Saint Martin's University

PCI BIG BEAM COMPETITION 2017 - 2018

Student Members:

Jarad Roschi, Joel Rodgers, Tyler Sloan, Carthney Laukon, Jesse San Nicolas, Luis Camacho, Turner Kreman, Chase Weeks

PCI Producer Member:

Austin Maue, PE - Concrete Technology Corporation

Faculty Advisor:

Jill Walsh, PhD. PE - Saint Martin's University

THIS PAGE INTENTIONALLY LEFT BLANK

Table of Contents

List of Tables

List of Figures

Summary/Intro

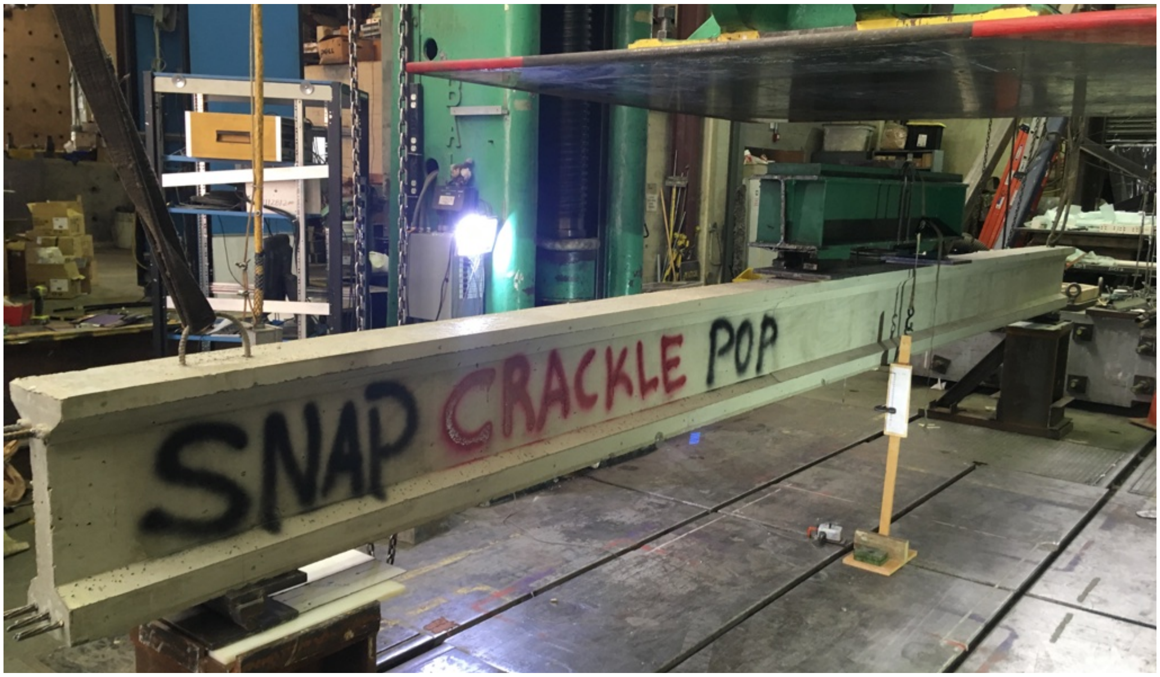
2018 marks the third year in a row for a team from Saint Martin's University to compete in the Precast/Prestressed Concrete Institute (PCI) Big Beam Competition. This year's competition includes designing and fabricating a 22-foot precast/prestressed concrete beam and then testing the beam and analyzing the data. The beam must meet the standards and criteria outlined in the official rules for the PCI competition. The team members included: Luis Camacho, Turner Kremen, Carthney Laukon, Jesse San Nicolas, Tyler Sloan, Chase Weeks and team leaders: Joel Rogers and Jarad Roschi. Dr. Jill Walsh, PhD, PE is the school faculty advisor and Austin Maue, PE is the PCI Producer Member sponsor from Concrete Technology Corporation.

The main goal for this year's team is to work on what has been learned from the previous years and to make more precise predictions to give better results. The design chosen is an I-beam with a constant depth and cross-section along the length of the beam. There are three prestressing strands in the bottom, two steel reinforcing bars in the top, and shear reinforcing stirrups running the length of the beam. The beam was designed using an Excel spreadsheet with macros which was made by the 2016 Saint Martin's University Big Beam Team. The spreadsheet has been improved over the last two years with more detailed calculations and programming. The length of the beam, the location of the two point loads, as well as the material properties were all changes that needed to be accounted for. This year, the team narrowed down a few different design options using the design spreadsheet and chose to go with "Snap, Crackle Pop" seen in Figure 1. This is a typical I-beam design and shape but utilizes admixtures in the cement to account for a shorter cure time. Further details will be in the design section. From the spreadsheet, the following calculations shown in Table 1 were chosen as the prediction values.

Table 1 - Predictions and Results

	Prediction	Actual	Percent Error
Cracking Load (kips)	22.23	20.18	9.21 %
Ultimate Load (kips)	35.57	35.66	0.261 %
Max Deflection (in)	4.52	4.12	8.85 %

Figure 1 - Snap Crackle Pop



Design

This year's team relied on their advisors and sponsors for help and information throughout the competition. The two team leaders were the only two returning members and all but one of the team members were junior level students who were taking reinforced concrete during the competition. No one on the team has taken prestressed concrete design so prestressed lessons were needed. Austin Maue and Dr. Walsh have been very helpful and patient while teaching us prestressed design in a crash course setting. The lack of experience, schedule conflicts and illness were all obstacles which the team faced during the competition which limited our curing time. The beam design was finalized on 24 April and the construction date was on the May 25 giving us a 14-day cure time on the day of testing.

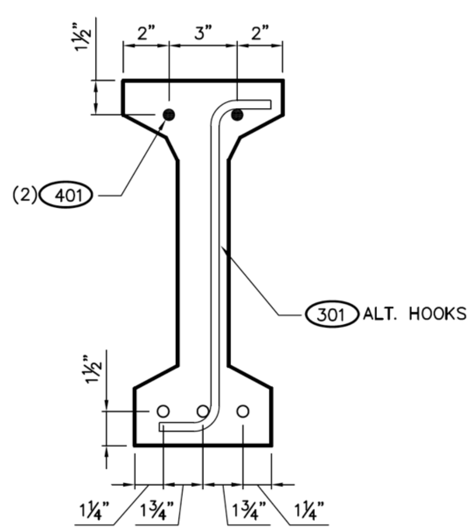
Reinforced concrete design gave a good foundation for the design process. The benefit of an I-beam or T-beam is the high moment of inertia which gives it a large carrying capacity compared to its size. Steel reinforcement can increase the load capacity of a concrete beam but as the span of the beam increases, so does the weight and therefore the load it is carrying. Prestressing allows reinforced concrete to increase the load capacity and/or increase the span length.

Prestressing a beam increases the flexural capacity by pre-compressing the bottom portion of the beam. The pre-compression significantly aids in controlling service stresses which increases the carrying capacity of the beam. As the load is applied the beam will deflect downwards and the top flange will be in compression and the bottom flange in tension. Since concrete is better in compression than tension, it is expected that cracks will form in the bottom of the beam first. Cracking does not necessarily mean the beam is no longer serviceable. There are ACI code previsions which allow cracks in service but extra steps are required to maintain serviceability. If a beam is exposed to the elements, corrosive materials could penetrate the beam if cracks were to form. In some cases, a beam is exposed for aesthetics but is not exposed to the elements. This would be a case where cracking is not an appealing look to have on a structural member indoors. These situations require designing for a cracking load above the service requirements. A service load is applied to the beam during testing to ensure there is no cracking below the service capacity requirement of 20 kips. When the tensile force in the prestressing strands are at a maximum, they will begin to yield and increase in length. The result is a downward deflection in the beam. Deflection and cracking are good warning signs of failure. Otherwise, the beam would break suddenly without warning like a plain concrete beam with no reinforcement.

Flexure

The flexure concept was a newer concept for this year's team. The team talked with sponsors, faculty and upper classmen who had more experience with prestressed design. The top reinforcement of two No. 4 bars were chosen over No. 3 bars to provide more steel within the cross section (Figure 2). The idea is to support the stirrups while providing extra resistance to concrete crushing in the top flange. They also provide resistance to the tensile forces being applied during the prestressing stage which can cause cracking early. A flexure failure is preferred over a shear failure so the team chose a design with that being the goal.

Figure 2 – Reinforcement Detail

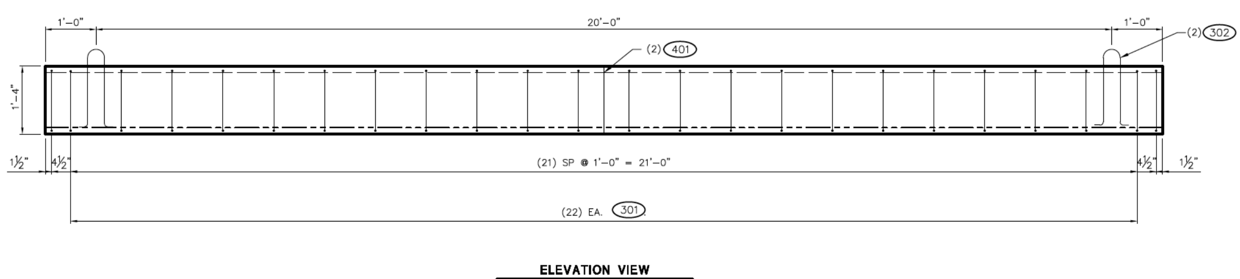


The prestressing strands were chosen because of the parameters of the competition. A service load of 20 kips with a failure window between 32 and 39 kips helped to narrow down the options. The team decided to use three $^{1}/_{2}$" uncoated seven wire low relaxation prestressing strands, ASTM A415 grade 270. Concrete Technology Corporation suggested prestressing strands from Sumiden Wire Product Corporation since they have a good quality product and it was used for last year's beam from Saint Martin's University. The prestressing strands with the top reinforcement provided the necessary flexure reinforcement needed to fit the design requirements.

Shear

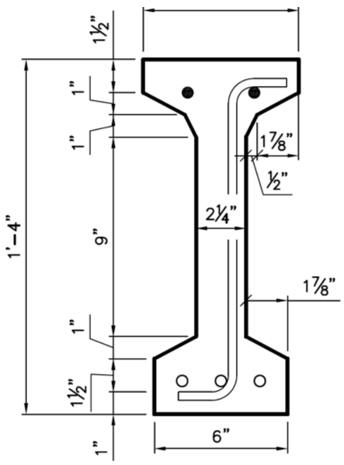
A flexural failure is much more desirable than a shear failure. Shear failures can be sudden and catastrophic so the tendency could be to over-design the beam and put the maximum amount of reinforcement needed. This could work but the cost of the beam and the time of labor has just increased as a result. Optimizing the shear reinforcement is a useful method to find the number and location of shear reinforcement along the length of the beam. For this competition strength is one of the top goals so the team decided to add more than required. The cost increases but the added strength is worth it. The first stirrup is placed 6" from the end and a stirrup at 12" on center to midspan and repeated on the other end (Figure 3).

Figure 3 - Shear Stirrup Spacing



The design spreadsheet has a macro to design the shear reinforcement which was written by the 2016 team. The coding follows ACI 318-11 by plotting the curves of the inclined shear strength, V_{ci}, and web shear, V_{cw}, on a graph of shear vs. span length. The lower of the two values, as the

Figure 4 - Typical Cross-Section



length increases, is the value used to design the shear reinforcement. This can be seen in Appendix C on the Shear Calculations sheet. This method is mainly an empirical method so exact results are not expected. The 2017 team used stirrups with a 135° bend in the top and a 90° bend at the bottom. This year's team decided to go with 90° bends at ends to ease installation and to ensure clear cover in the top flange (Figure 4).

Losses

The prestressing strands are made of steel and are stretched or strained to provide a high tensile capacity for prestressing. Steel is not a perfect material and as such will have losses associated over time. The prestressing losses are calculated using the stress-strain model for 270 ksi low-relaxation prestressing strands based on PCI standards using the Power Formula (found in Appendix C). Concrete is heterogeneous and will also have losses. The concrete losses are calculated with consideration to the age of the beam at release and testing as well as the prestressing losses. This was very helpful in our calculations with our beam being 14 days old on test day. The prestressing losses are then used to calculate the losses due to: elastic shortening of concrete, shrinkage and creep. (see Prestress Losses in Appendix C). Elastic shortening considers the loss of length due to the applied force when the prestressing strands are released. The strands will shorten causing shrinkage in the concrete. Shrinkage losses in the strands can be estimated as a function of the shrinkage of the concrete. The shrinkage of the strands also means a loss in strand stress. Creep losses are a result of the prolonged stressing of the concrete and prestressing strands. The losses associated with creep take longer to form but still need to be accounted for in the calculations. The total losses calculated came out to 23.32 ksi.

Materials

Concrete

The short cure time was the deciding factor when choosing the concrete mix design. This does not allow the beam to reach full strength or setting if a standard concrete mix were to be chosen. Concrete Technology Corporation has a large database of records kept from different concrete mix designs used in the past. With a goal of the contest being high strength, a design with a record of high strength was chosen. Austin Maue suggested using mix 140 after going through backup data reports. The backup data for mix 140 can be found in Appendix D. The backup data shows a list of 28-day strengths from a series of 30 cylinder crushing tests of the same mix design from early 2018. The 28-day cure time is expected to reach a compressive strength of 10,979 psi. Some analysis is performed on the average strength before giving a reliable value to be used for the specific batch. The compressive strength value is based on a probability of 1out of 100 that the average of three consecutive tests will be below the chosen compressive strength.

