crushing or strand fracture.
- Members fail in flexure.

MATERIALS

Concrete

The decision to enter the competition was made a little later than what would have been convenient which limited the amount of options available for concrete mix. There were three options of concrete mix; high-strength, normal-weight, or light-weight. The high strength concrete is more expensive than normal weight, but extra cost is mitigated by using less material (requiring less cross-sectional area). Light-weight concrete provides less dead weight but is also quite expensive. After debating the benefits of each type of available concrete mixes, the team chose a normal-weight, high-strength concrete mix. In future years, the design process should begin with enough time to make the proper arrangements to use a mix design specified by the team.

The chosen mix for the beam this year is used regularly for projects at Concrete Technology Corporation (CTC). The mix had a 0.27 water/cement ratio, a slump of 7.00 inches, an air content of 1.4%, and a unit weight of 152.5 pcf. TABLE 2 shows a summary of the mix; additional details can be found in APPENDIX D. The mix performed well for the teams requirements, the original design for the beam was to have an initial compressive strength of 7,000 psi and the actual mix surpassed that by more than enough.

TABLE 2. CONCRETE MIX FOR ONE CUBIC YARD OF CONCRETE

Cementitious Materials	Aggregates	Admixtures	Concrete Strength (psi)
750 lb Type III Cement	1,993 lb Course	1.9 lb WDRA 64	f'ci: 10,650
	1,264 lb Fine	4.2 lb ADVA 575	f'c: 13,505
			Tensile Strength: 1,670

Prestressing Strands

The Prestressing strands used in the beam were low relaxation ½" diameter ASTM A415 grade 270 strands. Sumiden Wire Products Corporation provided strand certifications that produced a yield point of 40.25 kips and a modulus of elasticity of 28,900 ksi. The strands were a constant depth for the total beam length. Detailed strand properties are in APPENDIX E.

Rebar

Two #4 bars, ASTM A615 grade 60 rebar, longitudinally continuous, were used in the top flange. The longitudinal bars were used to hold the shear reinforcement as well as to increase the tension capacity in the top flange. The design also included #3 ASTM A615 grade 60, Z-shaped stirrups for shear reinforcement spaced at 8" – 10".

DESIGN PROCESS

Design Concept

The goal this year was accuracy and maximizing deflection. Using an in house developed moment curvature analysis to predict the behavior of the beam, the team decided it would be best to optimize the accuracy of the theoretical calculations for future competitions before introducing other innovative factors such as; de-bonding, varied cross-section, harped strands, etcetera… The team considered two common cross-sections, T-shaped and I-shaped. After debating the pros and cons of each, the first design was a T-beam. The team performed the moment-curvature analysis on multiple variations of T-beams to finalize cross-section.

The next step was to analyze stresses directly following strand release. During the release-stress analysis, the assumed initial concrete compressive strength (f'ci of 7,000 psi) combined with the provided area of concrete below the neutral axis was not enough to resist the compression force applied by the prestressing strands. This is what caused the addition of the bottom flange. After adding a bottom flange, an analysis was performed on many iterations of an I-beam before deciding on the final cross-section shown below in FIGURE 1.

When designing a beam in a real-world scenario, it is important that the member deflects during the yielding phase of failure. Without deflection, hairline cracks may remain unnoticed by the general population causing a surprise failure that may cause serious injury or death. So the final decision of the cross section was made based on maximizing the predicted deflection.

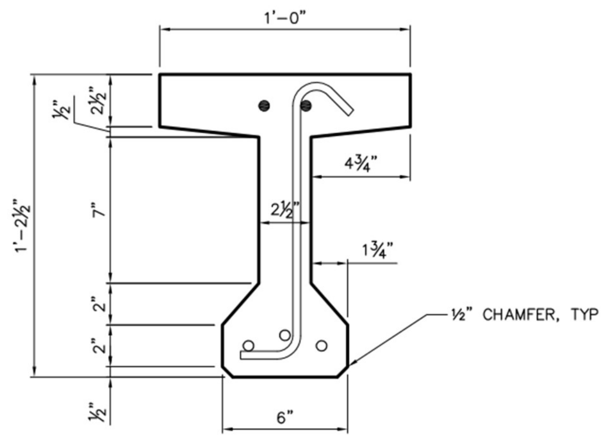


FIGURE 1. TYPICAL BEAM CROSS-SECTION

Flexural Design

Strand sizes were readily available in 0.5 inch diameter and 0.6 inch diameter. The smaller strands provided a larger variety of choices in the strand layout, which is why 0.5 in. dia. strands were chosen. Using an assumed strand stress at failure of 270 ksi and through manipulation of the strand locations, the final configuration was established. The ultimate decision was made based on a service load of 20.0 kips and a maximum load range of 32.0 – 39.0 kips. The team chose to aim for values in a few kips above the threshold for cracking and in the middle of the ultimate range to allow for some discrepancies between prediction and actual values while avoiding penalties. Complete design and fabrication drawings are included in APPENDIX A.

The two #4 longitudinal bars in the top flange provide sufficient tensile capacity during and after the release of the prestressing strands until the service load is applied.

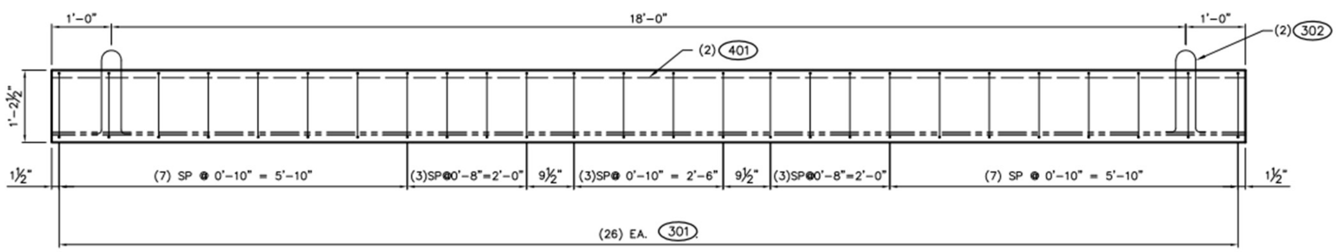
Shear Design

Flexure failure has many signs of distress, such as large deflections and cracking, whereas shear failure often occurs with little warning and is catastrophic. For this reason the design is conservative in shear. The team designed shear reinforcement using the maximum load allowed by the competition, 39 kips.

While this would add additional steel, and therefore cost, the guarantee of shear strength was deemed worth it.

The shear strength of the concrete was calculated based on the ACI 318-11 code, therefore the shear design was determined from the lesser of V_{ci}, V_{cw} and $(2)\sqrt{f'_c}(b_w)(d)$. Understanding that V_{ci} and V_{cw} varies along the length of the beam as the prestressing force develops and loading changes, these values were looked at, and many other points along the length of the beam. Key points such as h/2, l_t, l_d and mid-span, as well as ranges in between these points, were analyzed to produce a complete picture of the beams need for shear design. The shear reinforcement comprised alternating Z-shaped stirrups, placed at 10" for the end 5'-10" feet, 8" for the next 2 feet, one space of 9½", and 10" spacing for the middle 2'-6" of beam, as displayed in FIGURE 2 below.

FIGURE 2. REINFORCEMENT ELEVATION



BEAM FABRICATION

Reinforcement Construction

The formwork was designed and constructed by CTC after the submittal of the final design and May 5th, 2017 SMU's team was invited to CTC to assemble the rebar cage. Prior to the team arriving, CTC ran the three ½" diameter prestressing strands through the wooden end plates and stressed them. To begin construction, the team measured and marked the designed stirrup

spacing along the pre-stressing pallet. To assemble the rebar cage, the team used zip ties to position the alternating Z-shaped stirrups. At both ends and at the mid-span, the stirrups were tied together in alternating directions and then tied to the two longitudinal #4 bars. The two #4 bars were cut a little too long to allow them to pass through the end-piece formwork; the purpose of this was to help hold the longitudinal rebar in place while the stirrups were tied. Once the stirrups were set, the side forms of the beam were positioned and all seams of the formwork were sealed to prepare for the concrete pour.

Strand Prestressing and Beam Casting

The beam casting was completed by CTC. After the concrete was poured, the crew finished the top of the beam with a steel trowel. A thermal monitoring device, was inserted, and left in the wet concrete that was linked to a computer that monitored the temperature controlled test cylinders to ensure the cylinders cured at the same temperature as the beam. The beam was then covered and left to set for 92 hours before strand release and removal from its frame. The beam cured under damp burlap and a plastic covering to avoid uneven moisture loss. CTC tested two cylinders on the same day of release to record the initial compressive strength and. The beam was 28 days old at testing.

TESTING

One day prior to testing, CTC tested two additional cylinders and recorded the final compressive strength of the beam. See TABLE 2 for recoded compressive strength. Testing occurred on June 2, 2017, at the University of Washington's More Hall Structures Lab. Prior to SMU arriving, the lab technicians assembled the following test rigging beneath the Baldwin machine.

The locations of the supports, the mid-span, and the two point loads were marked on the beam. A steel bar was hot glued into place at the centerline of the mid-span mark beneath the beam and strings tied to the ends of the bar were attached to a potentiometer underneath the beam to measure deflection. As a back-up, in case the computer recording the data malfunctioned, a meter stick was placed vertically beside one of the two point loads and multiple video cameras were placed around the beam during testing. Along with the video cameras, tasks were assigned to each individual: data acquisition, videography, watching for cracking, and recording the time and load at which they occurred.

The electronic testing instruments were calibrated before the test began. The plan for the test was to load the beam to the service load of 20 kips and check for cracking, if the beam passed the inspection of CTC representative, Austin Maue, PE, the beam would be completely unloaded. The load application would begin again and the beam would be tested until failure. If cracks were noticed, the load application would continue from where it stopped without being unloaded because if the beam has cracked it will no longer behave elastically, and the actual ultimate load and maximum deflection would not be accurate. Once the test began, the Baldwin machine was set to approach 20 kips in a timeframe of 3 minutes. The beam passed the crack inspection and the load was removed; the beam was then loaded until failure. As the beam approached failure, it experienced flexural cracking in the central 3 – 4 feet of the beam. The beam eventually failed in compression in the top flange at a load of 34.88 kips and a corresponding deflection of 5.44 inches.

RESULTS

After testing, the data was collected from the computer and used to plot the load-deflection curve shown in FIGURE 3. The portion of the curve preceding the cracking load is quite linear making a linear approximation reasonably simple. However, following the cracking load, the graph is a nonlinear progression which made the linear approximation of the post cracking slope somewhat difficult compared to the pre-cracking slope. After analyzing the data, the team recorded the actual numbers shown in TABLE 3.

