PCI BIG BEAM COMPETITION

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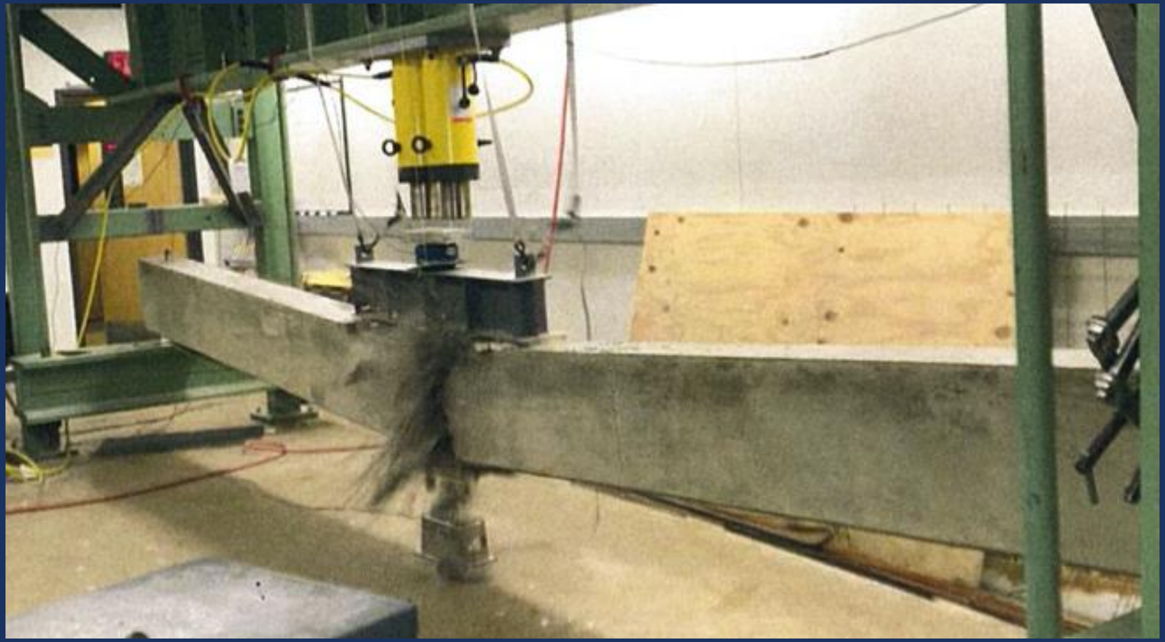
CENE 486 - FINAL PRESENTATION



STAKEHOLDERS

Figure 1. NAU Logo

Figure 2. PCI Logo

Figure 3. TPAC Logo

PROJECT INTRODUCTION

Purpose:

- Analyze, design, and test a prestressed concrete beam

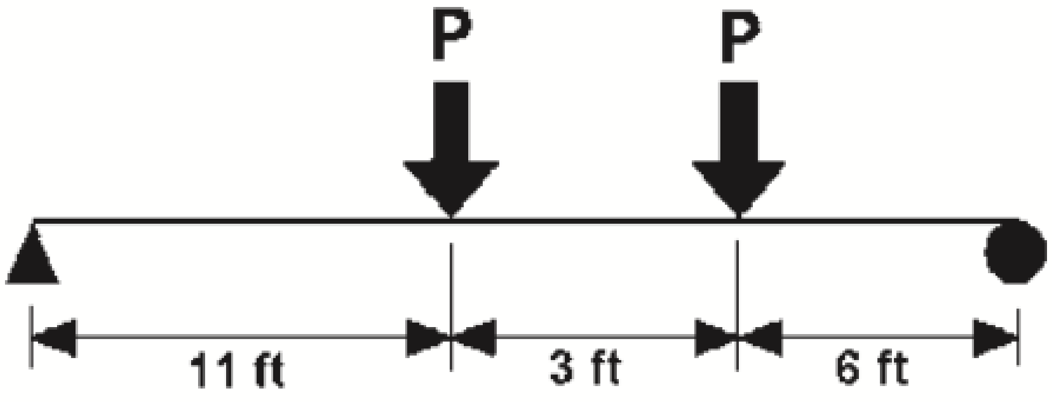


Figure 4. Load Distribution

Technical Aspects and Considerations:

- Rules for the competition
  - 20-foot long beam
  - Crack after 20 kips
  - Break between 32-40 kips

MILESTONES

- Task 1: Preliminary Research
- Task 2: Preliminary Beam Design
- Task 3: Final Design and Analysis
- Task 4: Predictions
- Task 5: Shop Drawings
- Task 6: Casting of Beam
- Task 7: Testing of Beam
- Task 8: Project Management
- Task 9: Project Impacts

TASK 1: PRELIMINARY RESEARCH

1.1 Three Stages of Design Prestressed Concrete Beam

- Release
- Cracking load
- Ultimate strength

1.2 Preliminary Cross-Section Designs

- I-beam
- T-beam
- Box
- Hollow Box

1.3 Preliminary Decision Matrix

- Determine decision matrix criteria based off PCI scoring

TASK 1.1: THREE STAGES OF DESIGN PRESTRESSED CONCRETE BEAM

- Release (1)

$$\sigma_{tp} := \frac{P}{A} + \frac{M_{PS} \cdot c}{I}$$

- Cracking load (2)

$$\sigma_{crack} := 7.5\sqrt{fc_{28}} = \frac{P}{A} + \frac{M_{PS} \cdot c}{I} + \frac{M_D \cdot c}{I} + \frac{M_{LL} \cdot c}{I}$$

- Ultimate strength (3)

$$m := A_p \cdot f_p \left(d - \frac{\beta_1 \cdot c}{2} \right) + M_{LL}$$

P = Vertical Load
A = Area
M_{PS} = Moment prestress
c = Distance from fiber to neutral axis
I = Moment of Inertia
fc_{28} = 28 compressive stress
M_D = Moment dead load
M_{LL} = Moment live load
A_p = Area Prestressing
f_p = Stress due to prestress
$\boldsymbol{B}_1$ = Depth factor