The concrete mix consists of Type III cement, $^{5}/_{8}$" coarse aggregate, sand and two admixtures. On build day, the mix had a w/c ratio of 0.313 at 70° F with an 8" slump, 1.6% air content and a unit weight of 152.8 pcf. The concrete mix and the batch data for the specific batch used for the beam can be found in Appendix D. The concrete mix system at Concrete Technology Corporation is an automated system while still providing accuracy in the mix design. The moisture levels in the aggregate silos can fluctuate which in turn will affect the water content in the concrete mix. There are moisture probes inside the silos which give a real-time moisture level reading to account for the changes. These changes can be seen in the batch report with the necessary adjustments being made to the amount of water added to the mix.

Two admixtures were chosen in the concrete mix design to help with the short cure time. ADVA® Cast 575 is a high-range water reducer which is designed to improve workability while preventing the mixture to separate and help develop an early strength in the concrete. ADVA® Cast 575 has a low viscosity with air entrainment control for rapid placement and consolidating while giving a nice finish on the molded surfaces. WRDA® 64 is the second admixture used in the concrete mix design and is also a water reducer (typically 8-10% reduction) used to achieve higher plasticity and develop high compressive and flexural strengths. WRDA® 64 helps to achieve an early setting time with less water while improving workability, strength and provides a smooth finish. Both admixtures were chosen to help the high-strength concrete mix reach strength capacity and set in the shortened amount of time.

The concrete mix design performed better than expected surpassing the design criteria. After 6 days, the beam was released from the formwork and two cylinder tests showed an average compressive strength of 10,135 psi at 6 days. This shows the admixtures are working compared to the 28-day compressive strength of mix 140. A second set of cylinders were tested on June 7th (day 13), one day before testing the beam, with the results shown in Table 2.

Table 2 - Concrete Cylinder Test Results

	6 days	**13 days**
f'_{ci} (psi)	10,135	
f'_{c} (psi)		12,155
MOE (ksi)		7,286
f'_{r} (psi)		833

Prestressing Strands

Three uncoated seven wire low relaxation steel prestressing strands each $^1/_2$" diameter rated at 270 ksi were used in the beam. The ASTM A416 strands were milled by Sumiden Wire Products Corporation who gave a certificate of inspection along with a load vs strain graph which can be found in Appendix D. The certificate shows the data for the strands chosen in the design and can be seen in Table 3. The jacking tolerances used for this design was +/- 3%. The jacking sheet shown in Appendix D shows the distances each strand was jacked. At 100% the lengths are 3 $^1/_2$", 3 $^1/_4$" and 3 $^1/_2$". This difference is considered small but prestressing losses over the 26-foot length add up.

Table 3 - Sumiden Prestressing Data

Results	Value
Break Strength (lbs)	42,965
Strain (%)	5.4
Yield Strength (lbs)	40,252
Area (in^2)	0.1514
MOE (ksi)	28,900

Shear and Mild Reinforcement

Z-shaped stirrups were chosen in the design for shear reinforcement. There is a total of 24 stirrups spaced at 1’ on center after the first stirrup at 6” from each end. The stirrups are made of No. 3 ASTM A615 grade 60 rebar. Two No. 4 bars each 22’ long were used in the top to support the stirrups and provide further tensile reinforcement in the top flange.

Cost

Using the guidelines given in the PCI competition rules, a complete cost analysis can be found in Appendix B. A summary of the cost can be seen in Table 4. The formwork was the highest cost on this project, accounting for more than half of the total cost. The higher cost for high-strength concrete can be accounted for by using less concrete than a lower strength concrete due to the increased strength.

Table 4 - Cost Summary

Materials	Cost
Concrete	$39.38
Prestressing Strands	$19.80
Steel Reinforcement	$21.19
Formwork	$86.97
Total	$167.34

Fabrication

Formwork

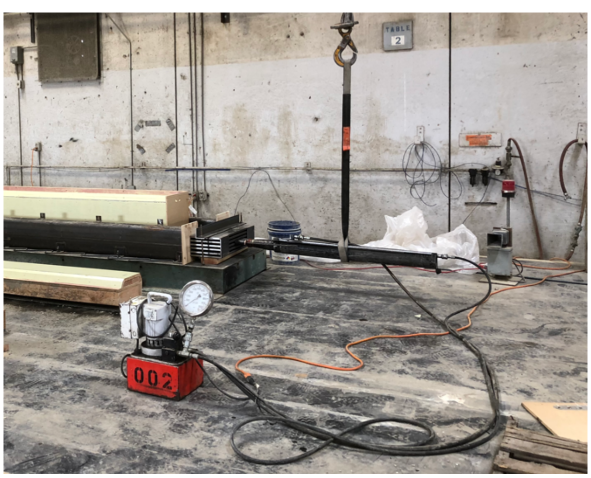
Figure 5 - Installing Formwork

The formwork was designed and constructed by Concrete Technology Corporation where the Saint Martin's University team members could help construct the beam. The bottom and steel bed frame were already in place but the sides needed to be installed and secured. One side of the formwork was installed (Figure 5) before applying a non-adhesive oil to all surfaces which will be in contact with concrete. This is used as a lubricant to minimize any damage that may occur during the release of the beam from the formwork. Once the prestressing strands and reinforcement were secured the second side and the two end pieces of the formwork could be installed and secured. The CAD drawings for the formwork and the stressing bay can be found in Appendix A.

Prestressing Strands

The prestressing strands used are uncoated and need to be clean of debris and other substances when being installed. Any small rock or oil can create a void or cause slipping after the concrete is poured so they are wiped down before placing them in the formwork. The prestressing strands were stressed to 31 kips of tension on each strand using a hydraulic ram shown in Figure 6. The stressing lengths were measured and recorded by the technicians at Concrete Technology Corporation and can be found in Appendix D. The prestressing strands were released and cut 3 days after construction.

Figure 6 - Hydraulic Prestressing



Reinforcement

Figure 7 - Installing Reinforcement

The 24 stirrups were installed (Figure 7) so that they ran above one of the top No. 4 bars and below two of the prestressing strands in the bottom and were attached using zip ties. Alternating direction of the stirrups gives the beam stronger reinforcement than if they were facing the same way. The first stirrup is placed 6" from each end with 1' on center spacing in between. The two No. 4 bars were cut about two inches longer than the formwork so they could stick out the ends and be supported. Two No. 4 U-hooks were installed for transportation, one at each end. These can be seen in Figure 3.

Casting/Curing

Once the reinforcement and formwork were in place the beam was ready to be cast. A temperature gauge was placed inside the formwork to track the temperature of the beam as it cured. The concrete was cast by the crew at Concrete Technology Corporation and covered with a large tarp to help maintain an even moisture lose throughout the beam. The beam was released from the formwork 6 days after construction. It was transported to University of Washington in Seattle by Concrete Technology Corporation and tested on day 14 of cure time.

Testing

The University of Washington (UW) in Seattle invited Saint Martin's University to More Hall Structures Lab to test their beam in the Baldwin hydraulic press. Dr. Stanton, Prof. UW Seattle civil engineering dept., and his staff ran the test (seen in Figure 8) and collected the data for the loading and deflection. The two-point load was distributed using a steel column with a weight of 600 lbs. This additional weight is not accounted for in the data and is added in the calculations shown in Appendix E. The deflection was measured using a potentiometer and recorded on a graph with the load. Multiple video cameras were set up to capture the deflection, cracking and the failure.

Figure 8 - Beam Loading

The first part of the test loads the beam to a simulated service load of 20 kips and then checked for cracks. The beam was loaded using load control at 80 $^{lbs}/_{sec}$ (roughly 4.5 minutes) up to the 20-kip mark. The beam had two small hairline cracks starting to form at the 20-kip mark. The graph seen in Figure 11 shows the yielding point below 20 kips but with the 600-lb. steel beam, the cracking load is seen to be over 20 kips. The loading was switched to a displacement controlled loading at $^{1}/_{2}$" per minute (roughly 7 minutes) up to failure. As the load increased the flexure cracks were growing in length and width with small shear cracking beginning just outside of the point loads. The beam continued to load until it suffered a crushing failure in the top flange between the two point loads (shown in Figures 9 and 10).

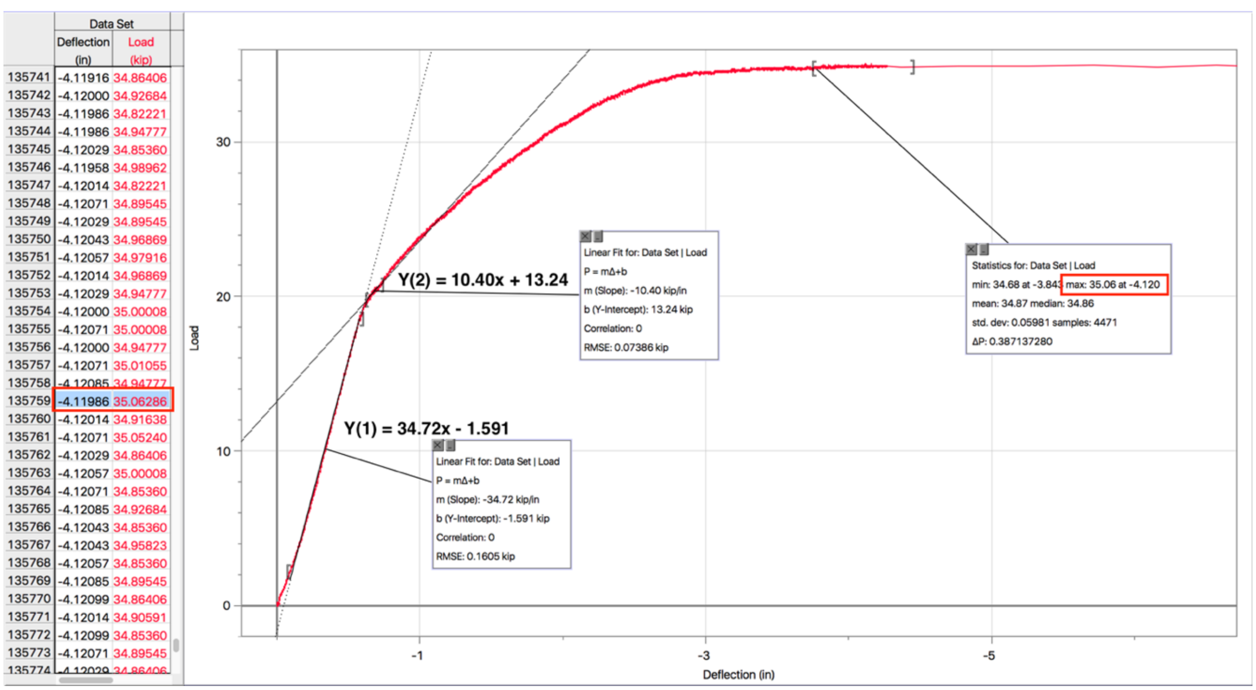
Figure 9 - Beam Failure

Figure 10 - Inspecting Failure

Results

The data from the test was imported into Logger Pro 3, a data collection and analyzing software. Logger Pro 3 has a "linear fit" option which gives the average linear approximation for a selected portion of the graph. The data collected can be seen in Figure 11 and in Appendix E. As previously stated, the graph does not include the additional 600 lb. due to the steel beam so it is added to the recorded value to determine the actual load value.

Figure 11 - Load vs Deflection Graph



The graph shows the beam beginning to yield below the 20-kip line. The cracking load is the load corresponding to the point on the graph where the initial slope starts to curve and become non-linear. This can be approximated by finding the intersection between the initial slope and the slope of the curve at the yielding point. The linear fit option shown in Figure 11 gives the slope and y-intercept values which are used to form two slope equations ($Y_{(1)}$, $Y_{(2)}$), shown on the graph. At the point of intersection, the two lines will have the same X and Y values but the Y value is the desired value. Solve for Y to find the cracking load. These calculations (found in Appendix E) showed cracking load of 19.58 kips. With the added 0.6 kip, the value becomes 20.18 kips as seen in Table 5. This is a 2.05-kip difference with an error 9.21% lower than the predicted value.

Table 5 - Results with Error

	Prediction	Graph Value	+ Steel Beam	Actual	Percent Error
Cracking Load (kips)	22.23	19.58	+ 0.6	20.18	9.21 %
Ultimate Load (kips)	35.57	35.06	+ 0.6	35.66	0.26 %
Max Deflection (in)	4.52	4.12	NA	4.12	8.85 %
				Total Error	18.32%

Since the beam showed signs of cracking at the 20-kip mark, the loading was not released before continuing the test. The beam was then loaded until failure at a constant rate. The data shows the beam reached ultimate loading before it crushed and broke apart. This type of failure is what was expected and what the team designed for. The goal is to avoid sudden failures since they tend to cause more damage and a higher risk of life or injury. The maximum ultimate load was the highest recorded value at 35.06 kips. These values are shown in the two red boxes on the Load vs Deflection Graph (Figure 11). Adding the 0.6 kip gives the actual load of 35.66 kips. This is a difference of 90 lbs. with an error of 0.26 % higher than the predicted value.

The maximum deflection is the deflection at the ultimate load. The max deflection was 4.12 inches and can be seen in the two red boxes on the Load vs Deflection Graph. The prediction was 4.52 inches which is a 0.4-inch difference. The actual value gives an error of 8.85% lower than predicted. This gives a total percent error of 18.32%.

Lessons Learned

The biggest lesson learned from this competition was time management and beginning earlier. Since the team was inexperienced with prestressing, more work was required to understand and design a beam. Once the team started they had more questions than they originally thought they would have. The lack of knowledge combined with busy schedules delayed the design and the build. Starting earlier in the year would provide more time to understand the concepts and give the beam more time to cure and reach full strength capacity.

The time crunch did give the team the opportunity to use admixtures and see how they can benefit the design. The concrete mix chosen was that of high strength without the admixtures. The shortened cure time meant the beam would not fully set and reach full strength capacity before being tested. The admixture chosen helped the concrete set early and reach a high strength within the 14-day cure time. The compressive strength was higher than the original batch mix at half of the cure time.