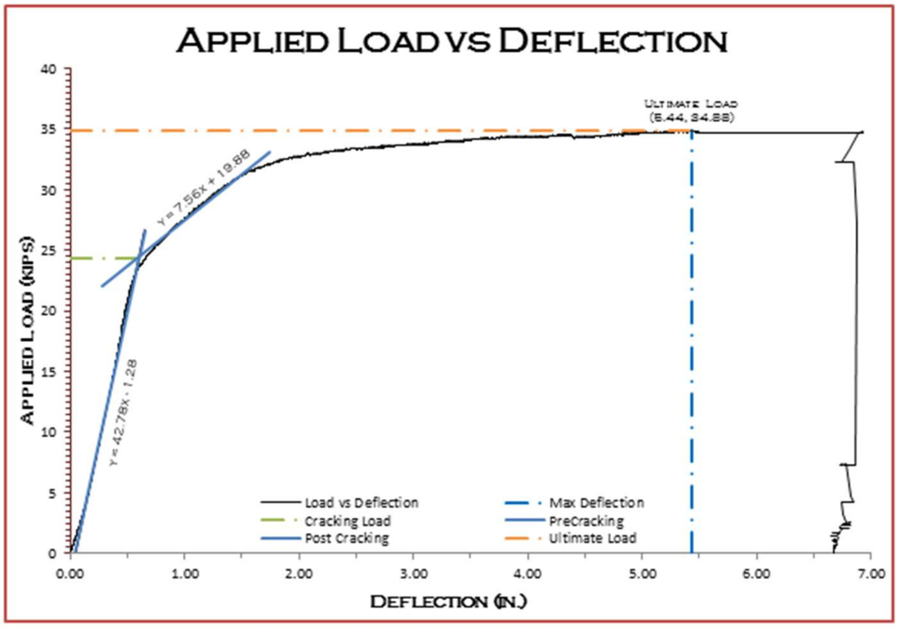


FIGURE 3. LOAD- DEFLECTION CURVE

	Prediction	Results	Error Analysis
Ultimate Load (kips)	34.61	34.88	0.79%
Deflection at Ultimate Load (in)	6.17	5.44	11.89%
Cracking Load (kips)	26.37	24.44	7.30%
Total	---	---	19.99%

TABLE 3. ERROR ANALYSIS

As apparent in TABLE 3, the predictions were rather close to the results. In 2016 the cracking load for "The Kraken" was calculated with the same moment curvature analysis spreadsheet with only 0.34% error and the ultimate load had an error of 6.65%. The original assumption was that the error in the predictions this year shifted from the ultimate load to the cracking load, but after careful consideration the team decided that the error in the cracking load was due to the system used to cure the test cylinders compared to the curing of the beam itself. The cylinders were cured in a lime bath at the CTC plant and the beam cured in the storage yard outside. This is what caused the cylinder's modulus of rupture (MOR) to be 1,670 psi instead of the actual MOR of approximately 1,300 psi. When the team used 1,300 psi as the MOR, the post-testing predictions were much more accurate (shown below in TABLE 4). As for the high deflection prediction, an error was made in assuming that the physically measured camber needed to be added to the calculation of deflection caused by the ultimate load. The reason for adding this has to do with the integration process used for determining the deflection of the beam. The team integrated the curvature of the beam twice to calculate the deflection and when integrating twice, there are two constants of integration. It was rational that one constant is found by performing the same procedure of calculating deflection considering only the self-weight of the beam, a zero-load case, and the second constant was the physically measured camber of the beam. After testing the beam it is apparent that the physically measured camber is already accounted for in the deflection calculation of the zero-load case. The total camber was measured to be about 0.875 inches; when this is subtracted from the prediction and after adjusting the MOR, the predicted deflection is rather precise (displayed in TABLE 4 and FIGURE 4).

	Prediction	Results	Error Analysis
Ultimate Load (kips)	34.61	34.88	0.79%
Deflection at Ultimate Load (in)	5.33	5.44	0.06%
Cracking Load (kips)	24.46	24.44	2.00%
Total	---	---	2.85%

TABLE 4. ERROR ANALYSIS WITH AN MOR OF 1300 PSI

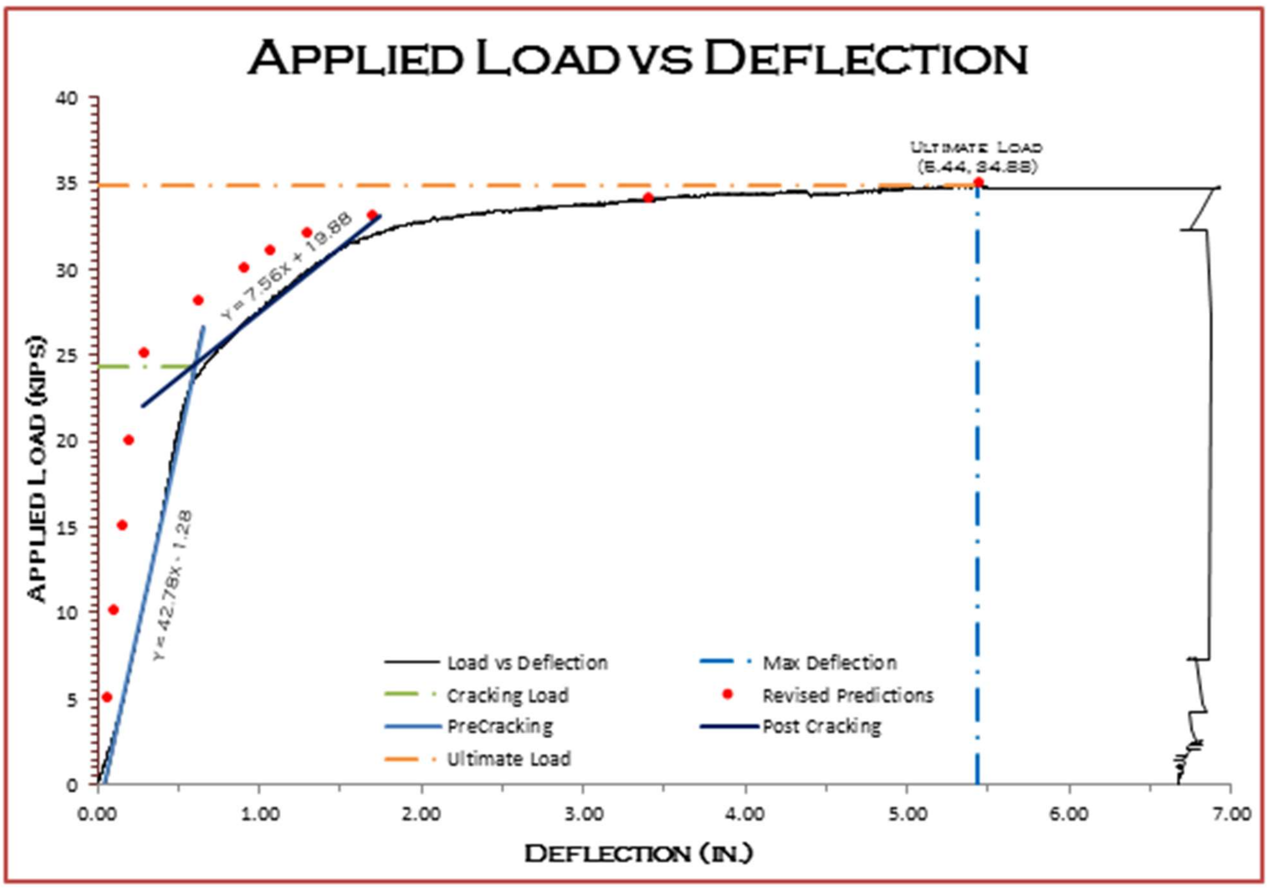


FIGURE 4. RE-EVALUATED PREDICTIONS GRAPH

LESSONS LEARNED

The team learned many lessons throughout the design, construction and during the data analysis. The first lessons were learned in the design process. During the initial cross-section comparisons, the differences between a T-beam and an I-beam were not apparent. It was not until the addition of release stress analysis to the Excel spreadsheet that the team noticed the significance of the bottom flange. However, in the real-world pre-stressed I beams, the bottom flange is typically only increased to allow for the addition of more prestressing strands which adds more moment capacity and lengthens the maximum span of a cross-section.

During construction, the team did not encounter any major difficulties in assembling the reinforcement cage. The only challenge was that most of the bent Z-shaped stirrups were a fraction too long. This caused the longitudinal bars to rise vertically out of the minimum clear cover in the top flange. The solution to this problem was to tilt each of the stirrups enough to bring the longitudinal bars to the desired height. The tilting was administered at an angle to intersect shear cracks. This is when the team realized how a singular minor discrepancy of the specified design could cause complications in fabrication which revealed the reason for simple design specifications. The team also became more familiar with the system used to jack the prestressing strands, how stirrups were placed, and overall how the CTC plant operated.

Through analyzing the results, the team gained a better understanding of how a moment-curvature analysis works and how it is used to predict ultimate deflection. As mentioned in the RESULTS section the team made an error in determining the constants of integration and by analyzing the predictions versus the actual data, the error was discovered. This should not have been an issue this year due to the fact that the same process for the deflection calculation was used in the 2016 PCI Big Beam Competition entry and any error should have been found then. However in 2016, the deflection calculation was 32.37% below the actual deflection and not above as it was this year, which is why the error in the integration constant was not apparent. This year the team decided that the reason for the error in 2016 was that the setup of the single point-load was not a true point-load and the load distribution to the top flange produced confinement in the compression region of the concrete, where the failure was designed to occur. This resulted in a 6.7% larger ultimate load which caused the deflection to be larger than predicted. Confinement of concrete was not an issue this year because the load was applied as two point-loads offset from the mid-span and therefore not directly applied to the designed failure region.

Finally, it became evident that communication is paramount throughout the entire process; from brainstorming design ideas and developing clear drawings to scheduling meetings and coordinating with CTC and UW for the build and test dates.

It is a rare and treasured opportunity to be able to design, build, and test a prestressed concrete product to the point of failure. The team is honored and thankful for the opportunity to participate in the competition. The team learned many lessons and gained experience that will better prepare them as they move forward in their future engineering careers.