TASK 1.1: THREE STAGES OF DESIGN PRESTRESSED CONCRETE BEAM

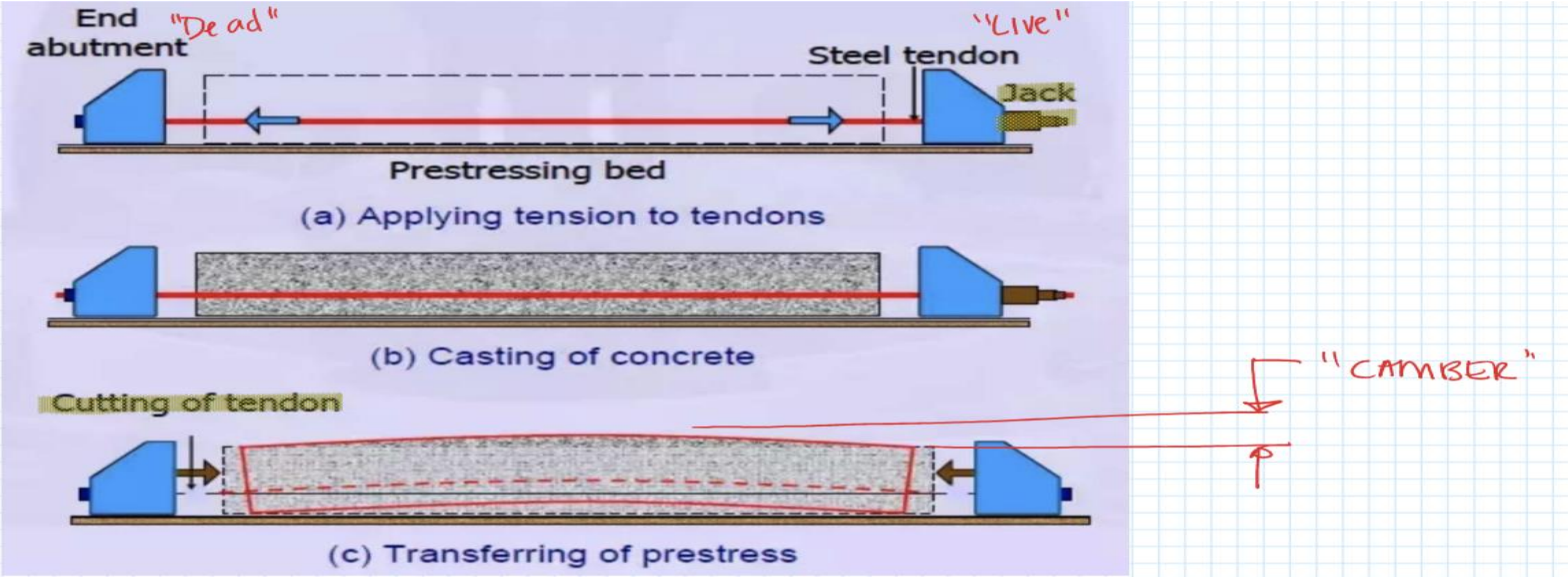


Figure 5. Release Process

TASK 1.2: PRELIMINARY DESIGNS

I-Beam

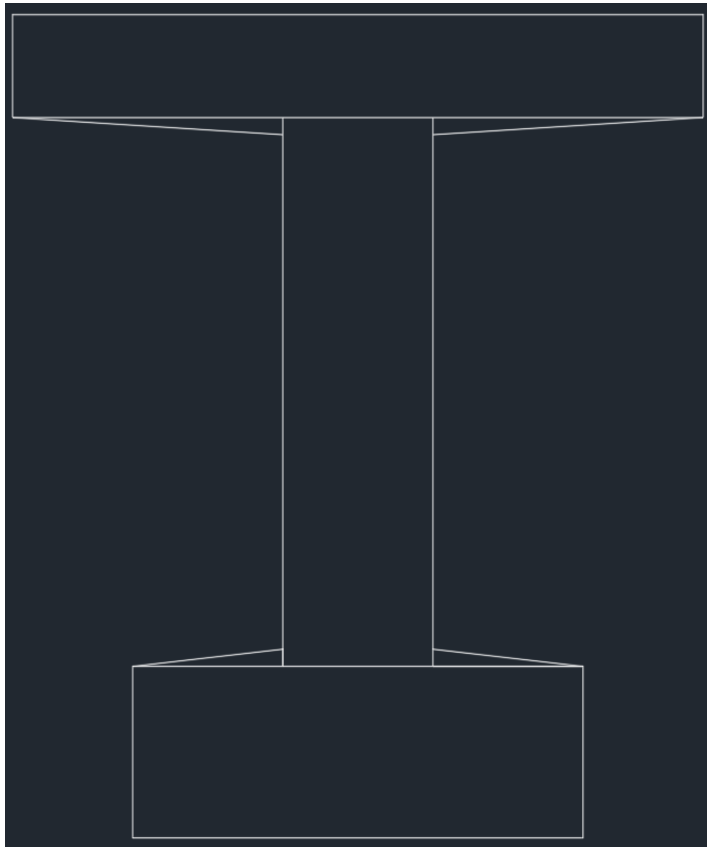


Figure 6. I-Beam

T-Beam

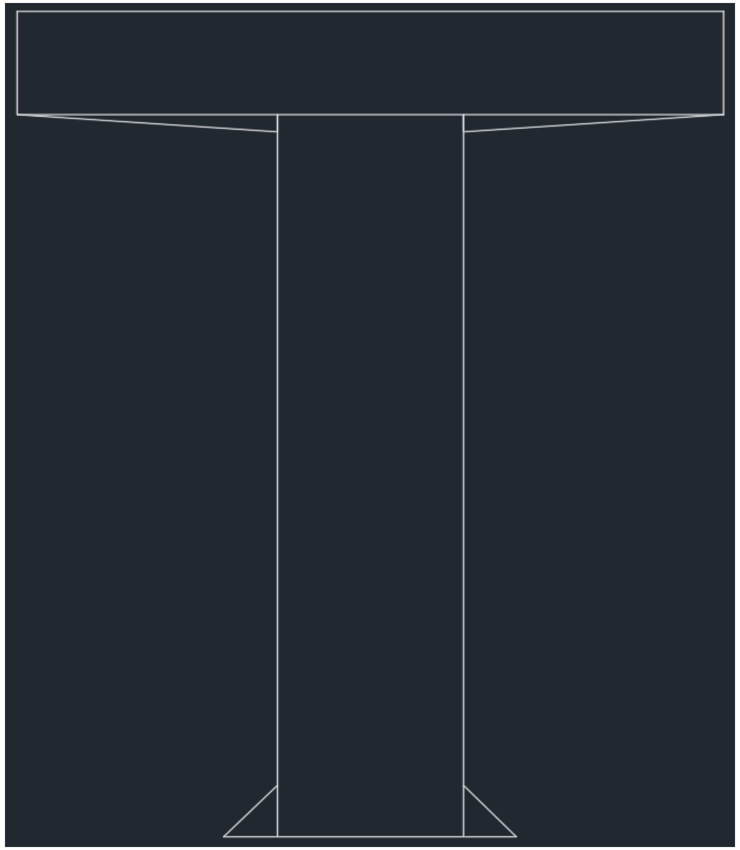


Figure 7. T-Beam

Box

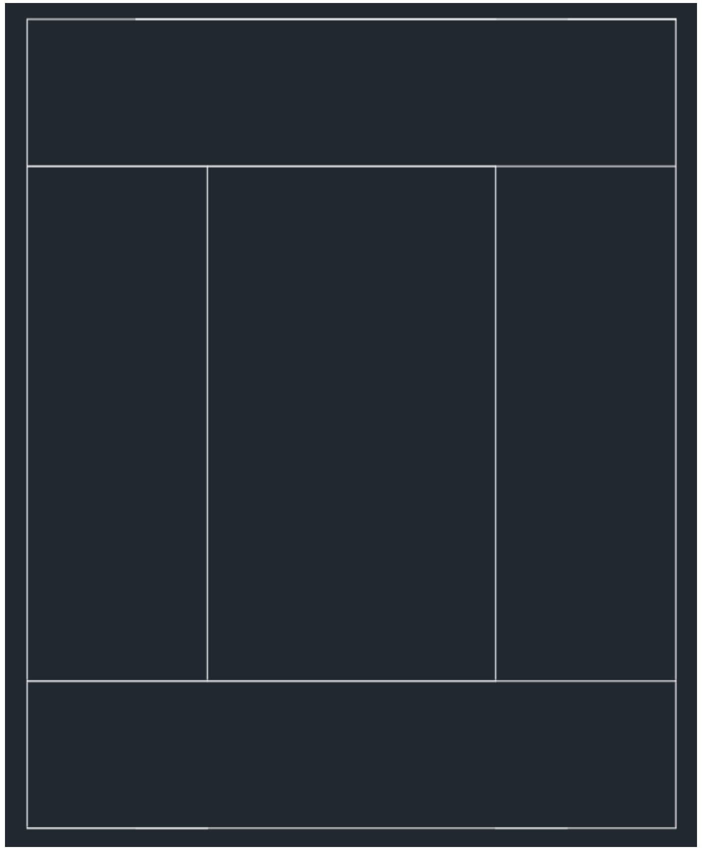


Figure 8. Hollow Box

TASK 1.3: PRELIMINARY DECISION MATRIX

- Determine decision matrix criteria based off PCI scoring
  - Lowest cost
  - Lowest weight
  - Largest deflection