The team learned about prestressed concrete beams and how prestressing is done. Being able to go to the plant, construct the formwork and reinforcement and watch the casting of the beam is a valuable lesson for upcoming engineers. It gives an understanding of what it takes to construct such a product and gives an insight into that field. The design process for a prestressing beam can be overwhelming if you are inexperienced. Asking questions and seeking out help was essential to this competition. The spreadsheet used is a great tool to help learn about prestressing. Having a tool that allows you to make changes to a design and see the results immediately was very valuable.

The moment curvature analysis used to predict the deflection has been one of the more difficult areas throughout the past three years of the competition for Saint Martin's University. Adjustments were made this year and the physically measured portion of the calculations have been removed. This value is accounted for in the constants of integration and has been a source of problems in the past. The deflection prediction was higher than the actual value. This could be due to the losses and the 14-day cure time.

The team learned about working together and communication not only between team mates but between our faculty and sponsors. Communication was critical to the success of the design, construction, testing, analyzing and reporting of the beam. This would not have been as successful as it was without good communication, helpful sponsors and a team of student engineers eager to learn.

Acknowledgments

Saint Martin's University' PCI Big Beam team considers this a privilege and opportunity to be able to participate in this competition. The sponsors guided and tutored the team on what they needed to design, build, test and analyze a prestressed/precast concrete beam.

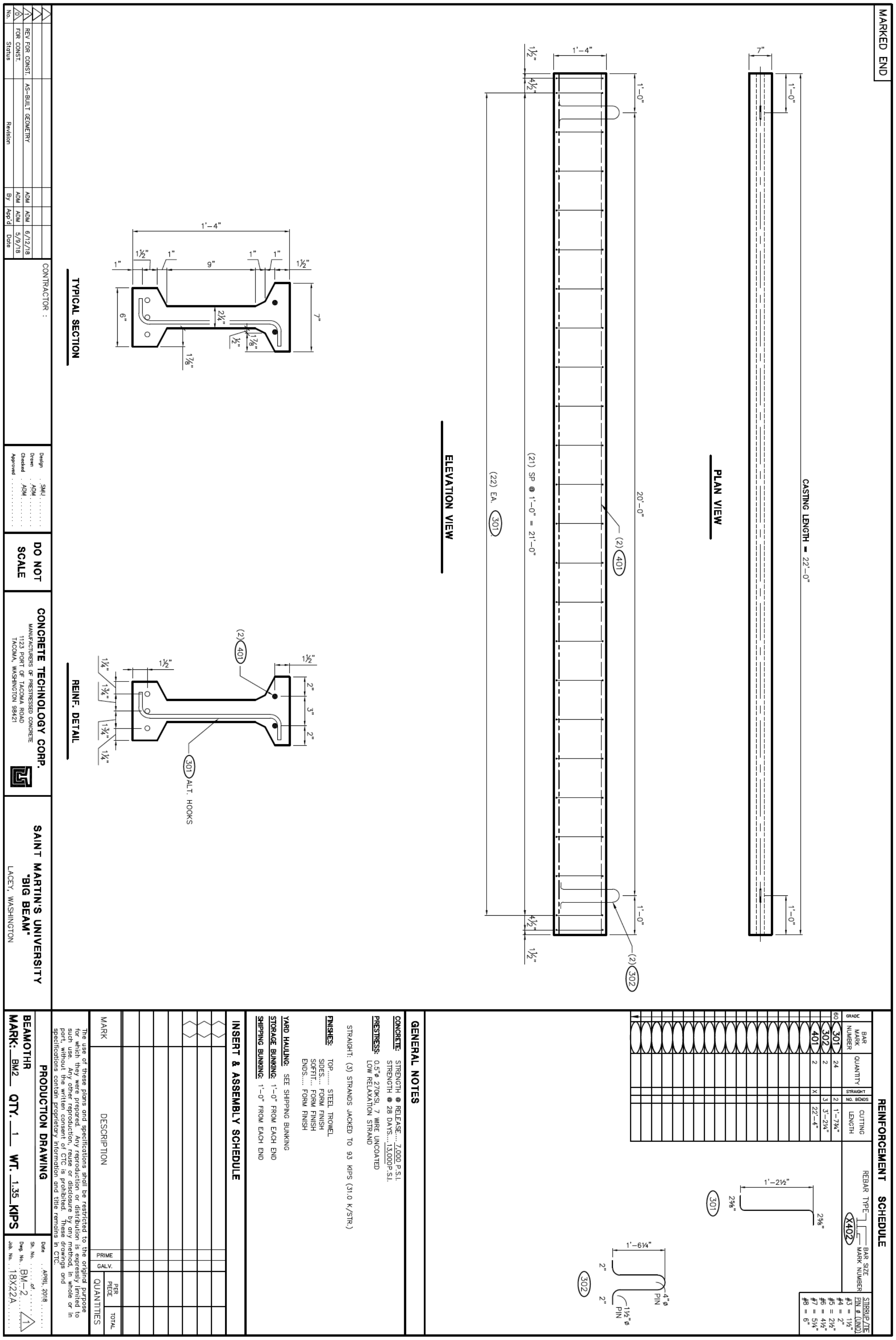
Thank you to Chief Engineer Cameron West, PE and Concrete Technology Corporation for choosing to sponsor Saint Martin's University for a third year in a row. Additionally, thank you to the employees at CTC who donated their time and effort to help construct the beam. Your continued support is very much appreciated and does not go unnoticed.

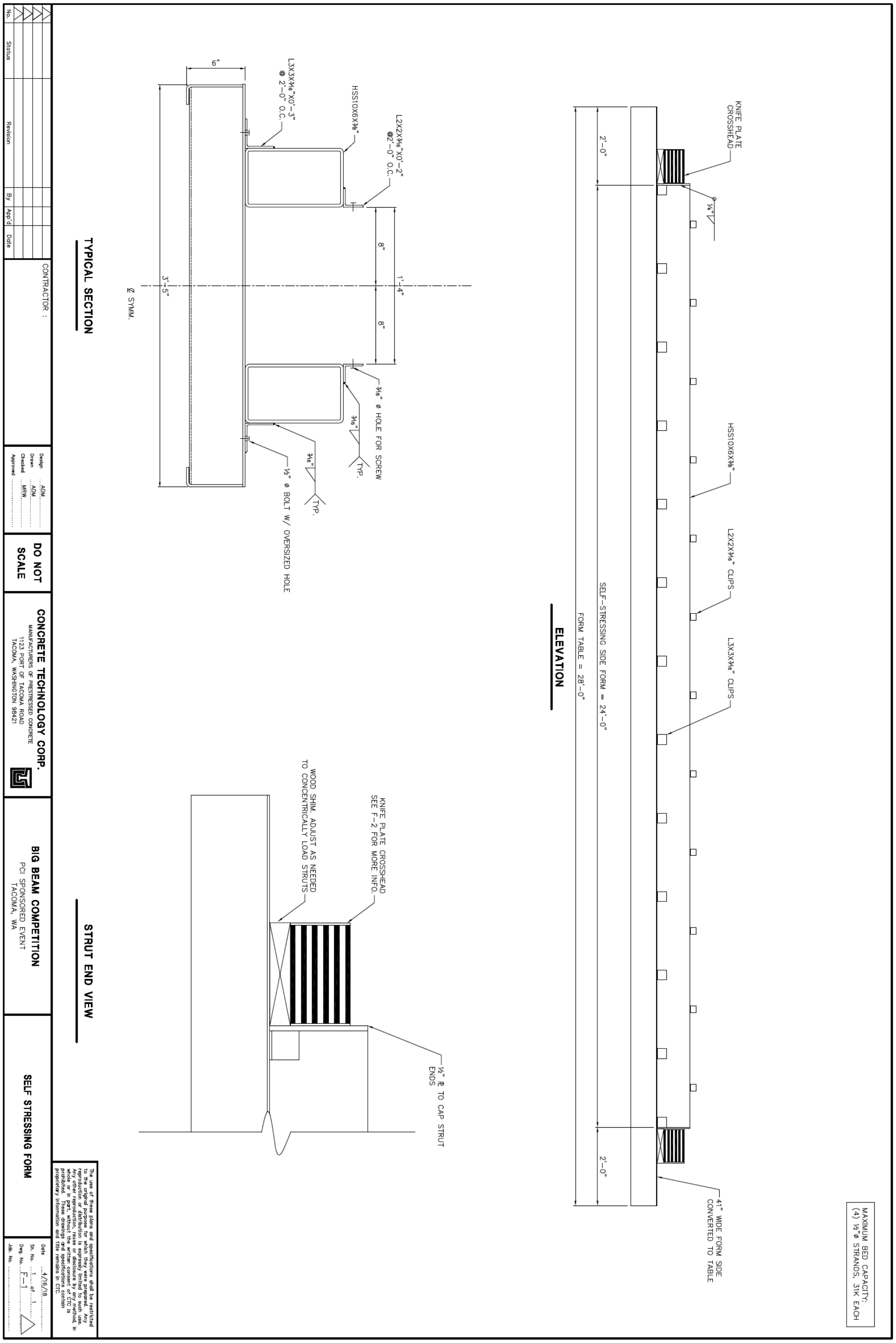
Austin Maue, PE from Concrete Technology Corporation has been the PCI Producer Member for Saint Martin's University for the past three years. Thank you for your continued support, guidance and patience to help make our goals become realities.

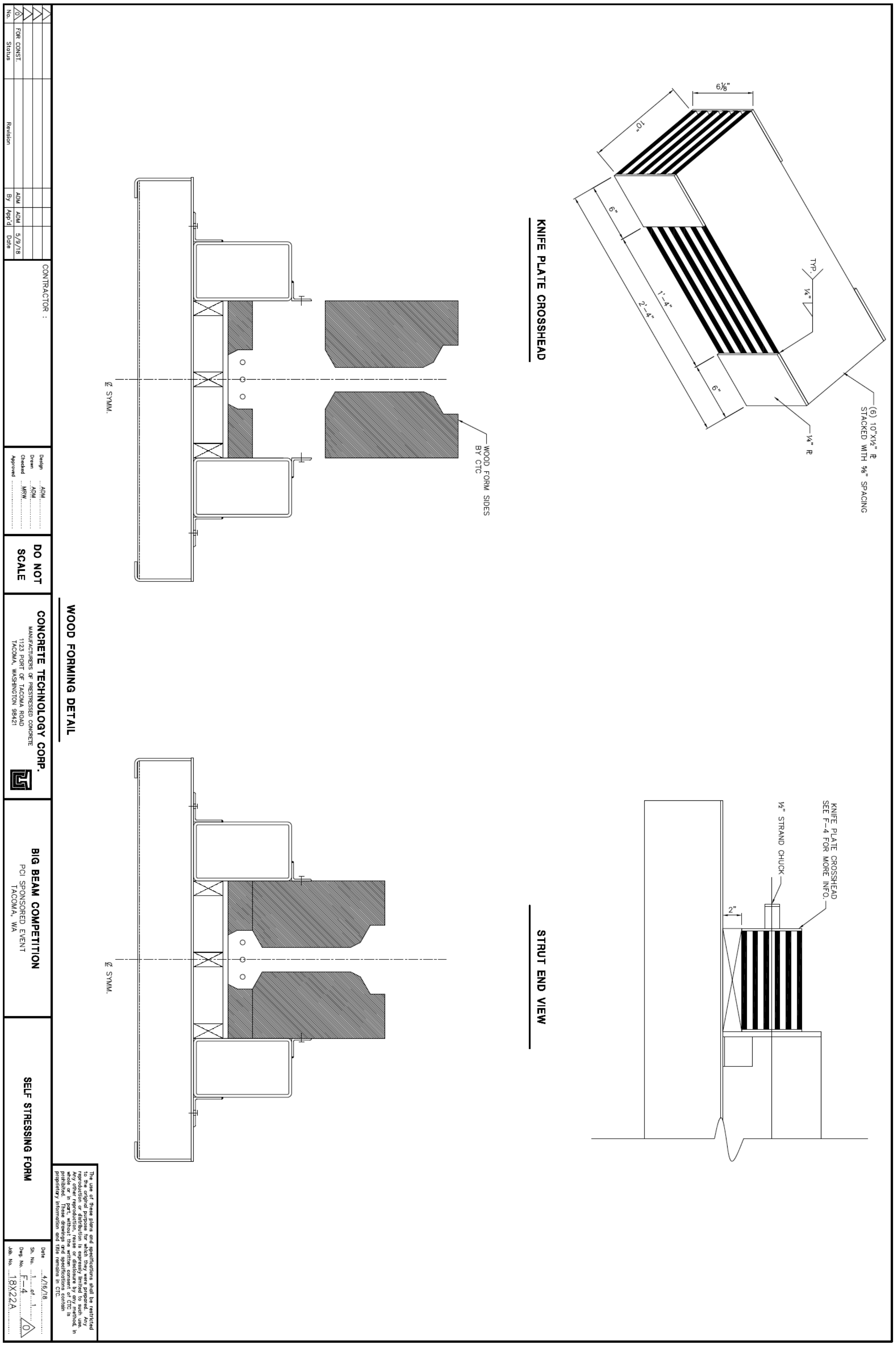
Thank you, Saint Martin's University, for the support received during this competition, and Jill Walsh, PhD, PE who has been our continued sponsor.

Finally, thank you to John Stanton, PhD, and the University of Washington for setting up, testing and collecting the data from our beam. We could not have competed in this competition without you and your staff's help.