APPENDICES

Appendix A

Drawings, Formwork, and Line Layout

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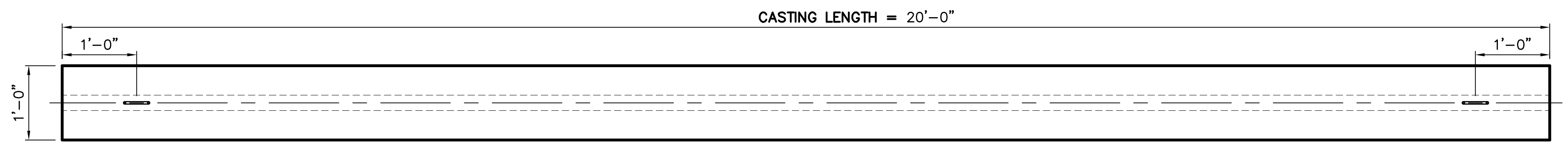
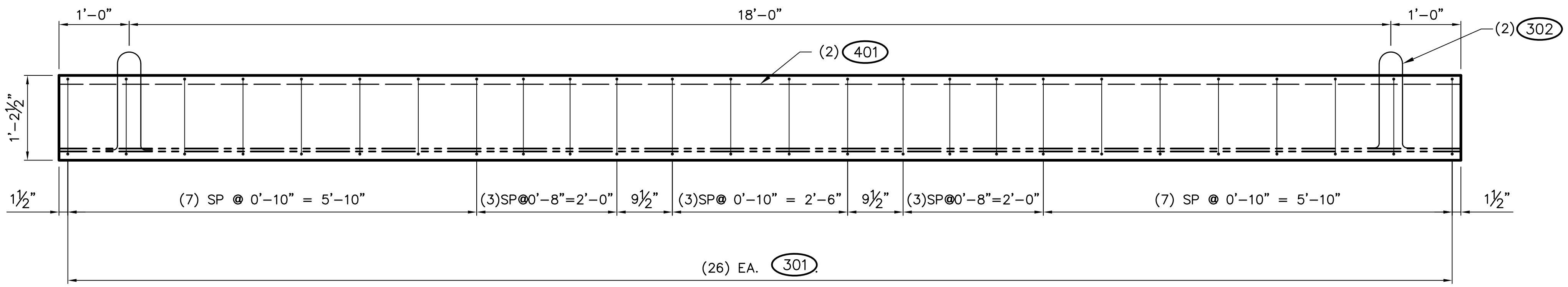
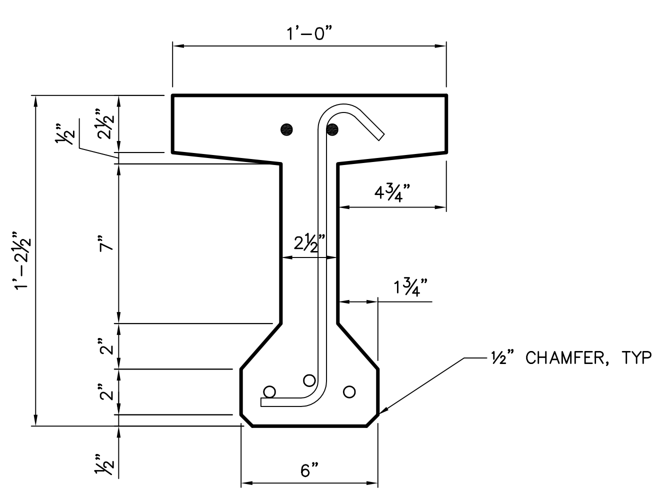


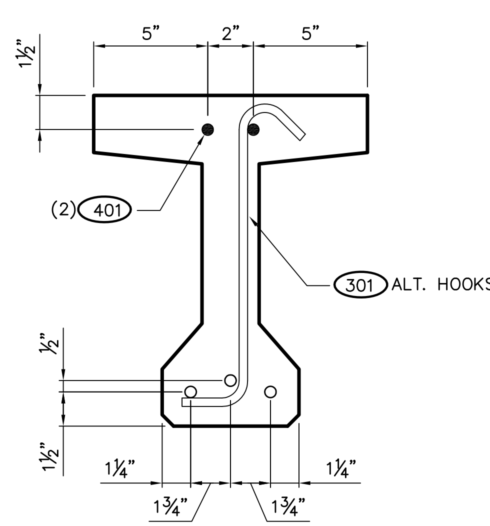
PLAN VIEW



ELEVATION VIEW



TYPICAL SECTION



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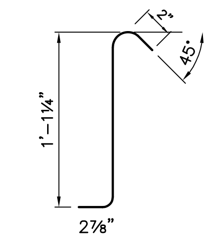

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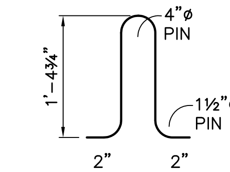

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GENERAL NOTES

CONCRETE: STRENGTH @ RELEASE.... 7,000 P.S.I.
STRENGTH @ 28 DAYS.... 13,000P.S.I.

PRESTRESS: 0.5"ø 270KSI, 7 WIRE UNCOATED LOW RELAXATION STRAND

STRAIGHT: (3) STRANDS JACKED TO 93 KIPS (31.0 K/STR.)

FINISHES: TOP....... STEEL TROWEL
SIDES.... FORM FINISH
SOFFIT... FORM FINISH
ENDS..... FORM FINISH

YARD HAULING: SEE SHIPPING BUNKING

STORAGE BUNKING: 1'–0" FROM EACH END

SHIPPING BUNKING: 1'–0" FROM EACH END

INSERT & ASSEMBLY SCHEDULE

MARK	DESCRIPTION	PRIME	GALV.	QUANTITIES PER PIECE	QUANTITIES TOTAL

No.	Status	Revision	By	App'd	Date
1	FOR CONST.	STIRRUP SPACING	ADM	ADM	4/26/17
0	SUBMITTAL		ADM	ADM	4/21/17

CONTRACTOR :

Design ....
Drawn ADM
Checked ADM
Approved ....

DO NOT SCALE

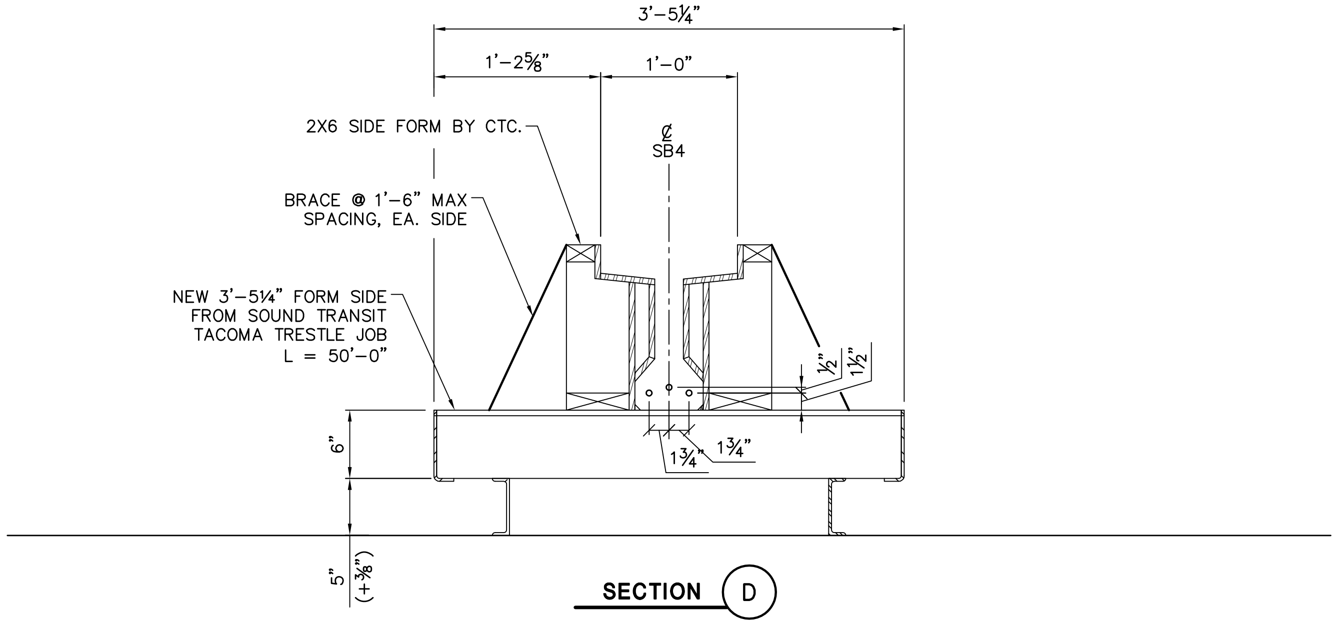
CONCRETE TECHNOLOGY CORP.
MANUFACTURERS OF PRESTRESSED CONCRETE
1123 PORT OF TACOMA ROAD
TACOMA, WASHINGTON 98421

SAINT MARTIN'S UNIVERSITY
"BIG BEAM"
LACEY, WASHINGTON

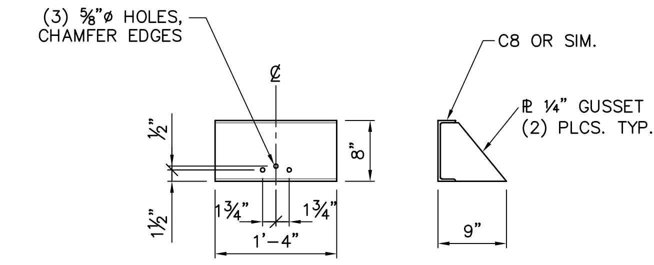
PRODUCTION DRAWING

BEAMOTHR
MARK: BM2 QTY. 1 WT. 1.55 KIPS

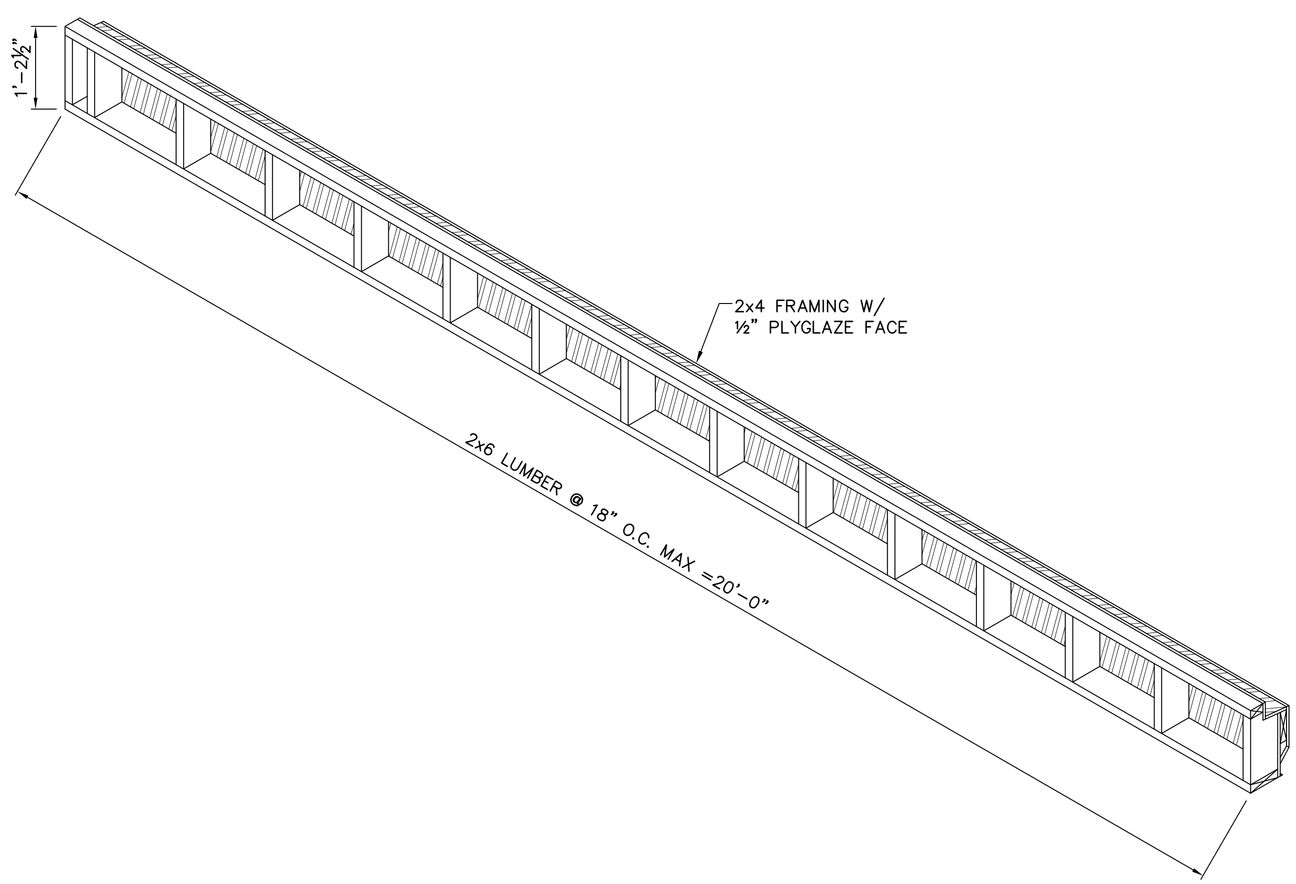
Date APRIL 2017
Sh. No. ..... of .....
Dwg. No. BM–2 (1)
Job. No. 17X08A