Figure 9. PCI Logo

TASK 2: PRELIMINARY BEAM DESIGN

2.1 Initial Beam Designs

- Design 6 beam options with different depths and cross sections

2.2 Final Decision Matrix

- Mix selection
- Beam selection

Figure 10. MathCAD Logo

TASK 2.1: INITIAL BEAM DESIGN

- Design 6 beam options with different depths and cross sections

Box

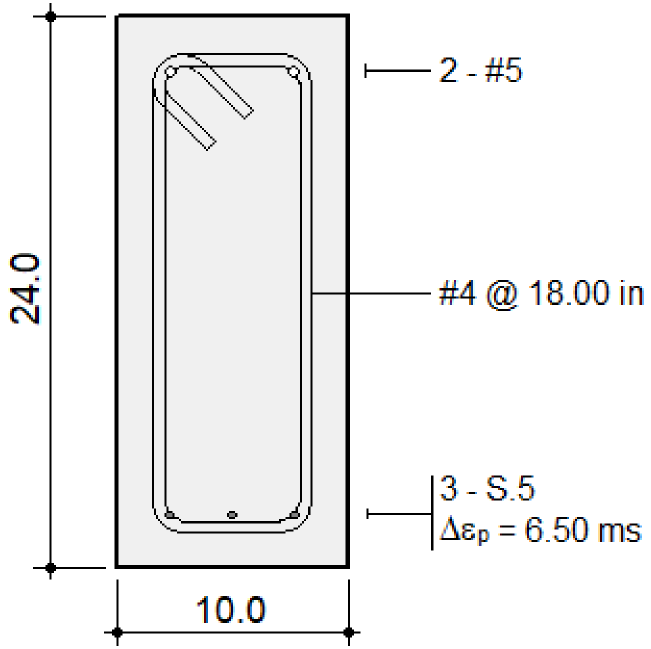


Figure 11. Box

I-Beam

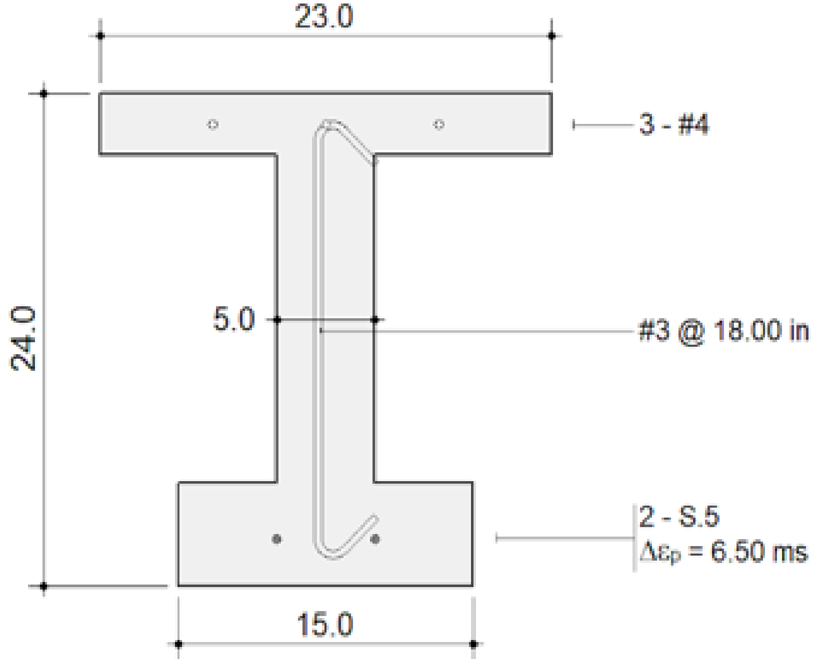


Figure 12. I-Beam

T-Beam

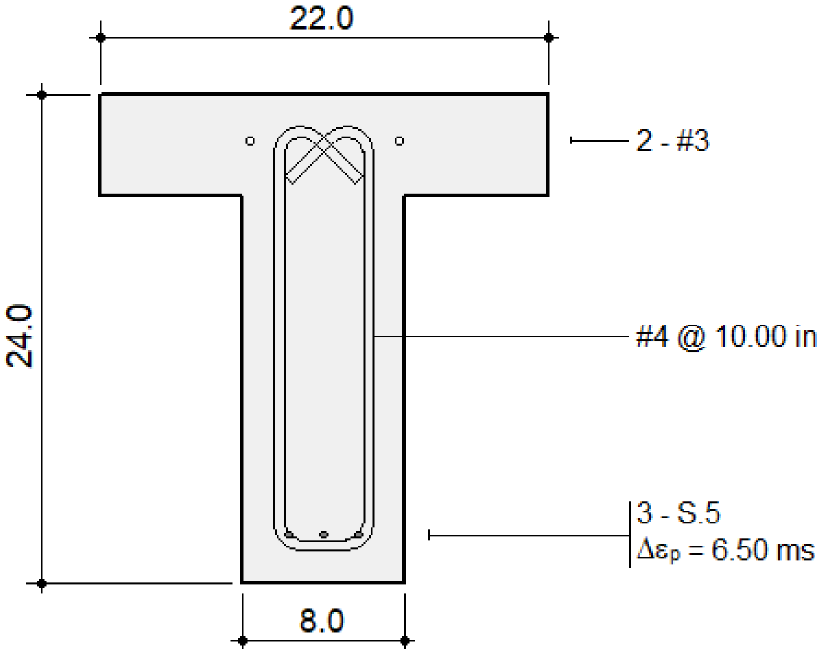


Figure 13. T-Beam

TASK 2.2: DECISION MATRIX

Beam Decision Matrix							
Cross Section	Cost ($)	Score	*Weight of Beam (pcf)*	Score	Deflection (inches)	Score	Total Score
T Beam LW	218.52	1.48	*6069.18*	5.17	7.04	10.00	16.65
T Beam NW	218.52	1.48	*7277.99*	0.91	7.25	5.96	8.35
I Beam LW	**183.13**	**10.00**	***4697.05***	**10.00**	**7.25**	**6.09**	**26.09**
I Beam NW	183.13	10.00	*5632.58*	6.71	7.46	1.97	18.68
Hollow Box Beam LW	224.66	0.00	*6285.22*	4.41	7.35	4.06	8.47
Hollow Box Beam NW	224.66	0.00	*7537.07*	0.00	7.57	0.00	0.00

Table 1. Beam Decision Matrix

TASK 3: PRELIMINARY RESEARCH

3.1 Shear Design

3.2 Reinforcement Design

3.3 Cracking Load

3.4 Max Load at Midspan

Figure 14. Bending Beam

TASK 3.1: SHEAR DESIGN

$$V_{cia} := .6\lambda\cdot\sqrt{fc}\cdot b_w\cdot d_p + v_d + \frac{v_i\cdot M_{cre}}{M_{max}}$$

$$V_{cib} := 1.7\lambda\cdot\sqrt{fc}\cdot b_w\cdot d_p$$

$$V_{cw} := \left(3.5\lambda\cdot\sqrt{fc} + .3fpc\right)\cdot b_w\cdot d_p + v_p$$

Figure 15. Equations for Shear

V_{cia} = Flexure Shear Capacity
λ = factor for density of concrete
fc = Compressive stress of concrete
b_w = base width
d_p = distance from compression steel to prestressing
v_d = shear force due to dead load
v_i = shear force due to max moment
M_{cre} = Moment of cracking die to applied load
M_{max} = Maximum moment
V_{cib} = Flexure Shear Capacity
V_{cw} = Web Shear Capacity
fpc = Compressive stress of concrete resisting external loads
v_p = Vertical effective prestress force

TASK 3.1: SHEAR DESIGN

- Shear design is based off the smaller value of the Flexure Shear Capacity (V_{ci}) and Web Shear Capacity (V_{cw})
- Calculated at the support that has maximum shear and the load point which has the maximum shear
- No.3 stirrups at 18” spacing were used on beam