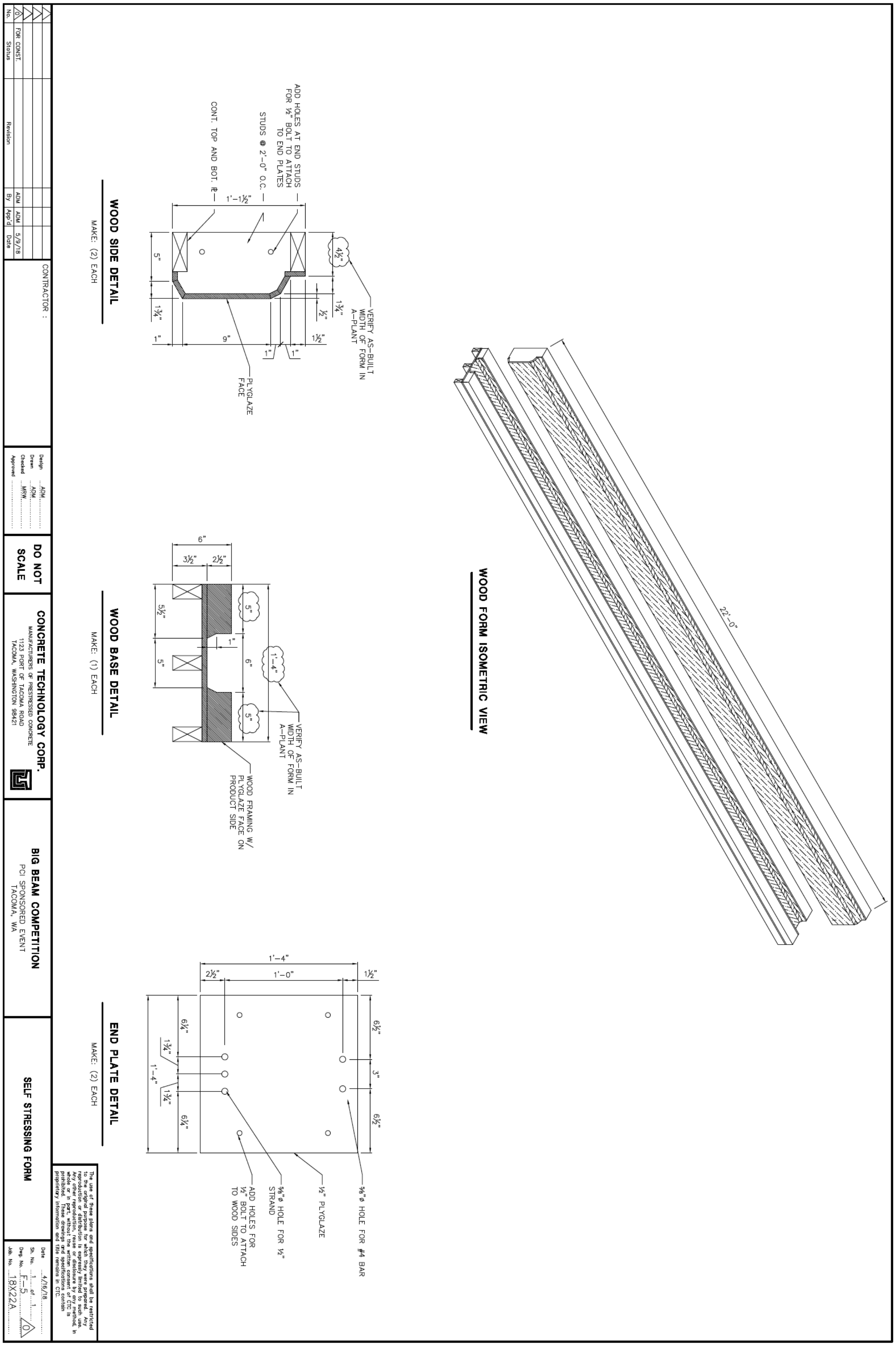
Appendix A: CAD Drawings


MARKED END
PLAN VIEW
CASTING LENGTH = 22'-0"
ELEVATION VIEW
20'-0"
(21) SP @ 1'-0" = 21'-0"
(22) EA. 301
(2) 401
(2) 302
TYPICAL SECTION
REINF. DETAIL
301 ALT. HOOKS
REINFORCEMENT SCHEDULE
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
QUANTITIES
CONCRETE TECHNOLOGY CORP.
MANUFACTURERS OF PRESTRESSED CONCRETE
1123 PORT OF TACOMA ROAD
TACOMA, WASHINGTON 98421
SAINT MARTIN'S UNIVERSITY
"BIG BEAM"
LACEY, WASHINGTON
DO NOT SCALE
CONTRACTOR :
BEAMOTHR
PRODUCTION DRAWING
MARK: BM2 QTY. 1 WT. 1.35 KIPS
REV FOR CONST. AS-BUILT GEOMETRY
FOR CONST.


TYPICAL SECTION
ELEVATION
STRUT END VIEW
KNIFE PLATE CROSSHEAD
HSS10X6X⅜"
L2X2X⅜" CLIPS
L3X3X⅜" CLIPS
SELF-STRESSING SIDE FORM = 24'-0"
FORM TABLE = 28'-0"
2'-0"
41" WIDE FORM SIDE CONVERTED TO TABLE
MAXIMUM BED CAPACITY: (4) ½"ø STRANDS, 31K EACH
KNIFE PLATE CROSSHEAD SEE F-2 FOR MORE INFO.
WOOD SHIM. ADJUST AS NEEDED TO CONCENTRICALLY LOAD STRUTS
½" PL TO CAP STRUT ENDS
½" ø BOLT W/ OVERSIZED HOLE
TYP.
DO NOT SCALE
CONCRETE TECHNOLOGY CORP.
MANUFACTURERS OF PRESTRESSED CONCRETE
1123 PORT OF TACOMA ROAD
TACOMA, WASHINGTON 98421
BIG BEAM COMPETITION
PCI SPONSORED EVENT
TACOMA, WA
SELF STRESSING FORM
CONTRACTOR :



KNIFE PLATE CROSSHEAD
6⅛"
10"
6"
1'-4"
2'-4"
TYP.
¼"
(6) 10"X½" ℙ STACKED WITH ⅝" SPACING
¼" ℙ
WOOD FORM SIDES BY CTC
℄ SYMM.
STRUT END VIEW
KNIFE PLATE CROSSHEAD SEE F-4 FOR MORE INFO.
½" STRAND CHUCK
2"
WOOD FORMING DETAIL
CONTRACTOR :
FOR CONST.
ADM
ADM
5/9/18
No.
Status
Revision
By
App'd.
Date
DO NOT SCALE
CONCRETE TECHNOLOGY CORP.
MANUFACTURERS OF PRESTRESSED CONCRETE
1123 PORT OF TACOMA ROAD
TACOMA, WASHINGTON 98421
BIG BEAM COMPETITION
PCI SPONSORED EVENT
TACOMA, WA
SELF STRESSING FORM
Date 4/16/18
Dwg. No. F-4
Job. No. 18X22A


WOOD SIDE DETAIL
MAKE: (2) EACH
ADD HOLES AT END STUDS FOR ½" BOLT TO ATTACH TO END PLATES
STUDS @ 2'-0" O.C.
CONT. TOP AND BOT.
1'-1½"
VERIFY AS-BUILT WIDTH OF FORM IN A-PLANT
PLYGLAZE FACE
WOOD FORM ISOMETRIC VIEW
22'-0"
WOOD BASE DETAIL
MAKE: (1) EACH
WOOD FRAMING W/ PLYGLAZE FACE ON PRODUCT SIDE
END PLATE DETAIL
MAKE: (2) EACH
1'-4"
1'-0"
9/16"ø HOLE FOR #4 BAR
½" PLYGLAZE
9/16"ø HOLE FOR ½" STRAND
ADD HOLES FOR ½" BOLT TO ATTACH TO WOOD SIDES
FOR CONST.
CONTRACTOR :
DO NOT SCALE
CONCRETE TECHNOLOGY CORP.
MANUFACTURERS OF PRESTRESSED CONCRETE
1123 PORT OF TACOMA ROAD
TACOMA, WASHINGTON 98421
BIG BEAM COMPETITION
PCI SPONSORED EVENT
TACOMA, WA
SELF STRESSING FORM
Date 4/19/18
Dwg No. F-5
Job No. 18X22A

Appendix B: Cost Analysis

Concrete:

$$Volume = \frac{58.00\ in^2}{144} * 22' = 8.86\ ft^2 = 0.328\ yd^3$$

$$Weight_{concrete} = 8.86\ ft^2 * 152.8\ pcf = 1353.98\ lbs$$

$$Cost_{Concrete} = \frac{\$120}{yd^3} * 0.328\ yd^3 = \$39.38$$

Steel Reinforcement:

Carbon A615 – Grade 60

No. 3

24 Stirrups – each 1'- 7 $^3/_4$" long = 39.50'

2 U-hooks – each 3'- 2 $^1/_4$" long = 6.375'

Total Length of No. 3 bar used = 45.875'

$$Weight_{No.3} = 0.376 \frac{lb}{ft} * 45.875\ ft = 17.249\ lb$$

No. 4

2 Straight Bars – each 22'- 4" long = 44.67'

$$Weight_{No.4} = 0.668 \frac{lb}{ft} * 44.67\ ft = 29.837\ lb$$

$$Cost_{Steel} = \frac{\$0.45}{lb} * (17.249 + 29.837)lb = \$21.19$$

Prestressing Strands:

½" Diameter

3 Strands – each 22' long = 66'

$$Cost_{Strands} = \frac{\$0.30}{ft} * 66\ ft = \$19.80$$

Forming:

$$Sides = \frac{36"}{12} * \ 22\,ft = 66.00\,ft^2$$

$$Bottom = \ \frac{11"}{12} \ * \ 22\,ft = 20.17\,ft^2$$

$$Ends = 2 * \ \frac{58\,in^2}{144} = 0.81\,ft^2$$

$$Cost_{Forming} \ = \frac{\$1.25}{ft^2} * (66.00 + 20.17 + 0.81)ft^2 = \$86.97$$

Total Beam Weight:

$$Weight_{Total} = \ 1353.98 + 17.249 + 29.837 = \ 1401.066\,lbs = 1.40\,kips$$

Total Beam Cost:

$$Cost_{Total} = \$(39.38 + 21.19 + 19.80 + 86.97) = \$167.34$$

Appendix C: Design Spreadsheets

Saint Martin's University

BEAM CRITERIA

LENGTH:	22.00	FT.
BEARING:	12.00	IN.
SPAN:	20.00	FT.
HEIGHT:	16.00	IN.

CONCRETE PROPERTIES

TYPE: HIGH STRENGTH

f'_c:	12,155	PSI
f'_{ci}:	10,135	PSI
γ:	152.8	PCF
E_c:	6,872	KSI
f_r:	827	PSI

REINFORCING STEEL

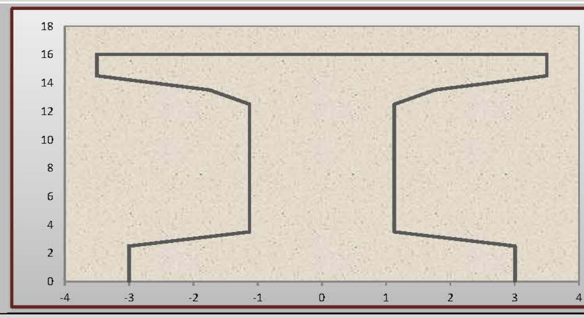
f_y:	60	KSI
E_s:	29,000	KSI

PRESTRESSED STRANDS

f_{pu}:	270.00	KSI
f_{pi}:	202.50	KSI
f_{se}:	179.18	KSI
LOSSES:	23	KSI
E_{ps}:	28,900	KSI

SECTION PLOT

WIDTH	HEIGHT
6.00	0.00
6.00	1.00
6.00	1.50
2.25	1.00
2.25	9.00
3.50	1.00
7.00	1.00
7.00	1.50
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00



PROPERTIES

DEPTH:	16.00	IN.
AREA:	58.00	$IN.^2$
I_x:	1754	$IN.^4$
Y_B:	8.00	IN.
Y_T:	8.00	IN.
S_B:	219	$IN.^3$
S_T:	219	$IN.^3$
PERIMETER:	49.64	IN.
V/S:	1.17	IN.
WEIGHT:	0.067	KLF
CENTROID:	0.004	IN.

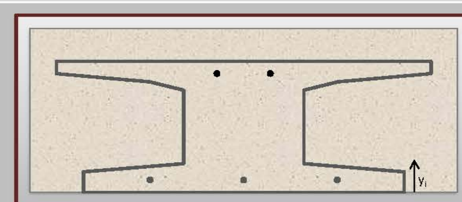
STRAND AND REBAR PLACEMENT

	STRAND SIZE	y_i (IN.)	x_i (IN.)	A_{ps} ($IN.^2$)
1	0.5	1.50	0	0.15
2	0.5	1.50	-1.75	0.15
3	0.5	1.50	1.75	0.15
4				0.00
5				0.00
6				0.00

DIA. IN IN.

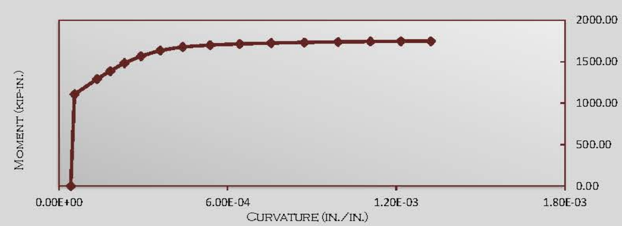
	BAR SIZE	y_i (IN.)	x_i (IN.)	A_s ($IN.^2$)	d_b ($IN.^2$)
1	4	14.5	-0.5	0.2	0.5
2	4	14.5	0.5	0.2	0.5
3				0	0
4				0	0
5				0	0
6				0	0

No.