SECTION D

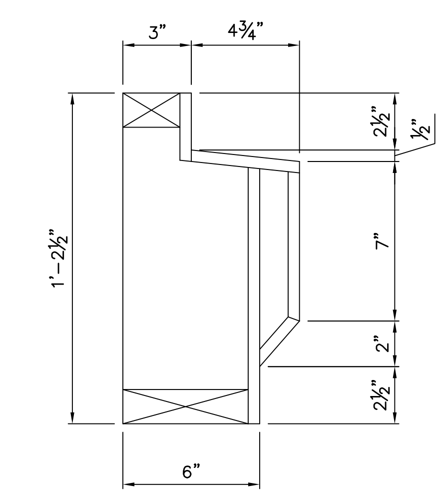


DISTRIBUTION B



FORM SIDES

MAKE: (2) EACH



FORM SECTION

No.	Status	Revision	By	App'd	Date
0	FOR CONST.		ADM	ADM	4/25/17

CONTRACTOR :

Design
Drawn ADM
Checked ADM
Approved

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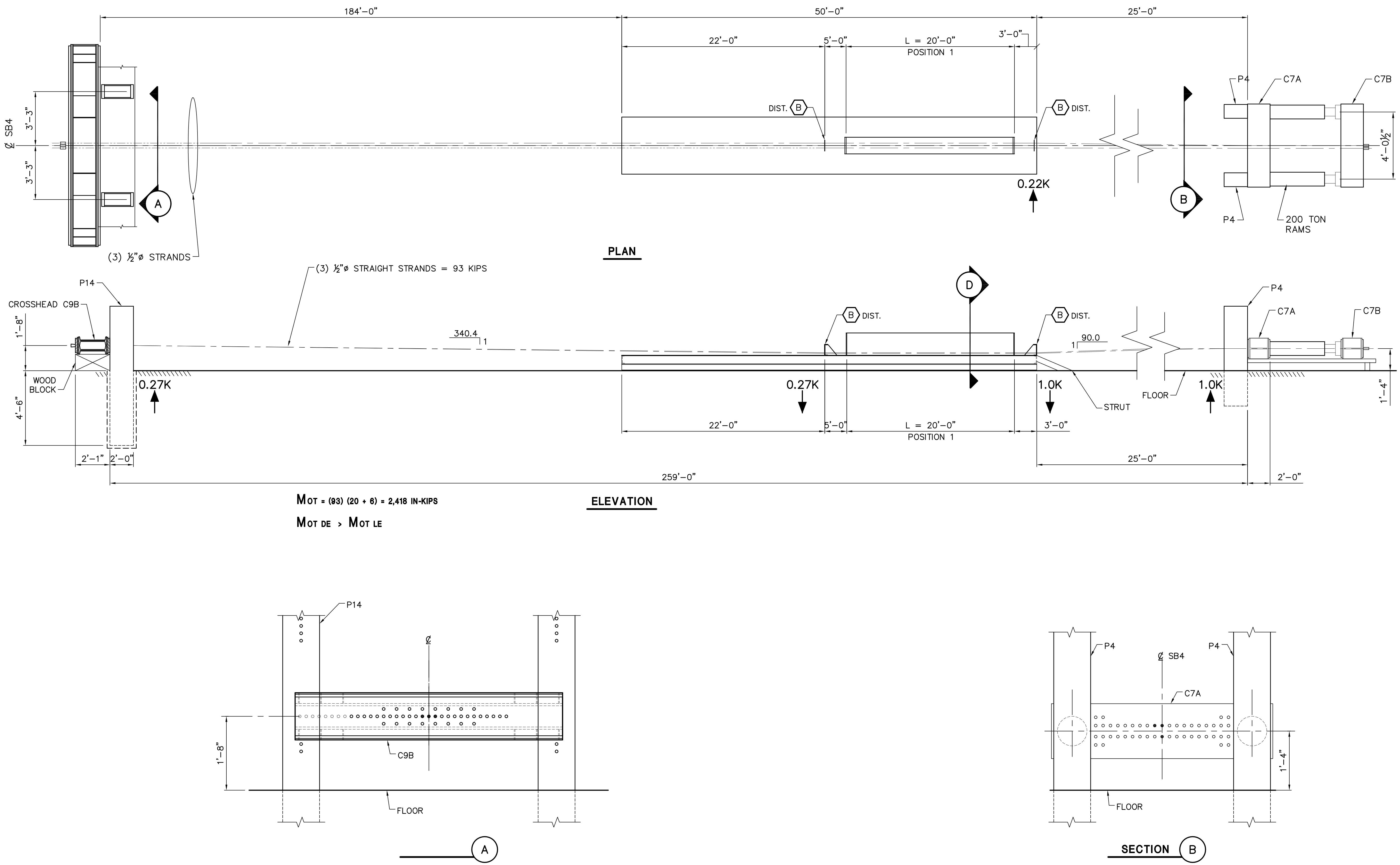
MANUFACTURERS OF PRESTRESSED CONCRETE
1123 PORT OF TACOMA ROAD
TACOMA, WASHINGTON 98421

2017 BIG BEAM
SEATTLE, WASHINGTON

P/S BEAM
SOUTH BAY 4

Date APRIL, 2017
Sh. No. of
Dwg. No. F-2.2 0
Job. No. 17X08 A



No.	Status	Revision	By	App'd	Date
0	FOR CONST.		ADM	ADM	4/25/17

CONTRACTOR :

Design
Drawn ADM
Checked ADM
Approved

DO NOT SCALE

CONCRETE TECHNOLOGY CORP.
MANUFACTURERS OF PRESTRESSED CONCRETE
1123 PORT OF TACOMA ROAD
TACOMA, WASHINGTON 98421

2017 BIG BEAM
SEATTLE, WASHINGTON

P/S BEAM
SOUTH BAY 4

Date APRIL, 2017
Sh. No. of
Dwg. No. F-2.1 0
Job. No. 17X08 A

Appendix B

Weight and Cost

Concrete Properties:

$$Volume = (Area)(Length) = \left(\frac{74.89\ in^2}{144}\right) 20ft = 10.40\ ft^3 = 0.352\ yd^3$$

$$Weight_{Concrete} = (Volume)(\gamma_c) = (10.40\ ft^3)(152.5\ pcf) = 1586\ lbs$$

$$Cost_{Concrete} = \left(\frac{\$120}{yd^3}\right)(0.352\ yd^3) = \$46.23$$

Reinforcing Steel:

$\#3\ Bars$

$28\ @\ 1' - 6" = 42' - 0"$

$2\ @ 3' - 5\frac{1}{2}" = 6' - 11"$

$Total\ Linear\ Feet = 48.92'$

$$Weight_{\#3} = \left(0.376\ \frac{lb}{ft}\right)(48.92) = 18.39\ lbs$$

$\#4\ Bars$

$2\ @\ 20' - 0" = 40' - 0"$

$Total\ Linear\ Feet = 40.00'$

$$Weight_{\#4} = \left(0.668\frac{lb}{ft}\right)(40.00) = 26.72\ lbs$$

$$Cost_{A615\ Bar} = \left(\frac{\$0.45}{lb}\right)(18.39\ lbs + 26.72\ lbs) = \$20.30$$

Prestress Strand:

$\frac{1}{2}"\ Diameter:$

$3\ @\ 20' = 60' - 0"$

$$Cost_{Strand} = \left(\frac{\$0.30}{ft}\right)(60') = \$18.00$$

Forming

$Sides = 39.7" * 20' = 66.17\ ft^2$

$Ends = 2\ @\ \frac{74.89\ in^2}{144} = 1.04\ ft^2$

$$Cost_{Forming} = \left(\frac{\$1.25}{ft^2}\right)(67.21\ ft^2) = \$84.01$$

Total Beam Weight

$$Weight_{Total} = W_{Concrete} + W_{\#3} + W_{\#4} = 1631\ lbs = 82\ plf$$

Total Beam Cost

$$Cost_{Concrete} = C_{Concrete} + C_{Bar} + C_{Strand} + C_{Forming} = \$168.54$$

Appendix C

Structural Design and Analysis Calculations

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Beam Criteria

Length:	20.00	ft.
Bearing:	12.00	in.
Span:	18.00	ft.
Height:	14.50	in.

Concrete Properties

Type:	High Strength	
f'_c:	13,505	psi
f'_{ci}:	10,650	psi
γ:	152.5	pcf
E_c:	6,974	ksi
f_r:	1,670	psi

Reinforcing Steel

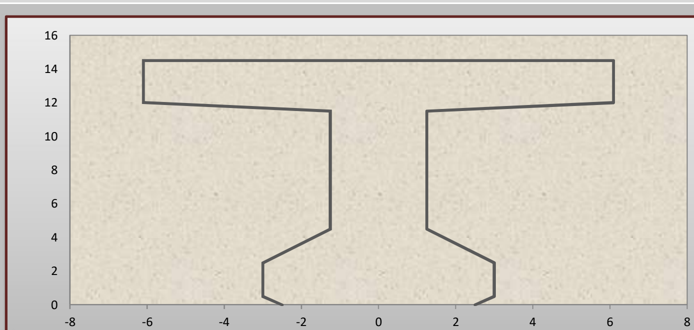
f_y:	60	ksi
E_s:	29,000	ksi

Prestressed Strands

f_{pu}:	270.00	ksi
f_{pi}:	202.50	ksi
f_{se}:	175.93	ksi
Losses:	27	ksi
E_{ps}:	28,900	ksi

Section Plot

Width	Height
5.00	0.00
6.00	0.50
6.00	2.00
2.50	2.00
2.50	6.00
2.50	1.00
12.19	0.50
12.19	2.50
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00



Properties

Depth:	14.50	in.
Area:	74.89	in.^{2}
I_x:	1825	in.^{4}
Y_B:	8.47	in.
Y_T:	6.03	in.
S_B:	215	in.^{3}
S_T:	303	in.^{3}
Perimeter:	56.66	in.
V/S:	1.32	in.
Weight:	0.084	klf
Centroid:	1.220	in.