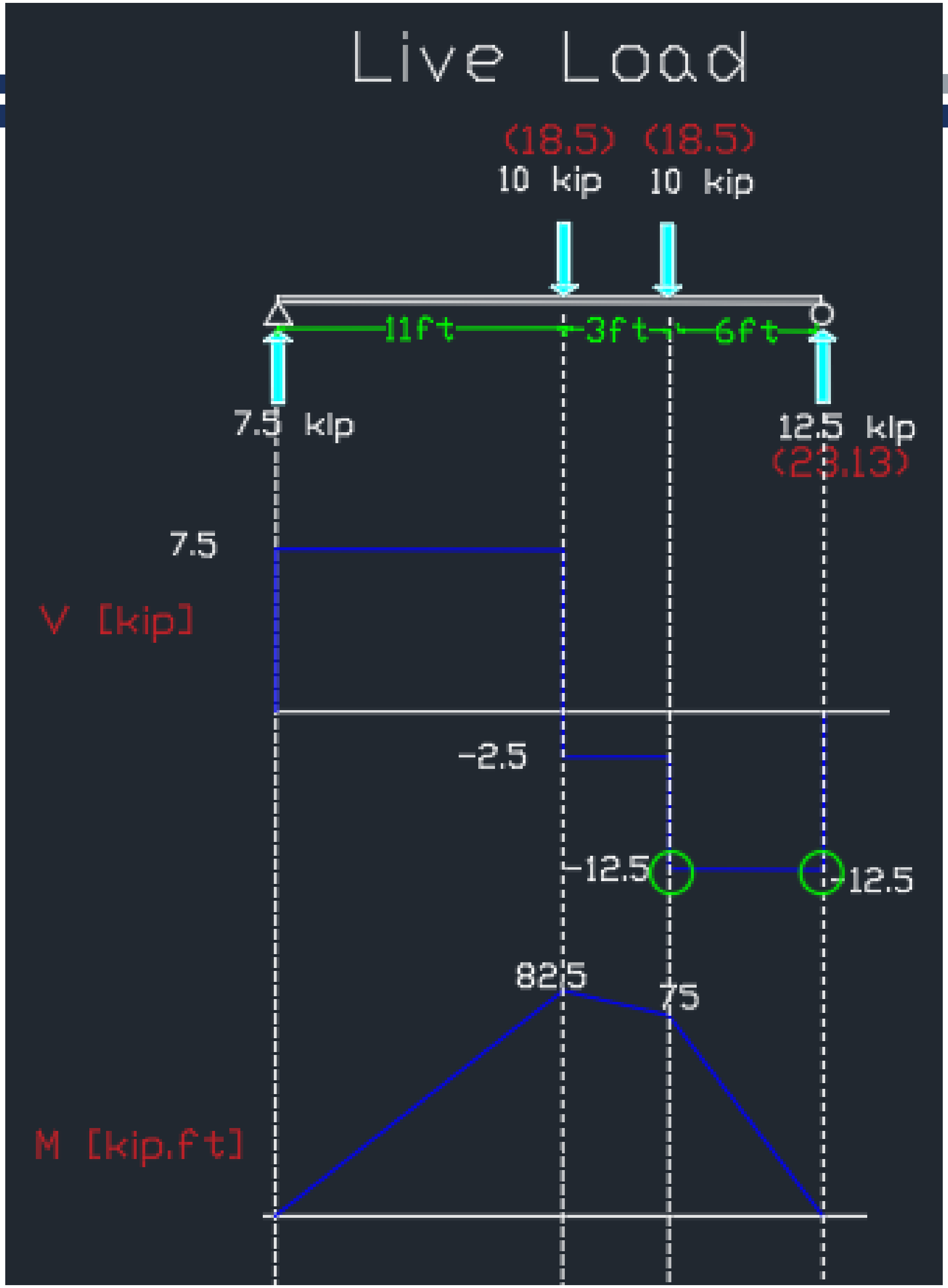


Figure 16. Live Load Diagrams

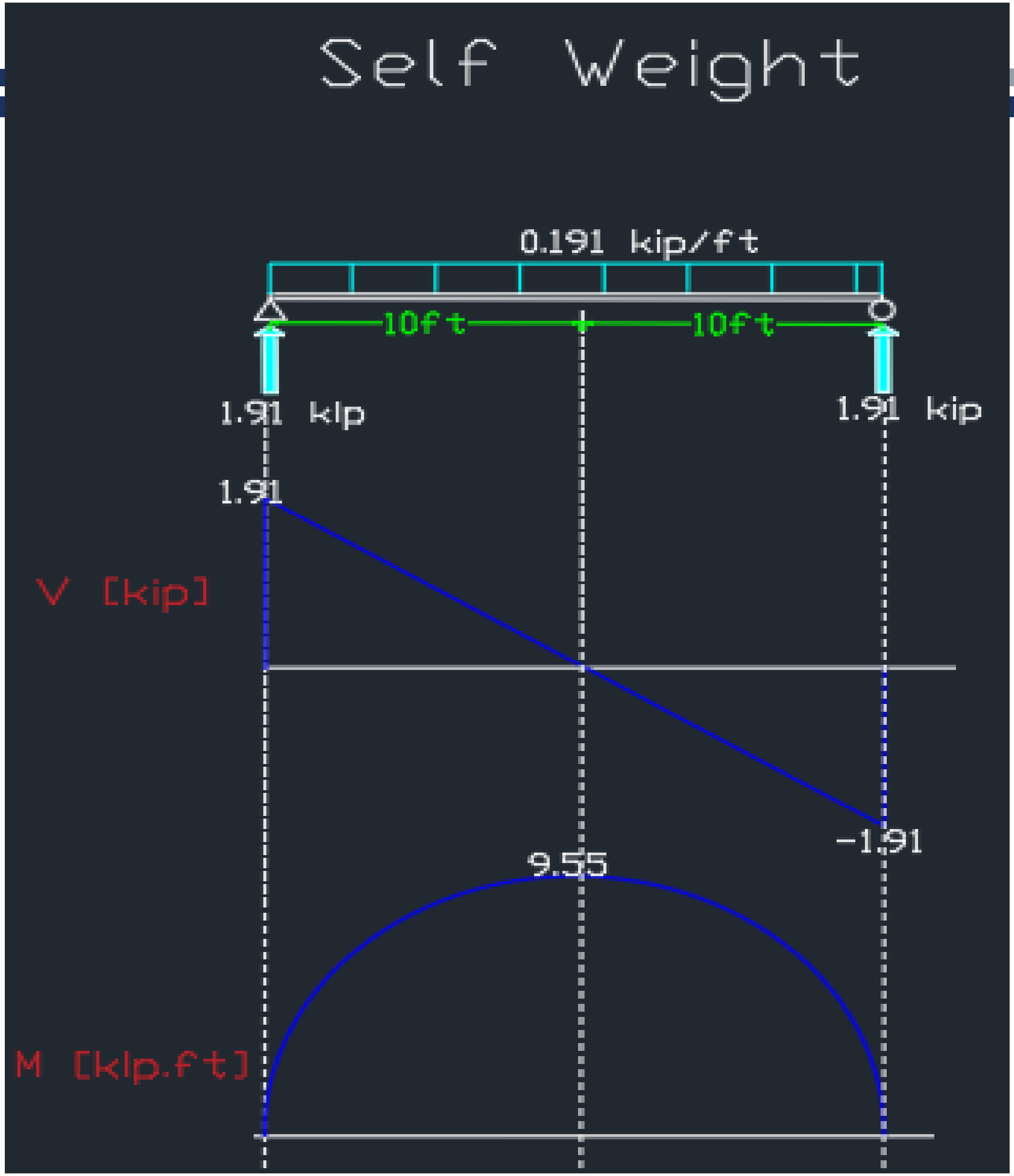


Figure 17. Self Weight Diagram

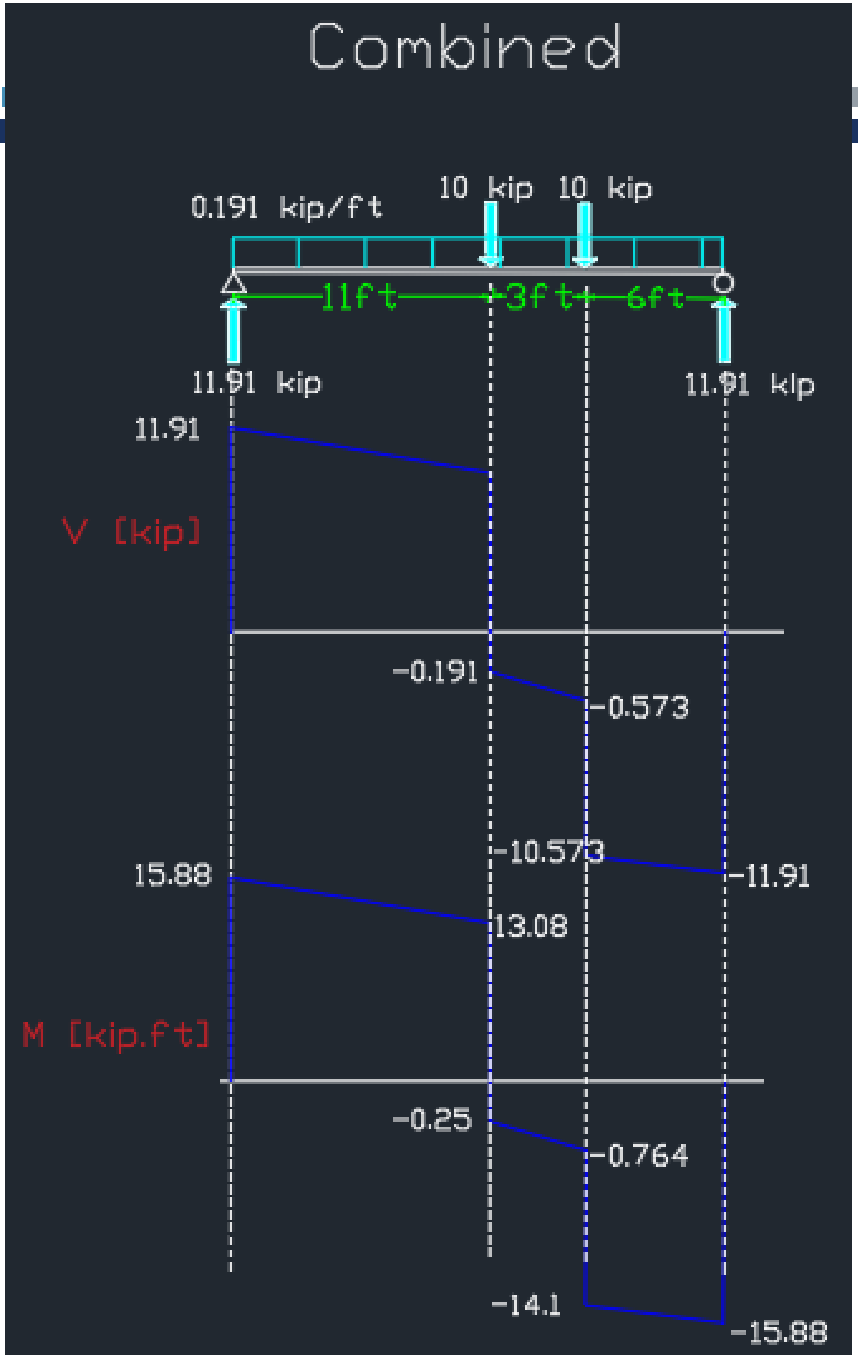


Figure 18. Combined Diagram

TASK 3.2: REINFORCEMENT DESIGN

Compression Steel (top of beam)

- 3 No. 4 bars

Prestressing Strand (bottom of beam)

- 2 of .5” Diameter Low Relax Strands

The Big Beam Theory

Figure 19. Big Beam Theory Logo

TASK 3.3: CRACKING LOAD

Cracking Capacity:

$\omega sw := (Agconcrete \cdot \gamma c) = 191.163 \cdot \frac{lbf}{ft}$

$L := 20ft$

$Msw := \frac{(\omega sw \cdot L^2)}{8} = 9.558 \cdot ft \cdot kip$

$\sigma sw := Msw \cdot \frac{ybar28}{Itr_{28}} = 83.755 \cdot psi$

$fcr := 7.5psi \sqrt{\frac{fc_{28}}{psi}} = 670.82 \cdot psi$

$MLL := 1kip \cdot in$

Given

$fcr = \left[-\sigma a + \sigma sw - \sigma f + \frac{(MLL \cdot ybar28)}{Itr_{28}} \right]$

$MLL := Minerr(MLL)$

$Pcr := \frac{2 \cdot (MLL)}{8ft} = 21.083 \cdot kip$

$MLL = 84.332 \cdot kip \cdot ft$

21.083 kip

Figure 20. MathCAD Sheet for Cracking Load

TASK 3.4: MAX LOAD AT MIDSPAN

Ultimate Capacity

$d := y_1 = 22.5 \cdot in$