MOMENT CURVATURE ANALYSIS

STRAIN ε_i (IN./IN.)	CURVATURE ϕ (1/IN.)	MOMENT M_i (KIP-IN.)	
0.00012177	4.10E-05	0.00	UNLOADED
-0.0006900	5.43E-05	1107.005	AT CRACKING
-0.00100	1.34E-04	1289.533	
-0.00115	1.82E-04	1387.33	
-0.00131	2.32E-04	1481.734	
-0.00146	2.91E-04	1567.244	
-0.00162	3.59E-04	1634.417	
-0.00177	4.40E-04	1677.695	
-0.00192	5.37E-04	1700.731	
-0.00208	6.42E-04	1714.419	
-0.00223	7.54E-04	1723.917	
-0.00238	8.72E-04	1731.333	
-0.00254	9.93E-04	1737.511	
-0.00269	1.11E-03	1742.688	
-0.00285	1.22E-03	1746.463	
-0.003	1.32E-03	1747.556	AT FAILURE



CRACKING MOMENT, M_{cr} =	1,107.00	KIP-IN.
CRACKING LOAD, P_{cr} =	22.23	KIPS
ULTIMATE MOMENT, M_u =	1,747.56	KIP-IN.
ULTIMATE LOAD, P_u =	35.57	KIPS

Saint Martin's University

MOMENT & CURVATURE CALCULATIONS

ε_c	-0.003	IN./IN.
NEUTRAL AXIS, c	2.268	IN.
MOMENT @ ε_c	1,748	KIP-IN.
CURVATURE @ ε_c	0.001	1/IN.

y	16	13.73
ε_c	-0.003	0.00

CONCRETE FORCES =	-118.33	KIPS
REBAR FORCES =	-9.58	KIPS
STRAND FORCES =	127.91	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	0.320	7	15.84	-0.002788	11834	26,509	420
2	0.320	7	15.52	-0.002365	12282	27,511	427
3	0.320	7	15.20	-0.001942	10459	23,427	356
4	0.320	7	14.88	-0.001518	8212	18,395	274
5	0.320	7	14.56	-0.001095	5923.9	13,270	193
6	0.320	6.09	14.24	-0.000672	3633.7	7,081	101
7	0.320	4.97	13.92	-0.000248	1343.5	2,137	30
8	0.320	3.85	13.60	0.000175	0	0	0
9	0.320	3.225	13.28	0.000598	0	0	0
10	0.320	2.825	12.96	0.001022	0	0	0
11	0.320	2.425	12.64	0.001445	0	0	0
12	0.320	2.25	12.32	0.001868	0	0	0
13	0.320	2.25	12.00	0.002292	0	0	0
14	0.320	2.25	11.68	0.002715	0	0	0
15	0.320	2.25	11.36	0.003138	0	0	0
16	0.320	2.25	11.04	0.003562	0	0	0
17	0.320	2.25	10.72	0.003985	0	0	0
18	0.320	2.25	10.40	0.004408	0	0	0
19	0.320	2.25	10.08	0.004832	0	0	0
20	0.320	2.25	9.76	0.005255	0	0	0
21	0.320	2.25	9.44	0.005678	0	0	0
22	0.320	2.25	9.12	0.006102	0	0	0
23	0.320	2.25	8.80	0.006525	0	0	0
24	0.320	2.25	8.48	0.006948	0	0	0
25	0.320	2.25	8.16	0.007372	0	0	0
26	0.320	2.25	7.84	0.007795	0	0	0
27	0.320	2.25	7.52	0.008218	0	0	0
28	0.320	2.25	7.20	0.008642	0	0	0
29	0.320	2.25	6.88	0.009065	0	0	0
30	0.320	2.25	6.56	0.009488	0	0	0
31	0.320	2.25	6.24	0.009912	0	0	0
32	0.320	2.25	5.92	0.010335	0	0	0
33	0.320	2.25	5.60	0.010758	0	0	0
34	0.320	2.25	5.28	0.011182	0	0	0
35	0.320	2.25	4.96	0.011605	0	0	0
36	0.320	2.25	4.64	0.012028	0	0	0
37	0.320	2.25	4.32	0.012452	0	0	0
38	0.320	2.25	4.00	0.012875	0	0	0
39	0.320	2.25	3.68	0.013298	0	0	0
40	0.320	2.775	3.36	0.013722	0	0	0
41	0.320	3.975	3.04	0.014145	0	0	0
42	0.320	5.175	2.72	0.014568	0	0	0
43	0.320	6	2.40	0.014992	0	0	0
44	0.320	6	2.08	0.015415	0	0	0
45	0.320	6	1.76	0.015838	0	0	0
46	0.320	6	1.44	0.016262	0	0	0
47	0.320	6	1.12	0.016685	0	0	0
48	0.320	6	0.80	0.017108	0	0	0
49	0.320	6	0.48	0.017532	0	0	0
50	0.320	6	0.16	0.017955	0	0	0

SECTION PLOT

WIDTH	HEIGHT
6.00	0.00
6.00	1.00
6.00	2.50
2.25	3.50
2.25	12.50
3.50	13.50
7.00	14.50
7.00	16.00
0.00	16.00
#N/A	#N/A
#N/A	#N/A
#N/A	#N/A
#N/A	#N/A

Σ FORCES =	118	KIPS
Σ MOMENTS =	1,800	KIP-IN.

Saint Martin's UNIVERSITY

STRAND STRESSES

STRAND DIA. $\varnothing_{ps}$ (IN.)	DEPTH y_i (IN.)	CONC. STRAIN ε_c (IN./IN.)	TOT. STRAIN $\varepsilon_c+\varepsilon_{ps}+\varepsilon_{ce}$ (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	1.50	0.0162	0.022855	278.7	0.153	42.64	63.96
0.5	1.50	0.0162	0.022855	278.7	0.153	42.64	63.96
0.5	1.50	0.0162	0.022855	278.7	0.153	42.64	63.96
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 = 127.91 KIPS
ΣMOMENTS = 191.87 KIP-IN.

STRAND STRAIN

ε_{pe} =	0.00620	IN./IN.
P_e =	82.2	KIPS
M_{Beam} =	3,346.26	FT-LBS
e =	6.50	IN
$\varepsilon_{ce\ Top\ Fiber}$ =	0.0001218	IN./IN.
ε_{ce} =	-0.0004732	IN./IN.
$\varepsilon_{ce\ Bottom\ Fiber}$ =	-0.0005347	IN./IN.
$\varepsilon_{pe} + \varepsilon_{ce}$ =	0.00667	IN./IN.

POWER FORMULA

A =	163.95	KIPS
B =	28,736.05	KIPS
C =	104.52	
D =	11.76	

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	14.5	-0.001	-29.45304	5.494	-23.9585	0.2	-4.792	-69.48
4.0	14.5	-0.001	-29.45304	5.494	-23.9585	0.2	-4.792	-69.48
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 = -9.58342 KIPS
ΣMOMENTS = -138.96 KIP-IN.

Saint Martin's University

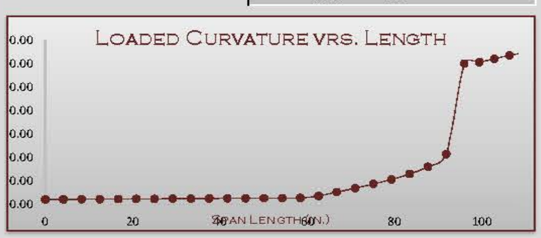
DEFLECTION CALCULATIONS

P =	35.57	KIPS
W_{DL} =	0.00558	KIPS/IN.
L =	240	IN.

LOADED

% Span	Length x_i (in.)	Moment M_i (kip-in.)	Curvature Ø (1 / in.)	Ø*δx*x_i (in.)	Ø*δx*x_j (in.)
0.00	0.00	0.00	0.00	0.00	0.00000
1.74	4.17	77.0	4.1955E-05	1.19E-04	0.00024
3.48	8.35	153.9	4.2877E-05	4.87E-04	0.00062
5.22	12.52	230.6	4.3798E-05	8.71E-04	0.00102
6.96	16.70	307.3	4.4718E-05	1.27E-03	0.00143
8.70	20.87	383.9	4.5636E-05	1.69E-03	0.00186
10.43	25.04	460.4	4.6553E-05	2.12E-03	0.00230
12.17	29.22	536.8	4.7469E-05	2.57E-03	0.00276
13.91	33.39	613.1	4.8384E-05	3.03E-03	0.00323
15.65	37.57	689.3	4.9298E-05	3.51E-03	0.00372
17.39	41.74	765.4	5.0211E-05	4.01E-03	0.00423
19.13	45.91	841.4	5.1122E-05	4.52E-03	0.00475
20.87	50.09	917.3	5.2032E-05	5.05E-03	0.00529
22.61	54.26	993.2	5.2942E-05	5.59E-03	0.00584
24.35	58.43	1,068.9	5.385E-05	6.15E-03	0.00641
26.09	62.61	1,144.5	7.0748E-05	6.72E-03	0.00904
27.83	66.78	1,220.0	0.00010387	9.45E-03	0.01418
29.57	70.96	1,295.4	0.00013722	1.48E-02	0.01992
31.30	75.13	1,370.8	0.00017375	2.07E-02	0.02674
33.04	79.30	1,446.0	0.00021314	2.77E-02	0.03466
34.78	83.48	1,521.1	0.00025941	3.59E-02	0.04444
36.52	87.65	1,596.2	0.00032058	4.59E-02	0.05771
38.26	91.83	1,671.1	0.00042747	5.96E-02	0.08068
40.00	96.00	1,746.0	0.00120132	8.32E-02	0.23719
41.43	99.43	1,746.4	0.00121348	2.00E-01	0.20446
42.86	102.86	1,746.7	0.00124277	2.09E-01	0.21670
44.29	106.29	1,747.0	0.00127163	2.22E-01	0.22920
45.71	109.71	1,747.3	0.00129407	2.34E-01	0.24085
47.14	113.14	1,747.4	0.0013101	2.46E-01	0.25154
48.57	116.57	1,747.5	0.00131971	2.57E-01	0.26114
50.00	120.00	1,747.6	0.00132292	2.66E-01	0.26955
			Σ =	1.97891	2.24169

Δ_{LOAD} = 4.22061 IN.

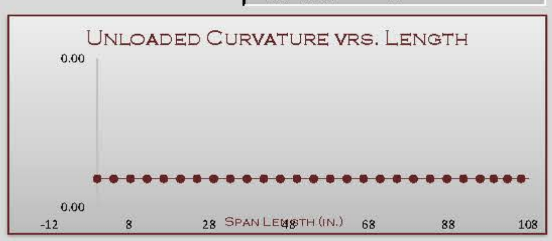


P =	0.00	KIPS
W_{DL} =	0.00558	KIPS/IN.
L =	240	IN.

UNLOADED

% Span	Length x_i (in.)	Moment M_i (kip-in.)	Curvature Ø (1 / in.)	Ø*δx*x_i (in.)	Ø*δx*x_j (in.)
0.00	0.00	0.00	0.00	0.00	0.00000
1.74	4.17	0.00	4.10E-05	1.19E-04	2.38E-04
3.48	8.35	0.00	4.10E-05	4.77E-04	5.96E-04
5.22	12.52	0.00	4.10E-05	8.34E-04	9.53E-04
6.96	16.70	0.00	4.10E-05	1.19E-03	1.31E-03
8.70	20.87	0.00	4.10E-05	1.55E-03	1.67E-03
10.43	25.04	0.00	4.10E-05	1.91E-03	2.03E-03
12.17	29.22	0.00	4.10E-05	2.26E-03	2.38E-03
13.91	33.39	0.00	4.10E-05	2.62E-03	2.74E-03
15.65	37.57	0.00	4.10E-05	2.98E-03	3.10E-03
17.39	41.74	0.00	4.10E-05	3.34E-03	3.46E-03
19.13	45.91	0.00	4.10E-05	3.69E-03	3.81E-03
20.87	50.09	0.00	4.10E-05	4.05E-03	4.17E-03
22.61	54.26	0.00	4.10E-05	4.41E-03	4.53E-03
24.35	58.43	0.00	4.10E-05	4.77E-03	4.88E-03
26.09	62.61	0.00	4.10E-05	5.12E-03	5.24E-03
27.83	66.78	0.00	4.10E-05	5.48E-03	5.60E-03
29.57	70.96	0.00	4.10E-05	5.84E-03	5.96E-03
31.30	75.13	0.00	4.10E-05	6.20E-03	6.31E-03
33.04	79.30	0.00	4.10E-05	6.55E-03	6.67E-03
34.78	83.48	0.00	4.10E-05	6.91E-03	7.03E-03
36.52	87.65	0.00	4.10E-05	7.27E-03	7.39E-03
38.26	91.83	0.00	4.10E-05	7.62E-03	7.74E-03
40.00	96.00	0.00	4.10E-05	7.98E-03	8.10E-03
41.43	99.43	0.00	4.10E-05	6.83E-03	6.91E-03
42.86	102.86	0.00	4.10E-05	7.07E-03	7.15E-03
44.29	106.29	0.00	4.10E-05	7.32E-03	7.40E-03
45.71	109.71	0.00	4.10E-05	7.56E-03	7.64E-03
47.14	113.14	0.00	4.10E-05	7.80E-03	7.88E-03
48.57	116.57	0.00	4.10E-05	8.04E-03	8.12E-03
50.00	120.00	0.00	4.10E-05	8.28E-03	8.36E-03
			Σ =	0.14606	0.14937

$\Delta_{SELF\ WEIGHT}$ = 0.29543 IN.



MOMENT CURVATURE ANALYSIS

Curvature Ø (1/in.)	Moment M_i (kip-in.)	
4.10E-05	0.00	UNLOADED
5.43E-05	1107.00	AT CRACKING
1.34E-04	1289.53	
1.82E-04	1387.33	
2.32E-04	1481.73	
2.91E-04	1567.24	
3.59E-04	1634.42	
4.40E-04	1677.69	
5.37E-04	1700.73	
6.42E-04	1714.42	
7.54E-04	1723.92	
8.72E-04	1731.33	
9.93E-04	1737.51	
1.11E-03	1742.69	
1.22E-03	1746.46	
1.32E-03	1747.56	AT FAILURE

TOTAL DEFLECTION

Δ_T = 4.52 IN.