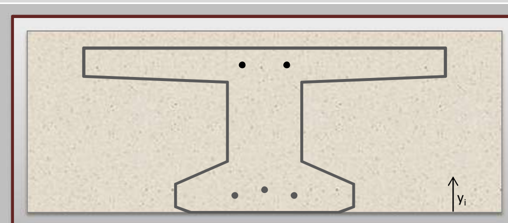
Strand and Rebar Placement

	Strand Size	y_i (in.)	x_i (in.)	A_{ps} (in.^{2})
1	0.5	2.00	0	0.15
2	0.5	1.50	-1	0.15
3	0.5	1.50	1	0.15
4				0.00
5				0.00
6				0.00

Dia. in in.

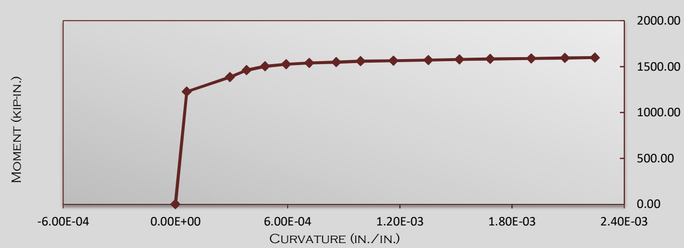
	Bar Size	y_i (in.)	x_i (in.)	A_s (in.^{2})	d_b (in.^{2})
1	4	13	-0.75	0.2	0.5
2	4	13	0.75	0.2	0.5
3				0	0
4				0	0
5				0	0
6				0	0

No.



Moment Curvature Analysis

Strain ε_i (in./in.)	Curvature ϕ (1/in.)	Moment M_i (kip-in.)	
8.6265E-05	-4.02E-09	0.00	Unloaded
-0.0005586	6.05E-05	1227.61	At Cracking
-0.00100	2.92E-04	1385.777	
-0.00115	3.81E-04	1460.21	
-0.00131	4.80E-04	1503.392	
-0.00146	5.92E-04	1525.762	
-0.00162	7.16E-04	1539.689	
-0.00177	8.61E-04	1548.538	
-0.00192	9.90E-04	1559.304	
-0.00208	1.17E-03	1564.555	
-0.00223	1.35E-03	1570.247	
-0.00238	1.52E-03	1577.292	
-0.00254	1.68E-03	1584.165	
-0.00269	1.90E-03	1588.626	
-0.00285	2.08E-03	1593.771	
-0.003	2.24E-03	1598.188	At Failure



Cracking Moment, M_{cr} = 1,227.61 kip-in.

Cracking Load, P_{cr} = 26.37 kips

Ultimate Moment, M_u = 1,598.19 kip-in.

Ultimate Load, P_u = 34.61 kips

Total Deflection, Δ = 6.17 in.

Section Properties Calculator

	Area in.^{2}	Y_B in.	A_{YB} in.^{3}	$A(CG-Y_B)^2$ in.^{4}	I in.^{4}	$I+A(Y_{BC}-Y_B)^2$ in.^{4}
Shape 1	2.75	0.26	0.71	185.49	0.06	185.54
Shape 2	12.00	1.50	18.00	583.03	4.00	587.03
Shape 3	8.50	3.36	28.58	221.74	2.67	224.42
Shape 4	15.00	7.50	112.50	14.12	45.00	59.12
Shape 5	2.50	11.00	27.50	16.00	0.21	16.21
Shape 6	3.67	11.80	43.35	40.83	0.07	40.90
Shape 7	30.47	13.25	403.71	696.06	15.87	711.93
Shape 8			0.00	0.00		0.00
Shape 9			0.00	0.00		0.00
Shape 10			0.00	0.00		0.00
∑	74.89		634.35			1825.15

A =	74.89	in.^{2}
I =	1825.15	in.^{4}
cg =	1.220	in.
Y_B =	8.47	in.
Y_T =	6.03	in.
S_B =	215.47	in.^{3}
S_T =	302.69	in.^{3}

Perimeter contributions from each shape

Shape 1	6.41	in.
Shape 2	4.00	in.
Shape 3	5.32	in.
Shape 4	12.00	in.
Shape 5	2.00	in.
Shape 6	9.74	in.
Shape 7	17.19	in.
∑	56.656	

Shape 1 : Trapezoid
Shape 2 : Rectangle
Shape 3 : Trapezoid
Shape 4 : Rectangle
Shape 5 : Rectangle
Shape 6 : Trapezoid
Shape 7 : Rectangle

Area Formulas:

Rectangle $= BH$

Trapezoid $= \frac{1}{2}H(B_1 + B_2)$

Y_B formulas

Rectangle = 0.5*H

*Trapezoid = $H - \left(\frac{H}{3} * \frac{B_2 + 2B_1}{B_2 + B_1}\right)$

Moment of Inertia Formulas:

Rectangle = $\frac{1}{12}BH^3$

Trapezoid = $\frac{H^3(B_2^2 + 4B_1B_2 + B_1^2)}{36(B_1 + B_2)}$

*B_1 is the bottom width

For the cg value,
+ indicates it is above D/2
- indicates it is Below D/2

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MOMENT & CURVATURE CALCULATIONS

ε_c	-0.003	in./in.
Neutral Axis, c	1.338	in.
Moment @ ε_c	1,598	kip-in.
Curvature @ ε_c	0.002	1/in.

y	14.5	13.16
ε_c	-0.003	0.00

Concrete Forces =	-133.03	kips
Rebar Forces =	4.23	kips
Strand Forces =	128.80	kips
Equilibrium =	0.00	kips

CROSS-SECTIONAL CONCRETE STRESS

Slice No. n_i	Height h_i (in.)	Width b_i (in.)	Depth y_i (in.)	Strain ε_i (in./in.)	Stress σ_i (psi)	Force F_i (lbs.)	Moment M_i (kip-in.)
1	0.290	12.19	14.36	-0.002675	13968	49,369	709
2	0.290	12.19	14.07	-0.002024	11412	40,336	567
3	0.290	12.19	13.78	-0.001374	7760.2	27,427	378
4	0.290	12.19	13.49	-0.000723	4086.2	14,442	195
5	0.290	12.19	13.20	-0.000073	412.18	1,457	19
6	0.290	12.19	12.91	0.000577	0	0	0
7	0.290	12.19	12.62	0.001228	0	0	0
8	0.290	12.19	12.33	0.001878	0	0	0
9	0.290	12.19	12.04	0.002529	0	0	0
10	0.290	7.247	11.75	0.003179	0	0	0
11	0.290	2.5	11.46	0.003830	0	0	0
12	0.290	2.5	11.17	0.004480	0	0	0
13	0.290	2.5	10.88	0.005131	0	0	0
14	0.290	2.5	10.59	0.005781	0	0	0
15	0.290	2.5	10.30	0.006432	0	0	0
16	0.290	2.5	10.01	0.007082	0	0	0
17	0.290	2.5	9.72	0.007732	0	0	0
18	0.290	2.5	9.43	0.008383	0	0	0
19	0.290	2.5	9.14	0.009033	0	0	0
20	0.290	2.5	8.85	0.009684	0	0	0
21	0.290	2.5	8.56	0.010334	0	0	0
22	0.290	2.5	8.27	0.010985	0	0	0
23	0.290	2.5	7.98	0.011635	0	0	0
24	0.290	2.5	7.69	0.012286	0	0	0
25	0.290	2.5	7.40	0.012936	0	0	0
26	0.290	2.5	7.11	0.013586	0	0	0
27	0.290	2.5	6.82	0.014237	0	0	0
28	0.290	2.5	6.53	0.014887	0	0	0
29	0.290	2.5	6.24	0.015538	0	0	0
30	0.290	2.5	5.95	0.016188	0	0	0
31	0.290	2.5	5.66	0.016839	0	0	0
32	0.290	2.5	5.37	0.017489	0	0	0
33	0.290	2.5	5.08	0.018140	0	0	0
34	0.290	2.5	4.79	0.018790	0	0	0
35	0.290	2.509	4.50	0.019441	0	0	0
36	0.290	3.016	4.21	0.020091	0	0	0
37	0.290	3.524	3.92	0.020741	0	0	0
38	0.290	4.031	3.63	0.021392	0	0	0
39	0.290	4.539	3.34	0.022042	0	0	0
40	0.290	5.046	3.05	0.022693	0	0	0
41	0.290	5.554	2.76	0.023343	0	0	0
42	0.290	6	2.47	0.023994	0	0	0
43	0.290	6	2.18	0.024644	0	0	0
44	0.290	6	1.89	0.025295	0	0	0
45	0.290	6	1.60	0.025945	0	0	0
46	0.290	6	1.31	0.026596	0	0	0
47	0.290	6	1.02	0.027246	0	0	0
48	0.290	6	0.73	0.027896	0	0	0
49	0.290	5.87	0.44	0.028547	0	0	0
50	0.290	5.29	0.15	0.029197	0	0	0

Σ Forces =	133	kips
Σ Moments =	1,868	kip-in.

SECTION PLOT

Width	Height
5.00	0.00
6.00	0.50
6.00	2.50
2.50	4.50
2.50	10.50
2.50	11.50
12.19	12.00
12.19	14.50
0.00	14.50
#N/A	#N/A
#N/A	#N/A
#N/A	#N/A
#N/A	#N/A

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STRAND STRESSES

Strand Dia. $\emptyset_{ps}$ (in.)	Depth y_i (in.)	Conc. Strain ε_c (in./in.)	Tot. Strain $\varepsilon_c + \varepsilon_{pe} + \varepsilon_{ce}$ (in./in.)	Strand Stress σ_{ps} (ksi)	Strand Area A_{ps} (in^2)	Strand Force F_i (kips)	Strand Moment M_{ps} (kip-in)
0.5	2.00	0.0250	0.031551	280.5	0.153	42.92	85.83
0.5	1.50	0.0262	0.032672	280.7	0.153	42.94	64.42
0.5	1.50	0.0262	0.032672	280.7	0.153	42.94	64.42
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Σ =	0.459	$in.^2$	

ΣFORCES =	128.80	KIPS
ΣMOMENTS =	214.67	KIP-IN.

STRAND STRAIN

ε_{pe} =	0.00609	IN./IN.
P_e =	80.8	KIPS
M_{Beam} =	3,410.21	FT-LBS
e =	6.80	IN
$\varepsilon_{ce\ Top\ Fiber}$ =	8.627E-05	IN./IN.
ε_{ce} =	-0.000426	IN./IN.
$\varepsilon_{ce\ Bottom\ Fiber}$ =	-0.000493	IN./IN.
$\varepsilon_{pe} + \varepsilon_{ce}$ =	0.00651	IN./IN.

POWER FORMULA

A =	156.96	KIPS
B =	28,743.04	KIPS
C =	104.31	
D =	11.92	

REBAR STRESSES

Bar Size	Depth y_i (in.)	Strain ε_s (in./in.)	Stress σ_s (ksi)	Conc. Stress σ_c (ksi)	Effective (ksi)	Steel Area A_s (in^2)	Steel Force F_s (kips)	Rebar Moment M_{RS} (kip-in)
4.0	13	0.0004	10.56759	0	10.5676	0.2	2.114	27.48
4.0	13	0.0004	10.56759	0	10.5676	0.2	2.114	27.48
0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0
					Σ =	0.400	$in.^2$	

ΣFORCES =	4.22704	KIPS
ΣMOMENTS =	54.9515	KIP-IN.