$dprime := y_6 = 2.5 \cdot in$

$$\beta := \begin{cases} 0.85 & \text{if } (fc_{28} \le 4000psi) \\ \left[0.85 - \left[0.5 \cdot \left(\frac{fc_{28} - 4000psi}{1000psi}\right)\right]\right] & \text{if } 4000psi < fc_{28} < 8000psi \\ 0.65 & \text{if } fc_{28} \ge 8000psi \end{cases} = 0.65$$

Initial Guess: $c := 1in$ Strain in Concrete at Failure: $\varepsilon := .003$

Given

$$(0.85 \cdot fc_{28} \cdot \beta \cdot c \cdot b_1) + \min\left[Asprime \cdot \varepsilon \cdot \left[\frac{(c - dprime)}{c}\right] \cdot Es, fy \cdot Asprime\right] - Ap \cdot fu = 0$$

$c := Minerr(c) = 1.284 \cdot in$ $h_3 = 5 \cdot in$

Check in Flange := $\begin{cases} \text{"Okay"} & \text{if } c \le h_3 \\ \text{"Incorrect Assumption"} & \text{if } c > h_3 \end{cases}$

Check in Flange = "Okay"

$Cc := 0.85 fc_{28} \beta \cdot c \cdot b_1 = 130.528 \cdot kip$ $\varepsilon = 3 \times 10^{-3}$

$$Cs := Asprime \cdot Es \cdot \varepsilon \cdot \left[\frac{(c - y_6)}{c}\right] = -49.438 \cdot kip$$

$T := Ap \cdot fu = 81.09 \cdot kip$

$Mn := fu \cdot Ap \cdot [d - (\beta \cdot c \cdot 0.5)] + Cs \cdot (\beta \cdot c \cdot 0.5 - dprime) = 157.804 \cdot ft \cdot kip$