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

Saint Martin's University

SHEAR CALCULATIONS

V_u =	39,000	LBS.
V_c =	7194	LBS.
φ =	0.75	

b_w =	2.25	IN.
d =	14.5	IN.

P_U =	39.00	KIPS
W_{DL} =	0.067	KIPS/IN.

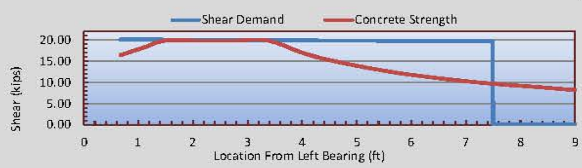
f_{pe} =	3.86	KSI
V_p =	0.00	KIPS

	X	Applied Shear (kips)			M_{cr}	Shear Strength (kips)		
	(FT.)	V_{DL}	V_{LL}	V_U	(KIP-IN.)	V_{cw}	V_{ci}	φV_c
$h/2$	0.67	0.62	19.50	20.12	706.2	21.88	91.06	16.41
	1.08	0.60	19.50	20.10	842.9	24.18	67.94	18.13
Lt	1.49	0.57	19.50	20.07	979.7	26.467	57.57	19.85
	2.12	0.53	19.50	20.03	975.5	26.467	41.07	19.85
	2.75	0.49	19.50	19.99	971.7	26.467	32.12	19.85
	3.38	0.44	19.50	19.94	968.2	26.467	26.50	19.85
	4.01	0.40	19.50	19.90	965	26.467	22.64	16.98
Ld	4.63	0.36	19.50	19.86	962.1	26.467	19.82	14.86
	5.71	0.29	19.50	19.79	958	26.467	16.43	12.32
	6.78	0.22	19.50	19.72	954.7	26.467	14.11	10.58
	7.49	0.17	19.50	19.67	953.1	26.467	12.93	9.698
	7.50	0.17	0.00	0.17	953.1	26.467	12.92	9.686
	8.57	0.10	0.00	0.10	951.4	26.467	11.50	8.626
Midspan	10.00	0.00	0.00	0.00	950.6	26.467	10.08	7.56
	11.07	-0.07	0.00	-0.07	951.4	26.467	10.97	8.226
	12.15	-0.14	0.00	-0.14	953.1	26.467	12.13	9.095
	13.22	-0.22	-19.50	-19.72	954.7	26.467	13.68	10.26
	14.29	-0.29	-19.50	-19.79	958	26.467	15.86	11.89
Ld	15.37	-0.36	-19.50	-19.86	962.1	26.467	19.10	14.32
	15.99	-0.40	-19.50	-19.90	965	26.467	21.83	16.38
	16.62	-0.44	-19.50	-19.94	968.2	26.467	25.61	19.21
	17.25	-0.49	-19.50	-19.99	971.7	26.467	31.15	19.85
	17.88	-0.53	-19.50	-20.03	975.5	26.467	40.02	19.85
Lt	18.51	-0.57	-19.50	-20.07	979.7	26.467	56.43	19.85
	18.92	-0.60	-19.50	-20.10	842.9	24.18	66.74	18.13
$h/2$	19.33	-0.62	-19.50	-20.12	706.2	21.88	89.81	16.41

Stirrup Design

φV_s REQ. ≥ V_u - φV_c

Location	φV_s Req.	
At $h/2$	3.71	KIPS
At Lt	0.22	KIPS
At Ld	5.00	KIPS
At Midspan	-7.56	KIPS



S_{MAX} =	12.00	IN.
S_{MAX} =	35.48	IN.
S_{MAX} =	24.34	IN.

S_{MAX} = 12.00 IN.

Controls

Spacing Requirements

Location	S_{REQ}		Spacing		φV_s		Spacing Usage
At $h/2$	19.34	IN.	12.00	IN.	5.981	KIPS	Use 12 in. Near Ends
At Lt	####	IN.	12.00	IN.	5.981	KIPS	Use 12 in. To Transition
At Ld	14.37	IN.	12.00	IN.	5.981	KIPS	Use 12 in. Near Ld
At Midspan	-9.49	IN.	12.00	IN.	5.981	KIPS	Use 12 in. Middle

Saint Martin's
UNIVERSITY

PARAMETERS

AREA =	58	$IN.^2$	AGE @ RELEASE =	144	HRS	NO. STRANDS =	3	0.5" DIA.
I_x =	1,754.50	$IN.^4$	AGE @ TESTING =	336	HRS	A_{ps} =	0.459	$IN.^2$
HEIGHT =	16.00	IN.	AGING COEFF., χ =	0.7		f_{pu} =	270	KSI
W =	66.9	PLF	HUMIDITY =	75	%	E_{ps} =	28,900	KSI
V/S =	1.1684	IN.	K1 =	1.0		y_c =	1.50	IN
LENGTH =	22.00	FT.	K2 =	1.0		f_{py} =	243.0	KSI
						f_{pj} =	202.5	KSI

PRESTRESS LOSSES

SHRINKAGE

K_f =	0.45	CONCRETE STRENGHT FACTOR
K_s =	1.30	SIZE FACTOR
K_{hs} =	0.93	HUMIDITY FACTOR FOR SHRINKAGE
K_{td} =	0.41	TIME DEVELOPMENT FACTOR
y_{sh} =	0.22	
ε_{sh} =	1.05E-04	SHRINKAGE STRAIN AT TESTING

CREEP

K_{td} =	0.28	TIME DEVELOPMENT FACTOR
K_{la} =	0.81	LOADING FACTOR
K_{hc} =	0.96	HUMIDITY FACTOR FOR CREEP
K_f =	0.45	CONCRETE STRENGTH FACTOR
K_s =	1.30	SIZE FACTOR
y_{cr} =	0.13	
ψ_{cr} =	0.24	

TRANSFORMED SECTION @ TRANSFER

w_c =	152.2	PCF	A_{ti} =	59.67	$IN.^2$	K_r =	0.935
E_{ci} =	6,235	KSI	Y_{bti} =	7.82	IN.	K_{rd} =	0.925
E_c =	6,828	KSI	I_{ti} =	1,823	$IN.^4$		
n_i =	4.63	MODUALR RATIO	e_{pti} =	6.32	IN.		
n =	4.23	MODULAR RATIO	e_p =	6.50	IN.		
			α =	2.40			

$$LR = \frac{f_{pj}}{45}\left(\frac{f_{pj}}{f_{py}} - 0.55\right) \times \log\left(\frac{Age\ at\ Release\ (hours) + 1}{1}\right) = 2.76 \text{ KSI}$$ RELAXATION PRIOR TO TRANSFER

f_{pi} = 199.74 KSI STRESS JUST BEFORE TRANSFER

$$\Delta ES_p = \frac{P_i \alpha K_r n_i}{A} = 16.437 \text{ KSI}$$ ELASTIC SHORTENING (FROM PRESTRESS)

$$\Delta ES_g = -M\frac{e_p}{I}K_r n_i = -0.0651 \text{ KSI}$$ ELASTIC SHORTENING (FROM SELF WEIGHT)

$$\Delta SH_{bd} = \varepsilon_{sh(final)} E_p K_{rd} = 2.82 \text{ KSI}$$ SHRINKAGE

$$\Delta CR_{bd} = n_i f_{cir} \psi_{cr} K_{rd} = 3.67 \text{ KSI}$$ CREEP

$$LR = \frac{f_{pj}}{45}\left(\frac{f_{pj}}{f_{py}} - 0.55\right) \times \log\left(\frac{Age\ at\ 28\ Days\ (hours) + 1}{Hours\ at\ Transfer + 1}\right) = 0.47 \text{ KSI}$$ RELAXATION LOSSES AFTER TRANSFER

TOTAL LOSSES = 23.32 KSI

Saint Martin's University

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

Material Parameters

E_{ps} =	28,900	KSI*	Modulus of Elasticity
P_y =	40,252	LB*	Yield force of strand
BS =	42.965	KIPS*	Break strenth of strand
A_s =	0.1514	IN²*	Area of individual strand
f_{py} =	265.87	KSI	Yield stress of the strand
f_{pu} =	283.78	KSI	Ultimate stress of the strand
ε_{pu} =	0.054	IN/IN*	Ultimate strain of strand
ε_{py} =	0.01	IN/IN*	Yield strain of the strand
f_{so} =	276.50	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

$$A = E_{ps}\left(\frac{f_{pu} - f_{so}}{\varepsilon_{pu}E_{ps} - f_{so}}\right) = 163.95 \text{ ksi}$$

$$B = E_{ps} - A = 28{,}736 \text{ ksi}$$

$$C = \frac{E_{ps}}{f_{so}} = 104.521$$

$$D = 11.76$$

Iterate values of D until $f_{ps} = f_{py}$. This is done when the 'Run Analysis' button is clicked on the 'Beam Section' sheet.

$$f_{ps} = \varepsilon_{ps}\left(A + \frac{B}{\left(1 + (C\varepsilon_{ps})^{D}\right)^{\frac{1}{D}}}\right) = 265.87 \text{ ksi}$$

Appendix D: Material Specification

BATCH REPORT by Batch Number

Concrete Technology Corporation, Tacoma, WA

Cast Date:	5/25/2018	Mixer Number:	1 Station Number: 2
DB ID#:	45287	Call Time:	1:06:19 PM
Recipe Number:	140	Mix Start Time:	1:09:28 PM
Recipe Name:	140	Complete Time:	1:11:37 PM
Daily Count No.:	65	Discharge Time:	1:11:42 PM
Batches this Pour:	1	W/C Target:	0.315
Yards this Pour:	1.5	W/C Actual:	0.313
Yards This Batch:	1.5	Water Temperature:	50.2 °F
Job Number:	18X22	Batched in Auto: ☑	Mixed in Auto: ☑ Hot Mix Alarm: ☐
Job Name:	BIG BEAM		
Mark Number:	BIG BEAM		

AGGREGATES

	Name	SSD Target lbs.	SSD Actual lbs.	Dev. %	Free Water lbs.	Total Moisture %	Absorbed Moisture %	Actual Wet Wt. lbs.
1	5/8"	1,462	1,440	-1.50%	15	2.00	0.95	1,455
2	5/8"	1,462	1,538	5.20%	15	2.00	0.95	1,553
3	Sand	897	882	-1.67%	28	5.00	1.85	910
4	Sand	898	890	-0.89%	25	4.73	1.85	915
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	4,719	4,750		83			4,833

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	1,128	1,123	-0.44%
	TOTAL	1,128	1,123	-0.44%

ADMIXTURES

	Name	Target oz.	Actual oz.	Dev. %	Water %
1.1	Daravair 1000	0.0	0.0	0.00%	0.0%
1.2	WDRA 64	51.0	51.0	0.00%	0.0%
1.3	VMAR	0.0	0.0	0.00%	0.0%
1.4	DCI	0.0	0.0	0.00%	0.0%
1.5	ADVA 575	105.0	105.0	0.00%	0.0%

WATER

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	
42.5 gal.	32.3 gal.	32.3 gal.	0.00%	0.0 gal.	0.0 gal.	32.2 gal.	10.0 gal.	0.0 gal.	42.2 gal.	1,000	at Final mix
354 lb.	269 lb.	269 lb.		0 lb.	0 lb.	268 lb.	83 lb.	0 lb.	351 lb.	1,000	at Discharge

Max. Probe Target: 0

operator

################

Page 1 of 1

CONCRETE TECHNOLOGY CORPORATION
CONCRETE MIX DESIGN - BACKUP DATA

MIX 140

	CAST DATE	JOB NUMBER	28 DAY DATE	28 DAY f'c #1	28 DAY f'c #2	INDIV TEST AVERAGE	3 TEST AVERAGE
1	03/08/18	17136A	04/05/18	11,520	11,250	11,385	11,343
2	03/08/18	17002A	04/05/18	10,880	10,640	10,760	11,142
3	03/07/18	17002A	04/04/18	11,880	11,890	11,885	11,390
4	03/06/18	17136A	04/03/18	10,610	10,950	10,780	11,312
5	03/06/18	17002A	04/03/18	11,360	11,650	11,505	11,643
6	03/05/18	17136A	04/02/18	12,010	11,290	11,650	11,898
7	03/05/18	17002A	04/02/18	11,740	11,810	11,775	11,853
8	03/02/18	17136A	03/30/18	12,250	12,290	12,270	11,700
9	03/01/18	17002A	03/29/18	11,380	11,650	11,515	11,410
10	03/01/18	17136A	03/29/18	11,240	11,390	11,315	11,650
11	02/28/18	17002A	03/28/18	11,190	11,610	11,400	12,090
12	02/28/18	17136A	03/28/18	12,190	12,280	12,235	12,292
13	02/28/18	17002A	03/28/18	12,650	12,620	12,635	12,190
14	02/27/18	17002A	03/27/18	11,950	12,060	12,005	12,115
15	02/27/18	17136A	03/27/18	11,860	12,000	11,930	12,233
16	02/27/18	17002A	03/27/18	12,470	12,350	12,410	12,167
17	02/26/18	17002A	03/26/18	12,410	12,310	12,360	11,963
18	02/26/18	17136A	03/26/18	12,010	11,450	11,730	11,933
19	02/26/18	17002A	03/26/18	11,930	11,670	11,800	11,973
20	02/23/18	17136A	03/23/18	12,030	12,510	12,270	12,082
21	02/22/18	17002A	03/22/18	12,060	11,640	11,850	11,735
22	02/21/18	17136A	03/21/18	12,120	12,130	12,125	11,572
23	02/20/18	17003A	03/20/18	11,140	11,320	11,230	11,105
24	02/20/18	17002A	03/20/18	11,680	11,040	11,360	11,360
25	02/20/18	17136A	03/20/18	10,560	10,890	10,725	11,288
26	02/19/18	17003A	03/19/18	11,980	12,010	11,995	11,780
27	02/19/18	17002A	03/19/18	10,770	11,520	11,145	11,368
28	02/16/18	17136A	03/16/18	12,330	12,070	12,200	11,530
29	02/15/18	17003A	03/15/18	11,030	10,490	10,760	-
30	02/14/18	17136A	03/14/18	11,860	11,400	11,630	-

30 ⇐ TOTAL NUMBER OF TESTS

AVERAGE f'cr = 11,688

STANDARD DEVIATION = 529

INDIV. TEST COEF./VAR. = 0.05

ACI 301 (4.2.3.3): FOR NUMBER OF TEST RECORDS 30 OR MORE:

Specified compressive strength f'c (psi)	Required Average compressive strength f'cr (psi)	Calc'd f'c (psi)
≤ 5,000	f'c + 1.34s	10,979
	f'c + 2.33s - 500	10,956
> 5,000	f'c + 1.34s	10,979
	0.90f'c + 2.33s	11,618

f'c = 10,979 psi

ADVA® Cast 575

High-range water-reducing admixture -- ASTM C494 Type A and F and ASTM C1017 Type I

Product 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.