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DEFLECTION CALCULATIONS

P =	34.61	kips
W_{DL} =	0.00702	kips/in.
L =	216	in.

P =	0.00	kips
W_{DL} =	0.00702	kips/in.
L =	216	in.

LOADED

% Span	Length x_i (in.)	Moment M_i (kip-in.)	Curvature ϕ (1 / in.)	$\phi * dx * x_i$ (in.)	$\phi * dx * x_j$ (in.)
0.00	0.00	0.00	0.00	0.00	0.00000
1.67	3.60	65.0	3.20E-06	6.90E-06	0.00001
3.33	7.20	129.9	6.39E-06	5.52E-05	0.00007
5.00	10.80	194.6	9.58E-06	1.45E-04	0.00017
6.67	14.40	259.3	1.28E-05	2.76E-04	0.00030
8.33	18.00	324.0	1.60E-05	4.48E-04	0.00048
10.00	21.60	388.5	1.91E-05	6.61E-04	0.00070
11.67	25.20	452.9	2.23E-05	9.15E-04	0.00096
13.33	28.80	517.2	2.55E-05	1.21E-03	0.00127
15.00	32.40	581.5	2.86E-05	1.55E-03	0.00161
16.67	36.00	645.6	3.18E-05	1.92E-03	0.00199
18.33	39.60	709.7	3.49E-05	2.34E-03	0.00242
20.00	43.20	773.7	3.81E-05	2.80E-03	0.00288
21.67	46.80	837.6	4.12E-05	3.30E-03	0.00339
23.33	50.40	901.4	4.44E-05	3.84E-03	0.00393
25.00	54.00	965.1	4.75E-05	4.41E-03	0.00452
26.67	57.60	1,028.7	5.07E-05	5.03E-03	0.00514
28.33	61.20	1,092.2	5.38E-05	5.69E-03	0.00581
30.00	64.80	1,155.6	5.69E-05	6.39E-03	0.00651
31.67	68.40	1,218.9	6.00E-05	7.13E-03	0.00726
33.33	72.00	1,282.2	1.40E-04	1.76E-02	0.01787
35.00	75.60	1,345.3	2.33E-04	3.06E-02	0.03114
36.67	79.20	1,408.4	3.19E-04	4.41E-02	0.04475
38.33	82.80	1,471.4	4.06E-04	5.88E-02	0.05968
40.00	86.40	1,534.3	6.68E-04	1.01E-01	0.10243
41.67	90.00	1,597.1	2.20E-03	3.47E-01	0.35194
43.33	93.60	1,597.5	2.22E-03	3.64E-01	0.36867
45.00	97.20	1,597.8	2.23E-03	3.80E-01	0.38502
46.67	100.80	1,598.0	2.24E-03	3.96E-01	0.40093
48.33	104.40	1,598.1	2.24E-03	4.12E-01	0.41634
50.00	108.00	1,598.2	2.24E-03	4.26E-01	0.43118
			Σ =	2.62540	2.65939

UNLOADED

% Span	Length x_i (in.)	Moment M_i (kip-in.)	Curvature ϕ (1 / in.)	$\phi * dx * x_i$ (in.)	$\phi * dx * x_j$ (in.)
0.00	0.00	0.00	0.00	0.00	0.00000
1.67	3.60	2.68	1.28E-07	2.77E-07	0.00000
3.33	7.20	5.27	2.56E-07	2.21E-06	0.00000
5.00	10.80	7.78	3.79E-07	5.73E-06	0.00001
6.67	14.40	10.19	4.98E-07	1.07E-05	0.00001
8.33	18.00	12.50	6.12E-07	1.72E-05	0.00002
10.00	21.60	14.73	7.22E-07	2.49E-05	0.00003
11.67	25.20	16.87	8.27E-07	3.39E-05	0.00004
13.33	28.80	18.92	9.28E-07	4.41E-05	0.00005
15.00	32.40	20.87	1.02E-06	5.53E-05	0.00006
16.67	36.00	22.73	1.12E-06	6.75E-05	0.00007
18.33	39.60	24.51	1.20E-06	8.06E-05	0.00008
20.00	43.20	26.19	1.29E-06	9.44E-05	0.00010
21.67	46.80	27.78	1.36E-06	1.09E-04	0.00011
23.33	50.40	29.28	1.44E-06	1.24E-04	0.00013
25.00	54.00	30.69	1.51E-06	1.40E-04	0.00014
26.67	57.60	32.01	1.57E-06	1.56E-04	0.00016
28.33	61.20	33.24	1.63E-06	1.73E-04	0.00018
30.00	64.80	34.37	1.69E-06	1.90E-04	0.00019
31.67	68.40	35.42	1.74E-06	2.07E-04	0.00021
33.33	72.00	36.38	1.79E-06	2.24E-04	0.00023
35.00	75.60	37.24	1.83E-06	2.41E-04	0.00025
36.67	79.20	38.01	1.87E-06	2.58E-04	0.00026
38.33	82.80	38.69	1.90E-06	2.75E-04	0.00028
40.00	86.40	39.29	1.93E-06	2.92E-04	0.00030
41.67	90.00	39.79	1.96E-06	3.08E-04	0.00031
43.33	93.60	40.20	1.98E-06	3.24E-04	0.00033
45.00	97.20	40.51	1.99E-06	3.40E-04	0.00034
46.67	100.80	40.74	2.00E-06	3.55E-04	0.00036
48.33	104.40	40.88	2.01E-06	3.69E-04	0.00037
50.00	108.00	40.92	2.01E-06	3.82E-04	0.00039
			Σ =	0.00490	0.00499

MOMENT CURVATURE ANALYSIS

Curvature ϕ (1/in.)	Moment M_i (kip-in.)	
-4.02E-09	0.00	Unloaded
6.05E-05	1227.61	At Cracking
2.92E-04	1385.78	
3.81E-04	1460.21	
4.80E-04	1503.39	
5.92E-04	1525.76	
7.16E-04	1539.69	
8.61E-04	1548.54	
9.90E-04	1559.30	
1.17E-03	1564.56	
1.35E-03	1570.25	
1.52E-03	1577.29	
1.68E-03	1584.16	
1.90E-03	1588.63	
2.08E-03	1593.77	
2.24E-03	1598.19	At Failure

TOTAL DEFLECTION

Δ_T = 6.17 in.

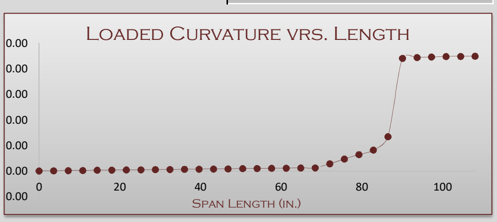
$\Delta_{Total} = \Delta_{Load} + \Delta_{Self\ Weight} + \Delta_{Camber}$

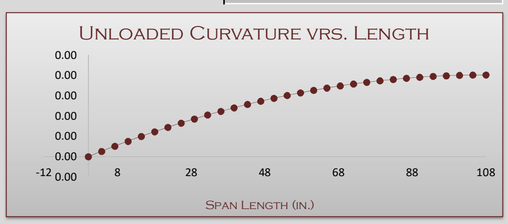
Δ_{LOAD} = 5.28480 in.

$\Delta_{SELF\ WEIGHT}$ = 0.00990 in.

Δ_{CAMBER} = 0.875 in.

*Physically Measured





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SHEAR CALCULATIONS

V_u =	39,000	LBS.
V_c =	7457	LBS.
φ =	0.75	

b_w =	2.50	IN.
d =	12.83	IN.

P_U =	39.00	KIPS
W_{DL} =	0.084	KIPS/IN.

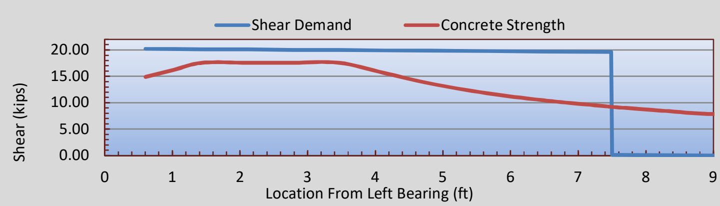
f_{pe} =	3.63	KSI
V_p =	0.00	KIPS

	X	Applied Shear (kips)			M_{cr}	Shear Strength (kips)		
	(FT.)	V_{DL}	V_{LL}	V_U	(KIP-IN.)	V_{cw}	V_{ci}	φV_c
$h/2$	0.60	0.71	19.50	20.21	658.2	19.86	93.72	14.90
	1.02	0.67	19.50	20.17	789	21.65	67.12	16.23
l_t	1.44	0.64	19.50	20.14	919.9	23.43	55.98	17.57
	2.12	0.58	19.50	20.08	915	23.43	38.85	17.57
	2.79	0.52	19.50	20.02	910.6	23.43	29.97	17.57
	3.46	0.47	19.50	19.97	906.6	23.43	24.53	17.57
	4.13	0.41	19.50	19.91	903	23.43	20.85	15.64
l_d	4.81	0.35	19.50	19.85	900	23.43	18.20	13.65
	5.64	0.28	19.50	19.78	896.8	23.43	15.76	11.82
	6.48	0.21	19.50	19.71	894.3	23.43	13.94	10.46
	7.49	0.13	19.50	19.63	892.2	23.43	12.29	9.218
	7.50	0.13	0.00	0.13	892.2	23.43	12.28	9.208
	8.34	0.06	0.00	0.06	891.3	23.43	11.20	8.4
Midspan	9.00	0.00	0.00	0.00	891.1	23.43	10.49	7.866
	9.84	-0.07	0.00	-0.07	891.3	23.43	11.27	8.451
	10.68	-0.14	0.00	-0.14	892.2	23.43	12.25	9.188
	11.52	-0.21	-19.50	-19.71	894.3	23.43	13.52	10.14
	12.36	-0.28	-19.50	-19.78	896.8	23.43	15.19	11.4
l_d	13.19	-0.35	-19.50	-19.85	900	23.43	17.49	13.12
	13.87	-0.41	-19.50	-19.91	903	23.43	20.03	15.03
	14.54	-0.47	-19.50	-19.97	906.6	23.43	23.60	17.57
	15.21	-0.52	-19.50	-20.02	910.6	23.43	28.93	17.57
	15.88	-0.58	-19.50	-20.08	915	23.43	37.69	17.57
l_t	16.56	-0.64	-19.50	-20.14	919.9	23.43	54.71	17.57
	16.98	-0.67	-19.50	-20.17	789	21.65	65.78	16.23
$h/2$	17.40	-0.71	-19.50	-20.21	658.2	19.86	92.31	14.90

Stirrup Design

φV_s REQ. ≥ V_u - φV_c

Location	φV_s Req.	
At $h/2$	5.31	KIPS
At ℓt	2.57	KIPS
At ℓd	6.21	KIPS
At Midspan	-7.87	KIPS



S_{MAX} =	10.88	IN.
S_{MAX} =	30.29	IN.
S_{MAX} =	24.13	IN.

S_{MAX} = 10.88 IN.