$$Pn := \frac{[(Mn - Msw) \cdot 2]}{8ft} = 37.062 \cdot kip$$

37.062 kip

Figure 21. MathCAD Sheet for Max Load

TASK 4: PREDICTIONS

4.1 Response 2000

- Moment curvature and Internal moment and axial force

4.2 Prediction Calculations

- Deflection
- Camber

Figure 22. Response 2000 Logo

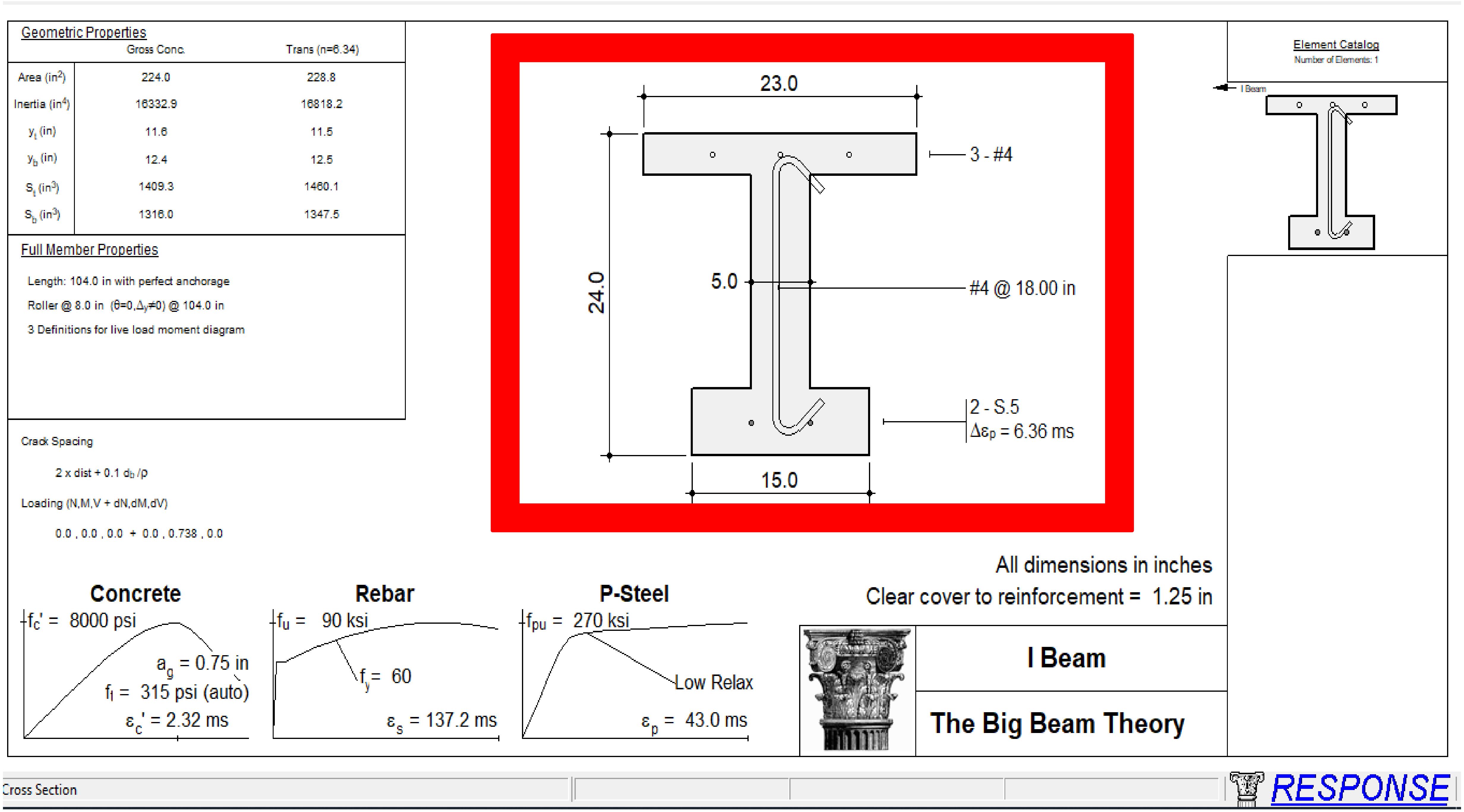


Figure 23. Response 2000 Input

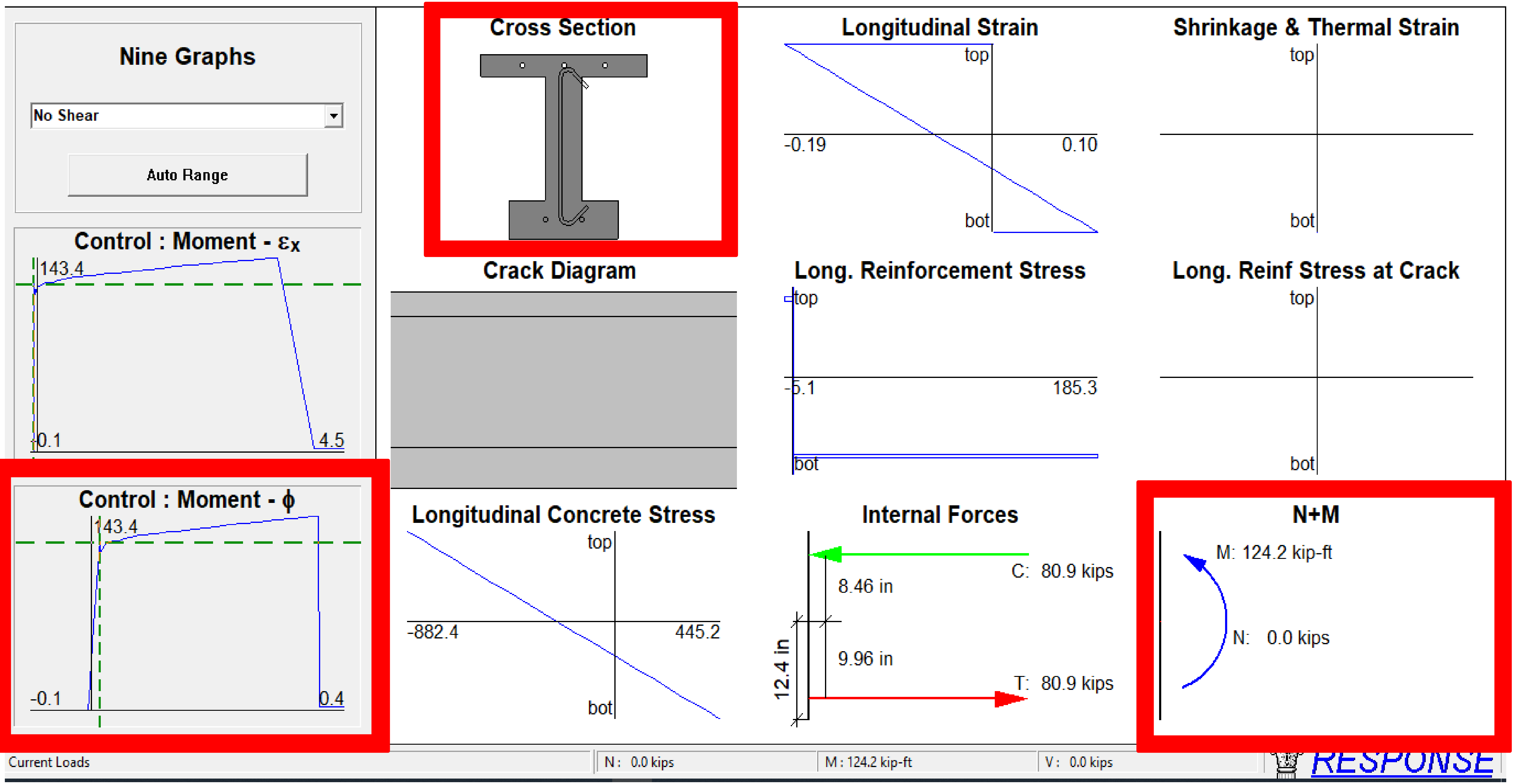


Figure 24. Response 2000 Output

TASK 4.1: RESPONSE 2000

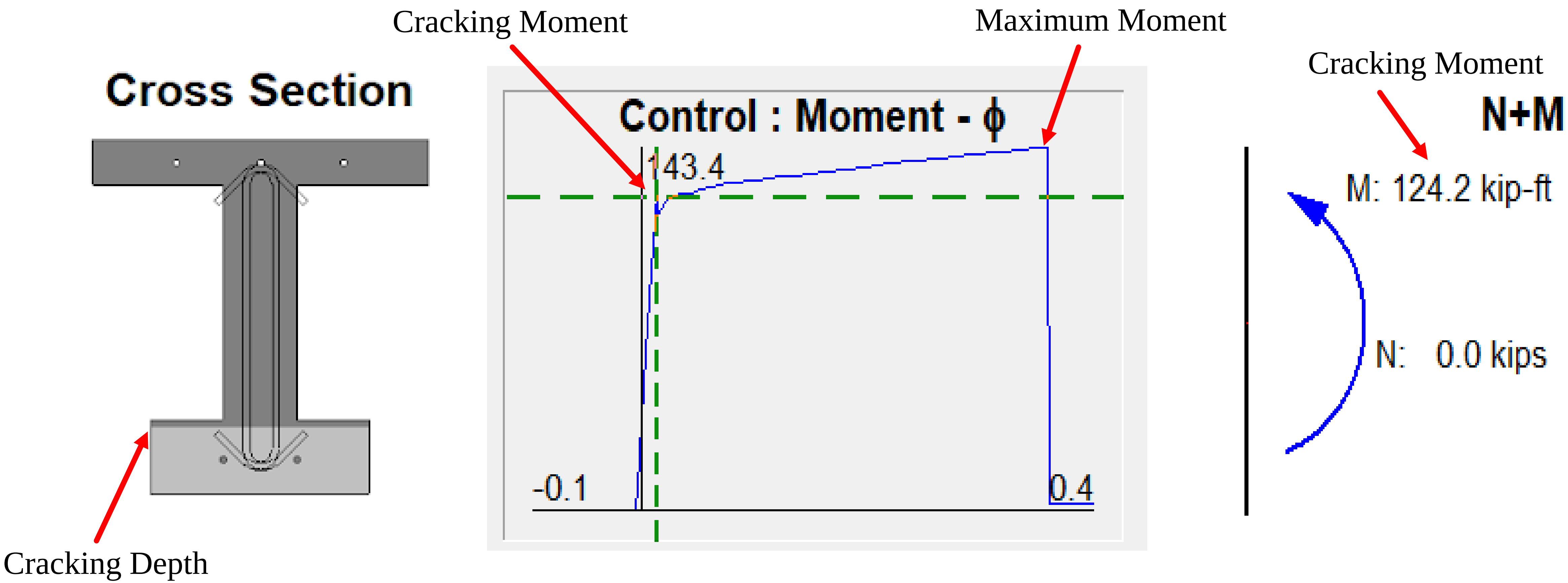


Figure 25. Response 2000 Output

TASK 4.1: RESPONSE 2000

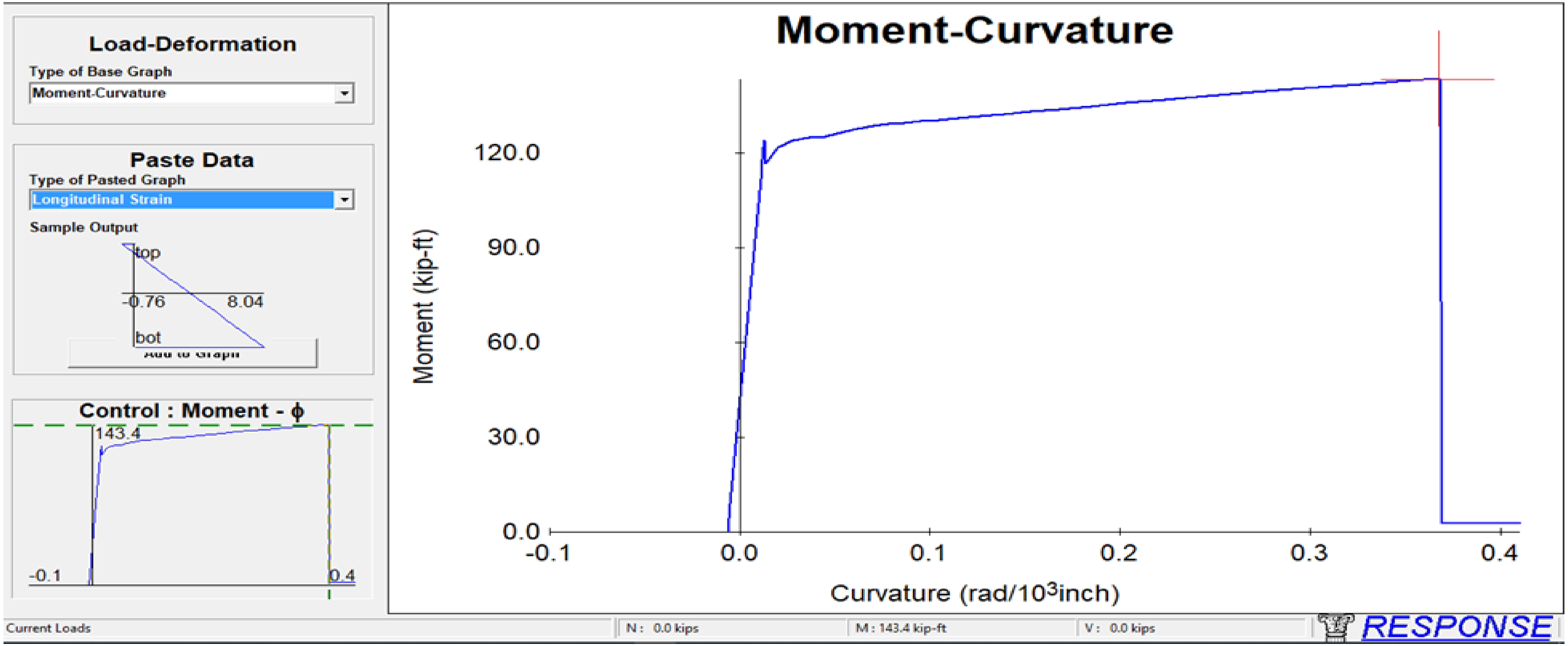


Figure 26. Response 2000 Output

TASK 4.2: PREDICTION CALCULATIONS

- Deflection - .477 inches
- Camber - .042 inches

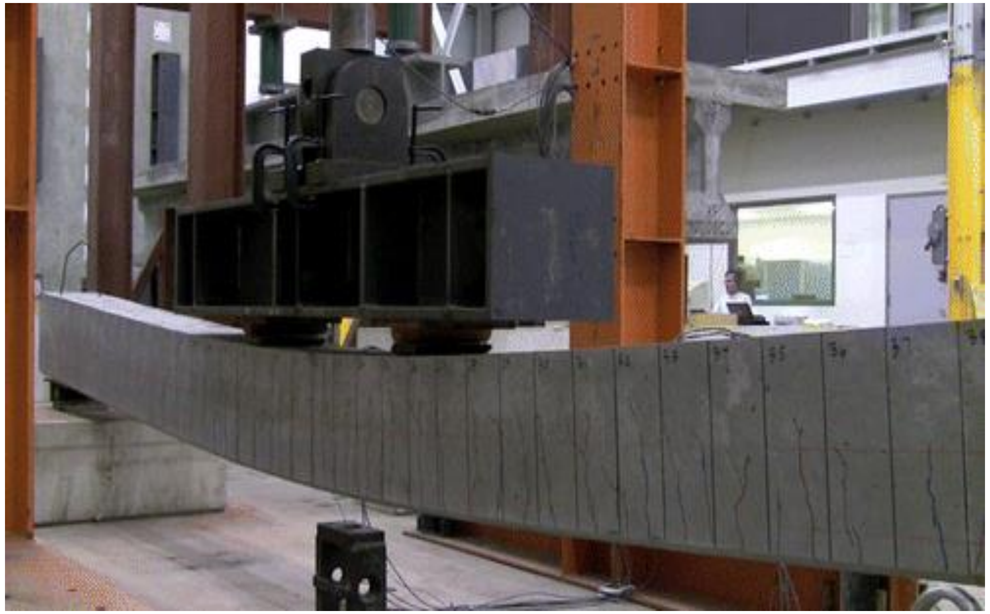


Figure 27. Beam Bending

$$l(\Delta) = \int_0^l \frac{Mm}{EI} dx$$

Δ = Deflection (in)
M = Internal Moments in the beam in the real diagram (kip*in)
m = Internal moments in the beam in the virtual diagram (kip*in)
E = Modulus of Elasticity (ksi)
I = Effective moment of Inertia (in^4)

$$\Delta c = \frac{1}{8} * \frac{PeL^2}{EIe}$$

Δc = Deflection due to Camber (in)
P = Prestressing force (kips)
e = Eccentricity (in)
L = Length of the beam (in)
E = Modulus of Elasticity (ksi)
Ie = Effective moment of Inertia (in^4)

TASK 4.2: PREDICTION CALCULATIONS

Losses

- **Elastic Shortening =** 3.38 ksi
  - Beam length gets shorter
- **Creep of Concrete =** 4.28 ksi
  - Pressure causes deformation in the concrete

Figure 28. Last year's formwork

TASK 4.2: PREDICTION CALCULATIONS

Losses

- **Shrinkage of Concrete =** 10.29 ksi
  - Drying of concrete affects stretch of the strands
  - Average annual humidity percentage
- **Relaxation of Tendons =** 4.28 ksi
  - Strands relaxation over time