Product 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**

Uses

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.

Addition Rates

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 GCP Applied Technologies 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 GCP Applied Technologies representative for more information and assistance.

Compatibility with Other Admixtures and Batch Sequencing

ADVA® Cast 575 is compatible with most GCP admixtures as long as they are added separately to the concrete mix. However, ADVA® products 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 GCP 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 GCP Applied Technologies representative for guidance.

Packaging & Handling

ADVA® Cast 575 is a light blue liquid available in bulk, delivered by metered trucks, in totes and drums. ADVA® Cast 575 will freeze at approximately 32°F

(0°C) but will return to full functionality after thawing and thorough mechanical agitation.

Dispensing Equipment

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

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

	US UNITS - CONTROL	US UNITS - ADVA® CAST 575	METRIC - CONTROL	METRIC - ADVA® CAST 575
Cement (pcy) (kg/m^3)	517	517	307	307
Coarse aggregate (pcy) (kg/m^3)	1944	1944	1153	1153
Fine aggregate (pcy) (kg/m^3)	1144	1214	679	720
Water (pcy) (kg/m^3)	248	211	147	125
w/cm	0.48	0.41	0.48	0.41
Slump (inches) (mm)	3.5	3.25	89	83
Plastic air (%)	5.4	5.5	5.4	5.5
Compressive strength				
1 day (psi) (MPa)	1460	2050	10.1	14.1
7 day (psi) (MPa)	4380	6040	30.2	41.6
28 day (psi) (MPa)	5570	7270	38.4	50.1
Initial set time (hr:min)	4:56	3:57	4:56	3:57
Length change 28 day (%)	-0.027	-0.029	-0.027	-0.029
Freeze-thaw resistance (RDME %)	88	91	88	91

gcpat.com | North America Customer Service: 1 877-4AD-MIX1 (1 877-423-6491)

We hope the information here will be helpful. It is based on data and knowledge considered to be true and accurate, and is offered for consideration, investigation and verification by the user, but we do not warrant the results to be obtained. Please read all statements, recommendations, and suggestions in conjunction with our conditions of sale, which apply to all goods supplied by us. No statement, recommendation, or suggestion is intended for any use that would infringe any patent, copyright, or other third party right.

This document is only current as of the last updated date stated below and is valid only for use in the United States. It is important that you always refer to the currently available information at the URL below to provide the most current product information at the time of use. Additional literature such as Contractor Manuals, Technical Bulletins, Detail Drawings and detailing recommendations and other relevant documents are also available on www.gcpat.com. Information found on other websites must not be relied upon, as they may not be up-to-date or applicable to the conditions in your location and we do not accept any responsibility for their content. If there are any conflicts or if you need more information, please contact GCP Customer Service.

gcp applied technologies

Last Updated: 2018-04-13

gcpat.com/solutions/products/adva-cast-high-range-water-reducers/adva-cast-575

WRDA® 64

Water-reducing admixture ASTM C494 Type A and D

Product Description

WRDA® 64 is a polymer based aqueous solution of complex organic compounds. WRDA 64 is a ready-to-use low viscosity liquid which is factory pre-mixed in exact proportions to minimize handling, eliminate mistakes and guesswork. WRDA 64 does not contain calcium chloride and weighs approximately 10.1 lbs/gal (1.21 kg/L).

Uses

WRDA 64 produces a concrete with lower water content (typically 8% to 10% reduction), greater plasticity and higher strength. It is used in ready-mix plants, block and concrete product plants, in lightweight and prestressed work wherever concrete is produced.

WRDA 64 also performs especially well in concrete containing fly ash and other pozzolans.

Finishability

The cement paste, or mortar, in WRDA 64 admixtured concrete has improved trowelability. The influence of WRDA 64 on the finishability of lean mixes has been particularly noticeable. Floating and troweling, by machine or hand, imparts a smooth, close tolerance surface.

Addition Rates

The addition rate of WRDA 64 is 3 to 6 fl oz/100 lbs (195 to 390 mL/100 kg) of cement. Pretesting is required to determine the appropriate addition rate for Type A and Type D performance. Optimum addition depends on the other concrete mixture components, job conditions, and desired performance characteristics.

Compatibility with Other Admixtures and Batch Sequencing

WRDA 64 is compatible with most GCP admixtures as long as they are added separately to the concrete mix, usually through the water holding tank discharge line. In general, it is recommended that WRDA 64 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 GCP 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, as conditions and materials change in order to assure compatibility, 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 GCP Applied Technologies representative for guidance.

Product Advantages

- **Consistent water reduction and set times**
- **Improves performance concrete containing supplementary cementitious materials**
- **Produces concrete that is more workable, easy to place and finish**
- **High compressive and flexural strengths**

Packaging & Handling

WRDA 64 is available in bulk, delivered by metered tank trucks, totes and drums.

WRDA 64 will freeze at about 28 °F (-2 °C), but will return to full strength after thawing and thorough agitation.

Dispensing Equipment

A complete line of accurate, automatic dispensing equipment is available. WRDA 64 may be introduced to the mix on the sand or in the water.

Specifications

Concrete shall be designed in accordance with *Standard Recommended Practice for Selecting Proportions for Concrete*, ACI 211.

The water-reducing (or water-reducing and retarding) admixture shall be WRDA 64, as manufactured by GCP Applied Technologies, or equal. The admixture shall not contain calcium chloride. It shall be used in strict accordance with the manufacturers' recommendations. The admixture shall comply with ASTM Designation C494, Type A water-reducing (or Type D water-reducing and retarding) admixtures. Certification of compliance shall be made available on request.

The admixture shall be considered part of the total water. The admixture shall be delivered as a ready-to-use liquid product and shall require no mixing at the batching plant or job site.

We hope the information here will be helpful. It is based on data and knowledge considered to be true and accurate, and is offered for consideration, investigation and verification by the user, but we do not warrant the results to be obtained. Please read all statements, recommendations, and suggestions in conjunction with our conditions of sale, which apply to all goods supplied by us. No statement, recommendation, or suggestion is intended for any use that would infringe any patent, copyright, or other third party right.

WRDA, Daravair and Darex are trademarks, which may be registered in the United States and/or other countries, of GCP Applied Technologies Inc. This trademark list has been compiled using available published information as of the publication date and may not accurately reflect current trademark ownership or status.

GCP Applied Technologies Inc., 62 Whittemore Avenue, Cambridge, MA 02140 USA.

In Canada, 294 Clements Road, West, Ajax, Ontario, Canada L1S 3C6.

This document is only current as of the last updated date stated below and is valid only for use in the United States. It is important that you always refer to the currently available information at the URL below to provide the most current product information at the time of use. Additional literature such as Contractor Manuals, Technical Bulletins, Detail Drawings and detailing recommendations and other relevant documents are also available on www.gcpat.com. Information found on other websites must not be relied upon, as they may not be up-to-date or applicable to the conditions in your location and we do not accept any responsibility for their content. If there are any conflicts or if you need more information, please contact GCP Customer Service.

Last Updated: 2018-01-30

gcpat.com/solutions/products/wrda-64

SUMIDEN WIRE PRODUCTS CORPORATION

Customer Service - PC Strand
East: Toll Free 866-491-5020 • 710 Marshall Stuart Dr., Dickson, TN 37055
West: Toll Free 866-246-3758 • 1412 El Pinal Dr., Stockton, CA 95205

SWPC

Domestic 1/2"
No Samples Necessary

CERTIFICATE OF INSPECTION

Order Number: SLPC150829-1 Page No : 1 OF 1
B/L No: SIPC152232 Issue Date : 07/14/2015

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.: 6-03314
Destination: CONTEC-WA
State Job No:
Packing: Cal Wrap - "The California Transporation Agency's Standard Specification, Section 50 for Prestressing Concrete."

No	Pack #	Heat #	B.S.	Elong.	Y.P.	Area	E-Modulus	CURVE#
			Min:41,300	3.5	37,170			
			(LB)	(%)	(LB)	(IN2)	(MPSI)	
1	S128436-2	S0278896	43,894	4.8	40,263	0.1517	28.4	S128436
2	S128436-6	S0278896	43,894	4.8	40,263	0.1517	28.4	S128436
3	S128439-7	S0278897	43,670	4.9	40,179	0.1514	28.4	S128439
4	S128441-1	S0278896	43,962	5.2	40,514	0.1519	28.6	S128441
5	S128441-2	S0278896	43,962	5.2	40,514	0.1519	28.6	S128441
* 6	S128441-3	S0278896	43,962	5.2	40,514	0.1519	28.6	S128441
7	S528595-2	S0278896	43,744	4.8	40,432	0.1515	28.4	S528595

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 raw material, and all manufacturing processes used in the production of the COMMODITY described above occurred in the USA, in compliance with the Buy America requirements of 23 CFR 635.410.
* 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,
[signature]
7/16/15

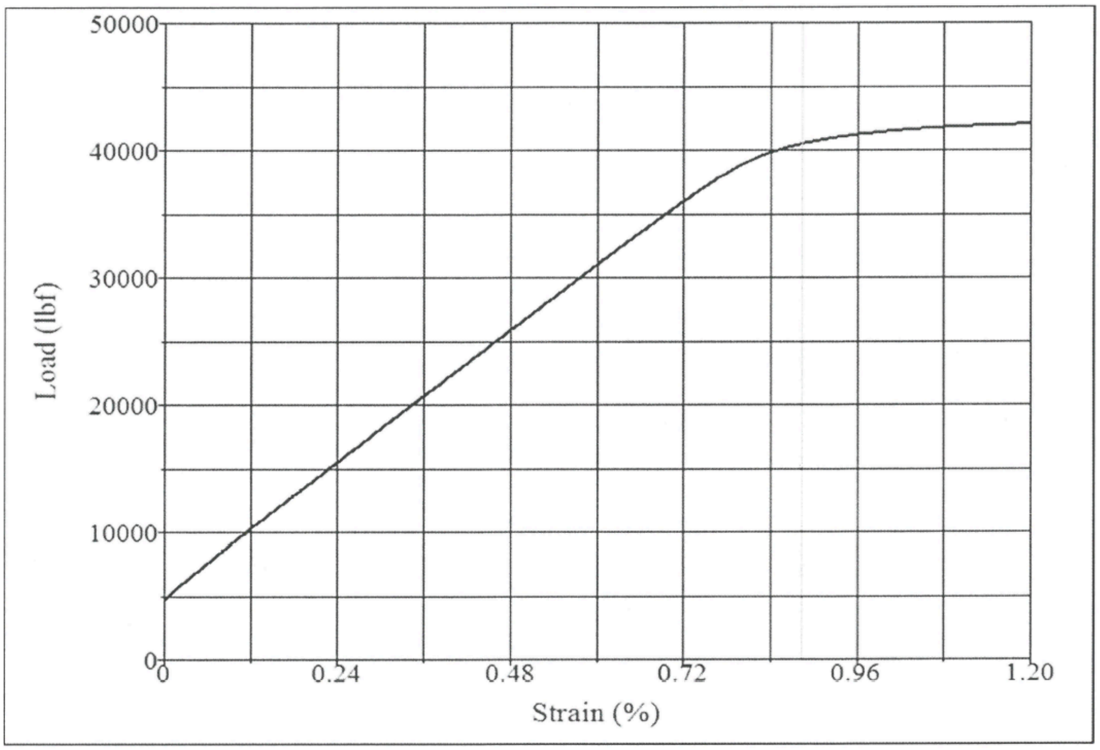
Date: 7/16/15 CMO: YES
PO: 6-03314
Job: Inventory
Item: Strand 1/2" Domestic

[signature]
Quality Assurance Section

SUMIDEN WIRE PRODUCTS CORPORATION

Customer Service - PC Strand
East: Toll Free 866-491-5020 • 710 Marshall Stuart Dr., Dickson, TN 37055
West: Toll Free 866-246-3758 • 1412 El Pinal Dr., Stockton, CA 95205

SWPC



***Vertical Line is drawn at 1% Extension Under Load**

Curve #	S128441
Pack Tested	S128441-1
Yield Point	40,514 lbf
Area	0.1519 in²
Modulus	28.6 Msi

CONCRETE TECHNOLOGY CORPORATION
SINGLE STRAND STRESSING RECORD

JOB NAME: BIG BEAM COMPETITION JOB NO.: 18X22A

PRODUCT: P/S BEAM MARK NO (S):

CAST DATE: 2-25-18 JACK SIZE: 22 TONS

BED LOCATION: A-PLANT JACK TYPE: FREYSSINET

STRAND LENGTH: 26 ft. EFFECTIVE AREA: 5.95 in^2

Strand	Strand Diameter (in.)	Load per Strand (kips)	Gauge Pressure (psi) Theoretical 20%	Gauge Pressure (psi) Theoretical 100%	Gauge Pressure (psi) Actual 100%	Elongation (in.) Actual 100%	Elongation (in.) Actual 20%	Elongation (in.) Actual 80%	Elongation (in.) Theoretical 80%
1	0.5	31.00	1,050	5,270		3 1/2	1 1/2	2	2-1/8" - 2-1/4"
2	0.5	31.00	1,050	5,270		3 1/4	1 1/4	2	2-1/8" - 2-1/4"
3	0.5	31.00	1,050	5,270		3 1/2	1 1/4	2 1/4	2-1/8" - 2-1/4"
4		0.00	0	0					
5		0.00	0	0					
6		0.00	0	0					
7		0.00	0	0					
8		0.00	0	0					
9		0.00	0	0					
10		0.00	0	0					
11		0.00	0	0					
12		0.00	0	0					
13		0.00	0	0					
14		0.00	0	0					
15		0.00	0	0					
16		0.00	0	0					
17		0.00	0	0					
18		0.00	0	0					
19		0.00	0	0					
20		0.00	0	0					
21		0.00	0	0					
22		0.00	0	0					
23		0.00	0	0					
24		0.00	0	0					

Initials of Stressing Operator ---> DPS

STRAND IDENTIFICATION	
PACK/COIL NO.	PACK/COIL NO.
5530982-5	

STRAND MANUFACTURER:
- Sumiden ☐
- Bekaert ☐
- Other ☐

COMMENTS

Operator shall confirm with QC that ram calibration is current.