Controls

Spacing Requirements

Location	$S_{REQ.}$		Spacing		φV_s		Spacing Usage
At $h/2$	11.96	IN.	10.00	IN.	6.353	KIPS	Use 10 in. Near Ends
At ℓt	24.76	IN.	10.00	IN.	6.353	KIPS	Use 10 in. To Transition
At ℓd	10.24	IN.	10.00	IN.	6.353	KIPS	Use 10 in. Near Ld
At Midspan	-8.08	IN.	10.00	IN.	6.353	KIPS	Use 10 in. Middle

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Parameters

Area =	74.89063	in.^{2}	Age @ Release =	92	hrs	No. Strands =	3	0.5'' Dia.
I_x =	1,825.15	in.^{4}	Age @ Testing =	672	hrs	A_{ps} =	0.459	in.^{2}
Height =	14.50	in.	Aging Coeff., χ =	0.7		f_{pu} =	270	ksi
w =	84.2	plf	Humidity =	75	%	E_{ps} =	28,900	ksi
V/S =	1.3219	in.	K1 =	1.0		y_c =	1.67	in
Length =	20.00	ft.	K2 =	1.0		f_{py} =	243.0	ksi
						f_{pj} =	202.5	ksi

Prestress Losses

Shrinkage

K_f =	0.43	Concrete Strenght Factor
K_s =	1.28	Size Factor
K_{hs} =	0.93	Humidity Factor for Shrinkage
K_{td} =	0.60	Time Development Factor
γ_{sh} =	0.31	
ε_{sh} =	1.47E-04	Shrinkage strain at testing

Creep

K_{td} =	0.57	Time Development Factor
K_{la} =	0.85	Loading Factor
K_{hc} =	0.96	Humidity Factor for Creep
K_f =	0.43	Concrete Strength Factor
K_s =	1.28	Size Factor
γ_{cr} =	0.26	
ψ_{cr} =	0.48	

Transformed Section @ Transfer

w_c =	153.5	pcf	A_{ti} =	76.48	in.^{2}	K_r =	0.942
E_{ci} =	6,477	ksi	Y_{bti} =	8.33	in.	K_{rd} =	0.924
E_c =	7,294	ksi	I_{ti} =	1,897	in.^{4}		
n_i =	4.46	Modualr Ratio	e_{pti} =	6.66	in.		
n =	3.96	Modular Ratio	e_p =	6.80	in.		
			α =	2.90			

$$LR = \frac{f_{pj}}{45}\left(\frac{f_{pj}}{f_{py}} - 0.55\right) \times \log\left(\frac{Age\ at\ Release\ (hours) + 1}{1}\right) = 2.51 \text{ ksi}$$ Relaxation prior to transfer

f_{pi} = 199.99 ksi — Stress just before transfer

$$\Delta ES_p = \frac{P_i \alpha K_r n_i}{A} = 14.938 \text{ ksi}$$ Elastic shortening (from prestress)

$$\Delta ES_g = -M\frac{e_p}{I}K_r n_i = -0.066 \text{ ksi}$$ Elastic shortening (from self weight)

$$\Delta SH_{bd} = \varepsilon_{sh(final)} E_p K_{rd} = 3.94 \text{ ksi}$$ Shrinkage

$$\Delta CR_{bd} = n_i f_{cir} \psi_{cr} K_{rd} = 6.66 \text{ ksi}$$ Creep

$$LR = \frac{f_{pj}}{45}\left(\frac{f_{pj}}{f_{py}} - 0.55\right) \times \log\left(\frac{Age\ at\ 28\ Days\ (hours) + 1}{Hours\ at\ Transfer + 1}\right) = 1.1 \text{ ksi}$$ Relaxation losses after transfer

TOTAL LOSSES = 26.57 ksi

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STRESS-STRAIN MODELING OF 270 KSI LOW-RELAXATION PRESTRESSING STRANDS - POWER FORMULA

Material Parameters

E_{ps} =	28,900	ksi*	Modulus of Elasticity
P_y =	40,253	lb*	Yield force of strand
BS =	42,869	kips*	Break strenth of strand
A_s =	0.1511	in^2*	Area of individual strand
f_{py} =	266.40	ksi	Yield stress of the strand
f_{pu} =	283.71	ksi	Ultimate stress of the strand
ε_{pu} =	0.052	in/in*	Ultimate strain of strand
ε_{ps} =	0.01	in/in*	Yield strain of the strand
f_{so} =	277.06	ksi	

***Based on extensive testing by authors Ravi K. Devalapura & Maher K. Tadros at the request of the PCI Industry Handbook Committee. producing refined constants of the previously develped power formula. Shown in several studies to predict prestressing steel stress for a given strain to within 1% error of any prescribed experimental value.*

Refrence Article Stress-Strain Modeling of 270 ksi Low-Relaxation Prestressing Strands published in the PCI Journal (1992)

*Note: Values are obtained from strand certifications

Power Formula Constant Calculations

$$\boldsymbol{A} = E_{ps}\left(\frac{f_{pu} - f_{so}}{\varepsilon_{pu}E_{ps} - f_{so}}\right) = 156.96 \text{ ksi}$$

$$\boldsymbol{B} = E_{ps} - A = 28{,}743 \text{ ksi}$$

$$\boldsymbol{C} = \frac{E_{ps}}{f_{so}} = 104.31$$

$$\boldsymbol{D} = 11.92$$

← Iterate values of "$\boldsymbol{D}$ " until $f_{ps} = f_{py}$
Once done hit the 'Run Analysis' button on the 'Beam Section' sheet.

$$f_{ps} = \varepsilon_{ps}\left(A + \frac{B}{\left(1 + (C\varepsilon_{ps})^D\right)^{\frac{1}{D}}}\right) = 266.40 \text{ ksi}$$

$$f_{py} = 266.40 \text{ ksi}$$

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$Top\ Flange\ Stress = f_t = \frac{P}{A} - \frac{Pe}{S_t} + \frac{M_{self-weigh}}{S_t}$

$Bottom\ Flange\ Stress = f_b = \frac{P}{A} + \frac{Pe}{S_b} - \frac{M_{self-weigh}}{S_b}$

$Allowable\ Tension\ Stress = 6\sqrt{f_c'}\ @\ Ends$

$Allowable\ Tension\ Stress = 3\sqrt{f_c'}\ @\ Otherwise$

$Allowable\ Compression\ Stress = 0.6f_c'$

SIGN CONVENTION : + = COMPRESSION
- = TENSION

P =	83.65	KIPS
E =	6.80	IN.
A =	74.89	IN^2
S_T =	302.69	IN^3
S_B =	215.47	IN^3

*ASSUMING CONCRETE STRENGTH AT RELEASE IS 10650 PSI

TOP OF BEAM

% SPAN	LENGTH x_i (IN.)	MOMENT M_i (KIP-IN.)	f SELF WEIGHT (KSI)	f PRESTRESS (KSI)	f TOTAL (KSI)	f ALLOWABLE (KSI)	MIN. fc REQUIRED (KSI)	AREA OF STEEL REQUIRED (IN^2)
0.00	0.00	0.00	0.00	0.00	0.00	-0.62	0.00	0.00
1.16	2.78	-0.03	0.00	-0.08	-0.08	-0.62	0.20	0.04
2.31	5.56	-0.11	0.00	-0.17	-0.17	-0.62	0.80	0.08
3.47	8.33	-0.24	0.00	-0.25	-0.26	-0.62	1.81	0.13
4.63	11.11	-0.43	0.00	-0.34	-0.34	-0.62	3.22	0.17
5.79	13.89	0.91	0.00	-0.42	-0.42	-0.62	4.92	0.21
6.94	16.67	2.95	0.01	-0.51	-0.50	-0.62	6.92	0.25
8.10	19.44	4.94	0.02	-0.59	-0.58	-0.62	9.26	0.28
9.26	22.22	6.87	0.02	-0.68	-0.66	-0.62	11.94	0.32
10.42	25.00	8.75	0.03	-0.76	-0.73	-0.62	14.98	0.36
12.22	29.32	11.57	0.04	-0.76	-0.73	-0.31	58.41	0.35
14.02	33.64	14.25	0.05	-0.76	-0.72	-0.31	56.99	0.34
15.81	37.95	16.80	0.06	-0.76	-0.71	-0.31	55.66	0.34
17.61	42.27	19.22	0.06	-0.76	-0.70	-0.31	54.41	0.33
19.41	46.59	21.51	0.07	-0.76	-0.69	-0.31	53.24	0.32
21.21	50.91	23.67	0.08	-0.76	-0.69	-0.31	52.15	0.32
23.01	55.23	25.70	0.08	-0.76	-0.68	-0.31	51.13	0.31
24.81	59.55	27.59	0.09	-0.76	-0.67	-0.31	50.19	0.31
26.61	63.86	29.36	0.10	-0.76	-0.67	-0.31	49.32	0.30
28.41	68.18	31.00	0.10	-0.76	-0.66	-0.31	48.53	0.30
30.21	72.50	32.50	0.11	-0.76	-0.66	-0.31	47.80	0.30
32.01	76.82	33.88	0.11	-0.76	-0.65	-0.31	47.14	0.29
33.81	81.14	35.12	0.12	-0.76	-0.65	-0.31	46.55	0.29
35.61	85.45	36.23	0.12	-0.76	-0.64	-0.31	46.02	0.29
37.41	89.77	37.21	0.12	-0.76	-0.64	-0.31	45.56	0.29
39.20	94.09	38.06	0.13	-0.76	-0.64	-0.31	45.16	0.28
41.00	98.41	38.78	0.13	-0.76	-0.64	-0.31	44.82	0.28
42.80	102.73	39.37	0.13	-0.76	-0.63	-0.31	44.55	0.28
44.60	107.05	39.83	0.13	-0.76	-0.63	-0.31	44.34	0.28
46.40	111.36	40.16	0.13	-0.76	-0.63	-0.31	44.18	0.28
48.20	115.68	40.35	0.13	-0.76	-0.63	-0.31	44.09	0.28
50.00	120.00	40.42	0.13	-0.76	-0.63	-0.31	44.06	0.28