CERTIFICATION

CONCRETE TECHNOLOGY CORPORATION hereby certifies that the above data conforms to but is not limited to the following specifications: WSDOT Standard Spec; ACI 318; PCI MNL 116.

CONCRETE TECHNOLOGY CORPORTATION

QC-7

Appendix E: Results

PCI BIG BEAM COMPETITION 2017-18

8 June 2018
Date

Saint Martin's University — Student Team (school name)
1 — Team Number
25 May 2018 — Date of Casting

Basic Information

1. Age of beam at testing (days) 14

2. Compressive cylinder tests*

Number tested: 2

Size of cylinders: 4 x 8

Average (psi): 12,155

3. Concrete properties

Unit weight of concrete (lb/ft³): 152.8

Slump (in.): 8

Air content (%): 1.6

Tensile strength (psi): 833

Circle one: (Split cylinder) MOR beam

4. Pretest calculations

a. Applied load (total) to cause cracking (kip): 22.23

b. Maximum applied point load at midspan (kip): 35.57

c. Maximum anticipated deflection due to applied load only (in.): 4.52

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): 35.66
2. Measured cracking load (kip)‡: 20.18
3. Cost (dollars): 167.34
4. Weight (lb): 1,348
5. Largest measured deflection (in.): 4.12
6. Most accurate calculations
   a. Absolute value of (maximum applied load – calculated applied load)/calculated applied load): 0.0026
   b. Absolute value of (maximum measured deflection – calculated deflection)/calculated deflection): 0.0885
   c. Absolute value of (measured cracking load – calculated cracking load)/calculated cracking load): 0.0921

Total of three absolute values (a + b + c) = 0.183

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

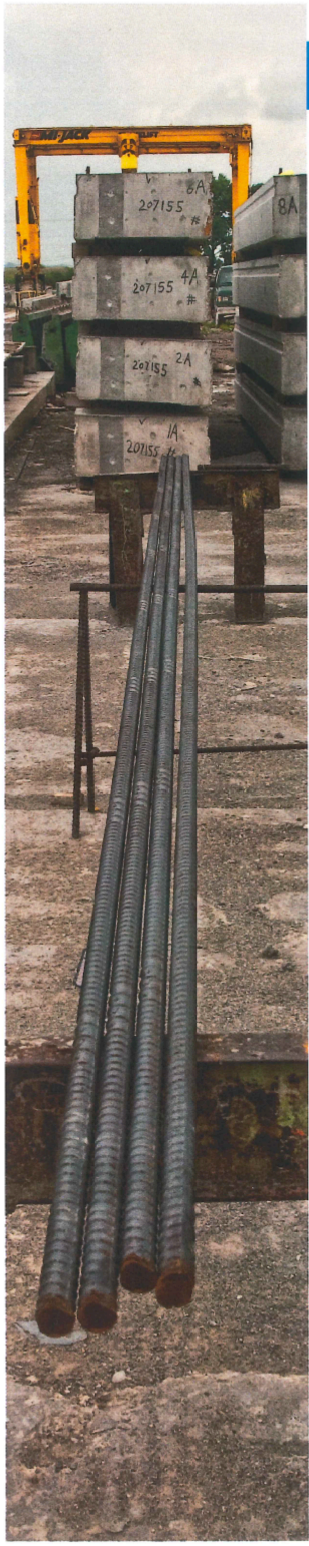
Test summary forms must be included with the final report, due June 15, 2018.

Sponsored by:

gcp applied technologies — GRACE CONSTRUCTION & PACKAGING

AUTODESK'S SOLUTION ASSOCIATE FOR PRECAST — EDGE REVIT — PTAC Consulting Engineers, Inc. ptac@ptac.com | www.ptac.com | www.edgeforrevit.com

ASPIRE



PCI BIG BEAM COMPETITION 2017-18

CERTIFICATION

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

SAINT MARTINS 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:

Austin D. Maue
Signature

AUSTIN D. MAUE, PE
Name (please print)

JUNE 12, 2018
Date

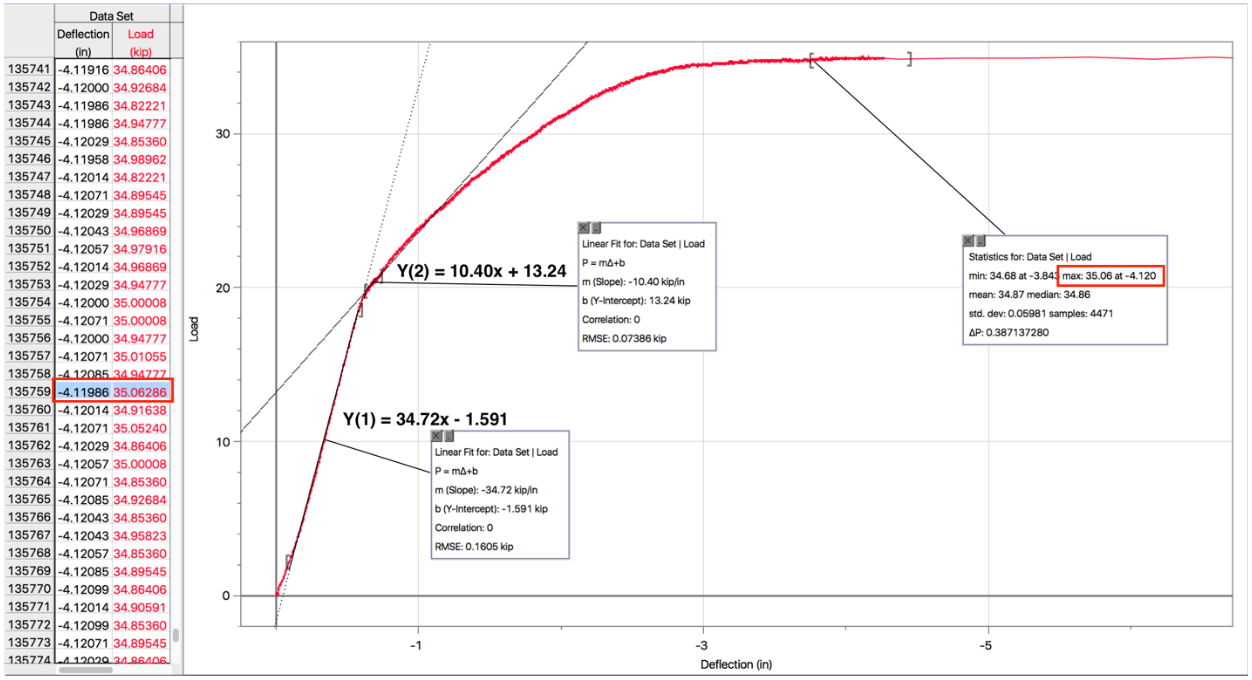
THIS CERTIFICATION MUST BE PART OF THE FINAL REPORT

Sponsored by:

AUTODESK'S SOLUTION ASSOCIATE FOR PRECAST
EDGE REVIT
PTAC Consulting Engineers, Inc.
ptac@ptac.com | www.ptac.com | www.edgeforrevit.com

ASPIRE

gcp applied technologies
GRACE CONSTRUCTION & PACKAGING



Solving for Cracking Load:

$$Y_1 = 34.72\Delta - 1.591$$

$$Y_2 = \ 10.40\Delta - 13.24$$

$$\Delta = \Delta$$

$$\frac{Y_1 + 1.591}{34.72} = \frac{Y_2 - 13.24}{10.40}$$

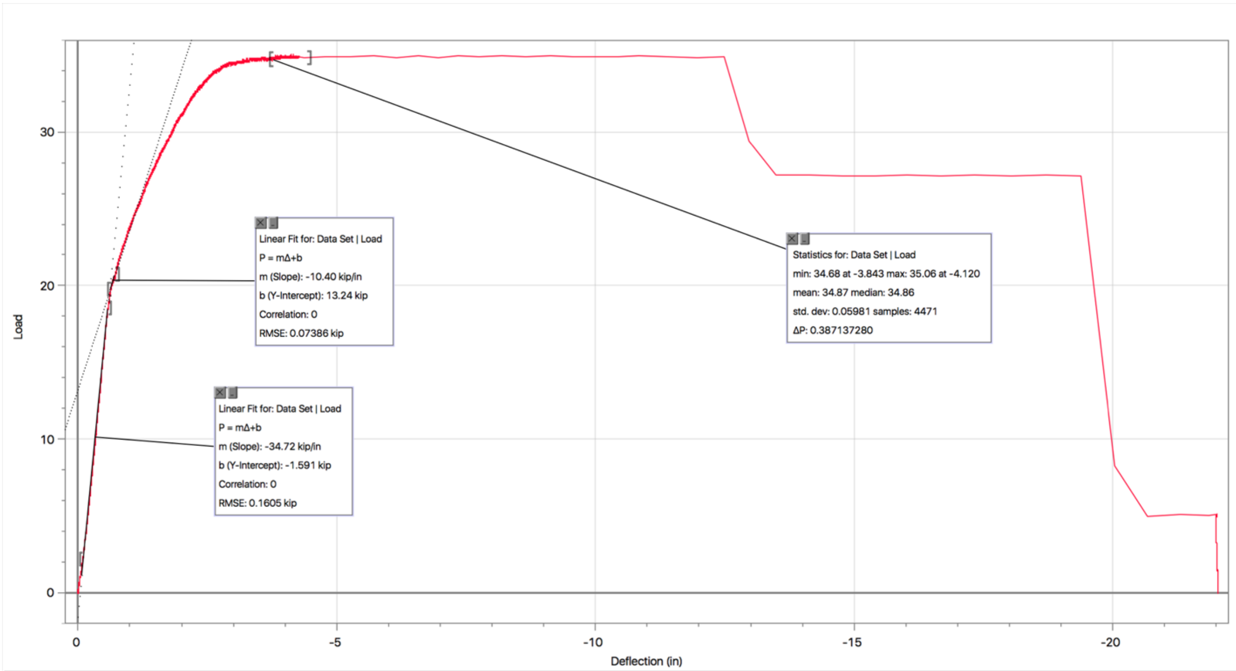
$$Y_1 = \frac{(Y_2 - 13.24)}{10.40} * 34.72 - 1.591$$

$$Y_1 = \ Y_2(3.338) - \ 45.792$$

$$45.792 = Y(2.338)$$

$$Y = 19.5822$$

$$Cracking\ Load = Y + 0.6\ kips\ for\ steel\ beam = 20.182\ kips$$



	Prediction	**Graph Value**	**+ Steel Beam**	**Actual**	**Percent Error**
Cracking Load (kips)	22.23	19.58	+ 0.6	20.18	9.21 %
Ultimate Load (kips)	35.57	35.06	+ 0.6	35.66	-0.261 %
Max Deflection (in)	4.52	4.12	NA	4.12	8.85 %
				Total Error	18.32%

Contact Info

Jill Walsh, PhD. PE	Jarad Roschi
Faculty Advisor	Team Leader
Hal & Inge Marcus School of Engineering	5712 Arcarro Ct SE
Saint Martin's University	Lacey, WA 98503
5000 Abbey Way SE	jarad.roschi@stmartin.edu
Lacey, WA 98503	317-372-7938
jwalsh@stmartin.edu	
Joel Rogers	Luis Camacho
Team Leader	Design
9241 Skokomish Way NE #2	5000 Abbey Way SE
Olympia, WA 98516	Lacey, WA 98503
joel.rogers@stmartin.edu	lcamachoplascencia@stmartin.edu
719-393-3793	509-312-0177
Turner Kremen	Carthney Laukon
Design/Fabrication	Design/Fabrication
19390 Byers Rd SE	3812 12th Ave SE
Maple Valley, WA 98039	Lacey, WA 98503
turner.kreman@stmartin.edu	carthney.laukon@stmartin.edu
425-301-7318	360-951-3397
Jesse San Nicolas	Tyler Sloan
Design	Media/Design/Fabrication
8131 Hidden Valley Dr SE	209 E Mommsen St
Olympia, WA 98503	McCleary, WA 98557
jesse.sannicolas@stmartin.edu	tyler.sloan@stmartin.edu
	360-890-7662
Chase Weeks	
Design	
701 Alta St SW B202	
Olympia, WA 98502	
Chase.weeks@stmartin.edu	
360-402-5335	