AREA OF REINFORCEMENT REQUIRED = 0.36

AREA OF REINFORCEMENT PROVIDED = 0.40 OK

BOTTOM OF BEAM

% SPAN	LENGTH x_i (IN.)	MOMENT M_i (KIP-IN.)	f SELF WEIGHT (KSI)	f PRESTRESS (KSI)	f TOTAL (KSI)	MIN fc REQUIRED (KSI)
0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.29	2.78	-0.03	0.00	0.42	0.42	0.70
2.57	5.56	-0.11	0.00	0.84	0.84	1.39
3.86	8.33	-0.24	0.00	1.25	1.25	2.09
5.14	11.11	-0.43	0.00	1.67	1.67	2.79
6.43	13.89	0.91	0.00	2.09	2.08	3.47
7.72	16.67	2.95	-0.01	2.51	2.49	4.15
9.00	19.44	4.94	-0.02	2.92	2.90	4.83
10.29	22.22	6.87	-0.03	3.34	3.31	5.51
11.57	25.00	8.75	-0.04	3.76	3.72	6.20
13.57	29.32	11.57	-0.05	3.76	3.70	6.17
15.57	33.64	14.25	-0.07	3.76	3.69	6.15
17.57	37.95	16.80	-0.08	3.76	3.68	6.13
19.57	42.27	19.22	-0.09	3.76	3.67	6.12
21.57	46.59	21.51	-0.10	3.76	3.66	6.10
23.57	50.91	23.67	-0.11	3.76	3.65	6.08
25.57	55.23	25.70	-0.12	3.76	3.64	6.07
27.57	59.55	27.59	-0.13	3.76	3.63	6.05
29.57	63.86	29.36	-0.14	3.76	3.62	6.04
31.57	68.18	31.00	-0.14	3.76	3.61	6.02
33.56	72.50	32.50	-0.15	3.76	3.61	6.01
35.56	76.82	33.88	-0.16	3.76	3.60	6.00
37.56	81.14	35.12	-0.16	3.76	3.60	5.99
39.56	85.45	36.23	-0.17	3.76	3.59	5.98
41.56	89.77	37.21	-0.17	3.76	3.59	5.98
43.56	94.09	38.06	-0.18	3.76	3.58	5.97
45.56	98.41	38.78	-0.18	3.76	3.58	5.96
47.56	102.73	39.37	-0.18	3.76	3.58	5.96
49.56	107.05	39.83	-0.18	3.76	3.57	5.96
51.56	111.36	40.16	-0.19	3.76	3.57	5.95
53.56	115.68	40.35	-0.19	3.76	3.57	5.95
55.56	120.00	40.42	-0.19	3.76	3.57	5.95

CONCRETE STRENGTH REQUIRED = 6.20

CONCRETE STRENGTH PROVIDED = 10.65 OK

Appendix D

Concrete Mix Design

BATCH REPORT by Batch Number

Concrete Technology Corporation, Tacoma, WA

Cast Date:	5/5/2017	Mixer Number:	2 Station Number: 2
DB ID#:	22378	Call Time:	2:14:33 PM
Recipe Number:	140	Mix Start Time:	2:21:17 PM
Recipe Name:	140	Complete Time:	2:23:33 PM
Daily Count No.:	64	Discharge Time:	2:24:38 PM
Batches this Pour:	1	W/C Target:	0.270
Yards this Pour:	2.3	W/C Actual:	0.268
Yards This Batch:	2.3	Water Temperature:	59.3 °F
Job Number:	17X8O	Batched in Auto:	☑ Mixed in Auto: ☑ Hot Mix Alarm: ☐
Job Name:	BIG BEAM		
Mark Number:			

AGGREGATES

	Name	SSD Target lbs.	SSD Actual lbs.	Dev. %	Free Water lbs.	Total Moisture %	Absorbed Moisture %	Actual Wet Wt. lbs.
1	5/8"	2,270	2,274	0.18%	23	2.00	0.95	2,297
2	5/8"	2,270	2,265	-0.22%	23	2.00	0.95	2,288
3	Sand	1,393	1,373	-1.44%	64	6.50	1.85	1,437
4	Sand	1,396	1,393	-0.21%	78	7.47	1.85	1,471
5	#8 PEA GRAVEL	0	0	0.00%	0	0.00	0.00	0
6	#8 PEA GRAVEL	0	0	0.00%	0	0.00	0.00	0
	TOTAL	7,329	7,305		188			7,493

CEMENTS

	Name	Target lbs.	Actual lbs.	Dev. %
1	Silica Fume	0	0	0.00%
2	Fly Ash	0	0	0.00%
3	TYPE III	0	0	0.00%
4	TYPE III	1,729	1,724	-0.29%
	TOTAL	1,729	1,724	-0.29%

ADMIXTURES

	Name	Target oz.	Actual oz.	Dev. %	Water %
2.1	Daravair 1000	0.0	0.0	0.00%	0.0%
2.2	WDRA 64	69.0	69.0	0.00%	0.0%
2.3	DCI	0.0	0.0	0.00%	0.0%
2.4	VMAR	0.0	0.0	0.00%	0.0%
2.5	ADVA 575	156.0	156.0	0.00%	0.0%

WATER

Max. Probe Target: 0

Total Metered Target	Adjusted Metered Target	Metered Actual	Dev. %	Probe Metered Actual	Manual Metered Actual	Total Metered Actual	Aggregate Moisture	Admixture Moisture	TOTAL Water Actual	Probe Readings	
55.9 gal.	33.2 gal.	33.1 gal.	-0.30%	0.0 gal.	0.0 gal.	33.0 gal.	22.6 gal.	0.0 gal.	55.6 gal.	0	at Final mix
465 lb.	277 lb.	276 lb.		0 lb.	0 lb.	275 lb.	188 lb.	0 lb.	463 lb.	0	at Discharge

operator

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Appendix E

Strand Specifications

SUMIDEN WIRE
PRODUCTS CORPORATION

Prestressed Concrete Strand Division
East: 710 Marshall Stuart Drive, Dickson, TN 37055 • 866-491-5020
West: 1412 El Pinal Drive, Stockton, CA 95205 • 866-246-3758

Import 1/2
No samples needed

MILL CERTIFICATE OF INSPECTION

Order Number: SLPC170283-1 Page No : 1 OF 1
B/L No: SIPC171044 Issue Date : 04/25/2017

Commodity: Steel Strand, Uncoated Seven Wire for Prestressed Concrete
Size & Grade: 1/2" x 270 KSI
Specification: ASTM A416-Latest 1/2"-Low Relaxation
Customer Name: CONCRETE TECHNOLOGY CORPORATION
Customer P.O.: 6-04151
Destination: CONTEC-WA
State Job No:

No	Pack #	Heat #	B.S.	Elong.	Y.P.	Area	E-Modulus	CURVE#
			Min:41,300	3.5	37,170			
			(LB)	(%)	(LB)	(IN2)	(MPSI)	
1	S129195-5	S0286957	42,962	4.6	39,844	0.1513	28.8	S129195
2	S529386-3	S0286956	43,291	5.0	40,411	0.1514	28.8	S529386
*3	S529394-6	S0286409	42,869	5.2	40,253	0.1511	28.9	S529394
4	S529395-3	S0286957	42,732	4.9	40,282	0.1513	28.9	S529395
5	S529396-1	S0286957	42,829	5.4	40,274	0.1516	28.7	S529396
6	S529396-2	S0286957	42,829	5.4	40,274	0.1516	28.7	S529396
7	S529398-7	S0286959	42,833	5.5	40,094	0.1520	28.7	S529398

We hereby certify that:
* We have accurately carried out the inspection of COMMODITY and met the requirements in accordance with the applicable SPECIFICATION, both listed above.
* The material described above will bond to concrete of a normal strength and consistency in conformance with the prediction equations for transfer and development length given in the ACI/AASHTO specifications.
* The individual below has the authority to make this certificate legally binding for SWPC.

Received by,
Scott G. McCallon
4/28/17

Date: 4/25/17 CMO: NO
PO: 6-04151
Job: Inventory
Item: Strand 1/2" Commercial

Quality Assurance Section

SUMIDEN WIRE
PRODUCTS CORPORATION

Prestressed Concrete Strand Division
East: 710 Marshall Stuart Drive, Dickson, TN 37055 • 866-491-5020
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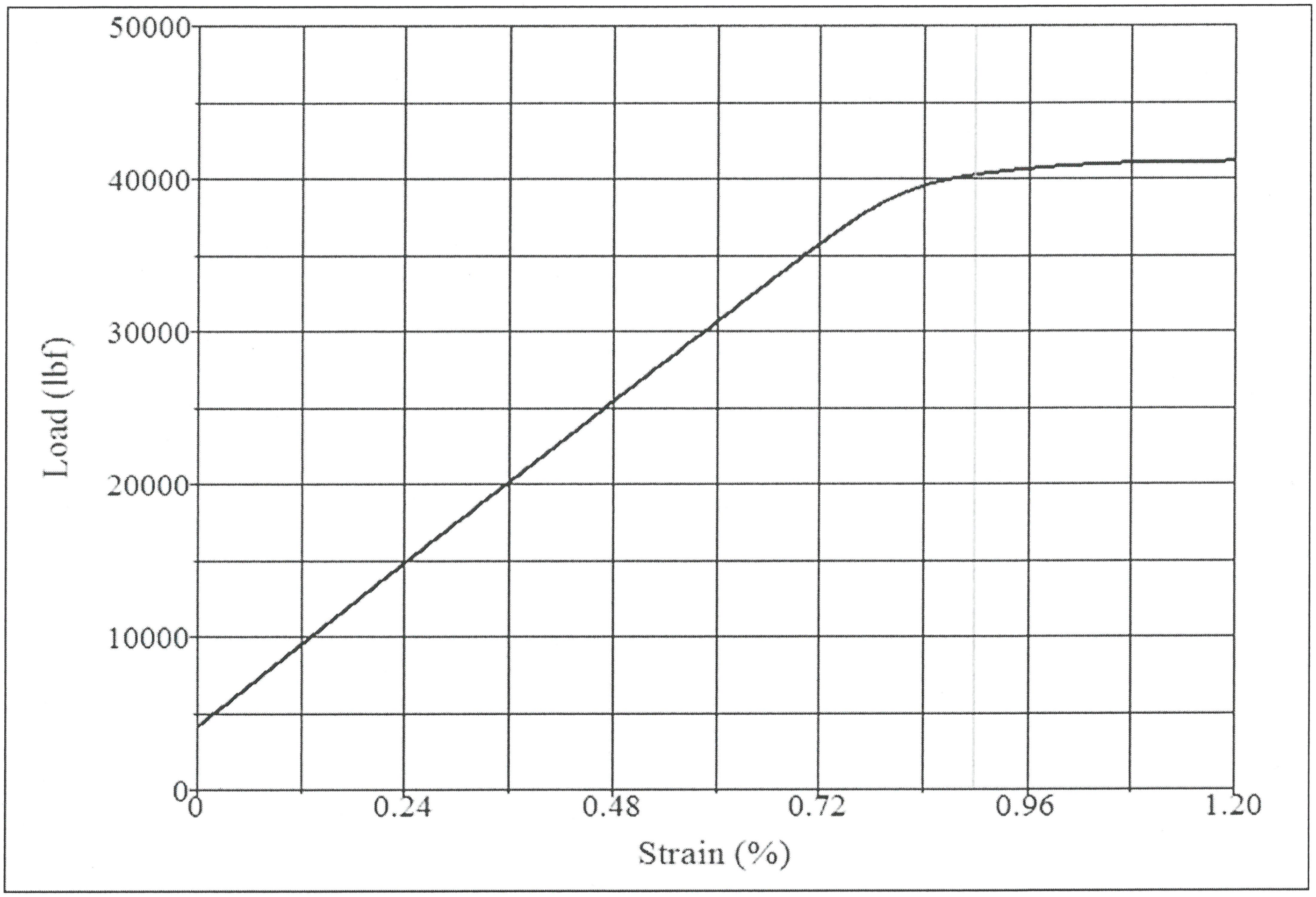

*Vertical Line is drawn at 1% Extension Under Load

Curve # S529394

Yield Point	40253 lbf
Area	0.1511 in²
Modulus	28.9 Msi

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