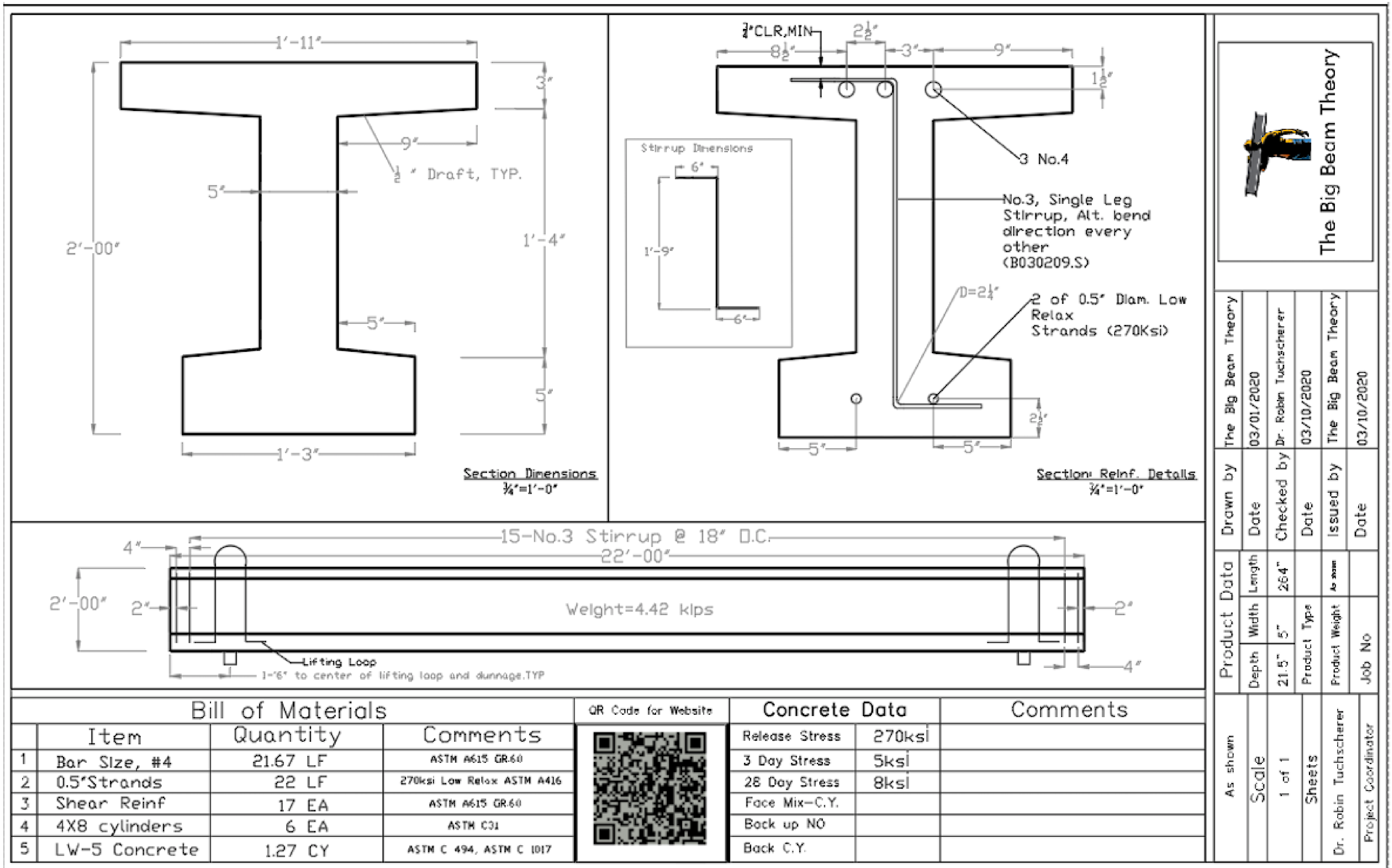
Figure 29. Last year's Screeding of Concrete

TASK 5: SHOP DRAWINGS

5.1 AutoCAD

- 5.1.1 Side Elevation
- 5.1.2 Cross Section
- 5.1.3 Profile View

Figure 30. AutoCAD Logo



Bill of Materials

	Item	Quantity	Comments
1	Bar Size, #4	21.67 LF	ASTM A615 GR.60
2	0.5"Strands	22 LF	270ksi Low Relax ASTM A416
3	Shear Reinf	17 EA	ASTM A615 GR.60
4	4X8 cylinders	6 EA	ASTM C31
5	LW-5 Concrete	1.27 CY	ASTM C 494, ASTM C 1017

Concrete Data

Release Stress	270ksi
3 Day Stress	5ksi
28 Day Stress	8ksi
Face Mix-C.Y.	
Back up NO	
Back C.Y.	

Figure 31. Shop Drawings

TASK 5.1.1: SIDE ELEVATION

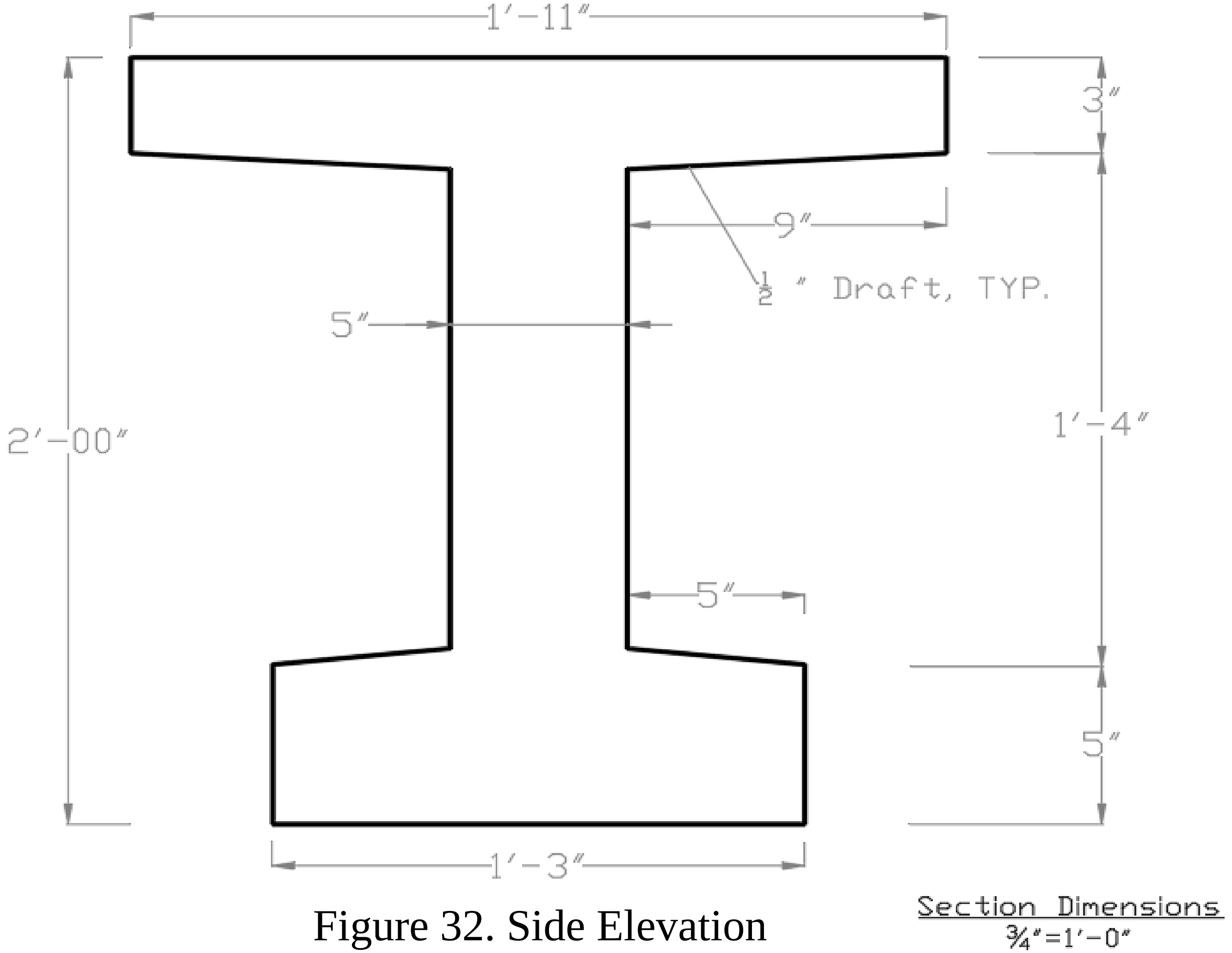


Figure 32. Side Elevation

TASK 5.1.2: CROSS SECTION

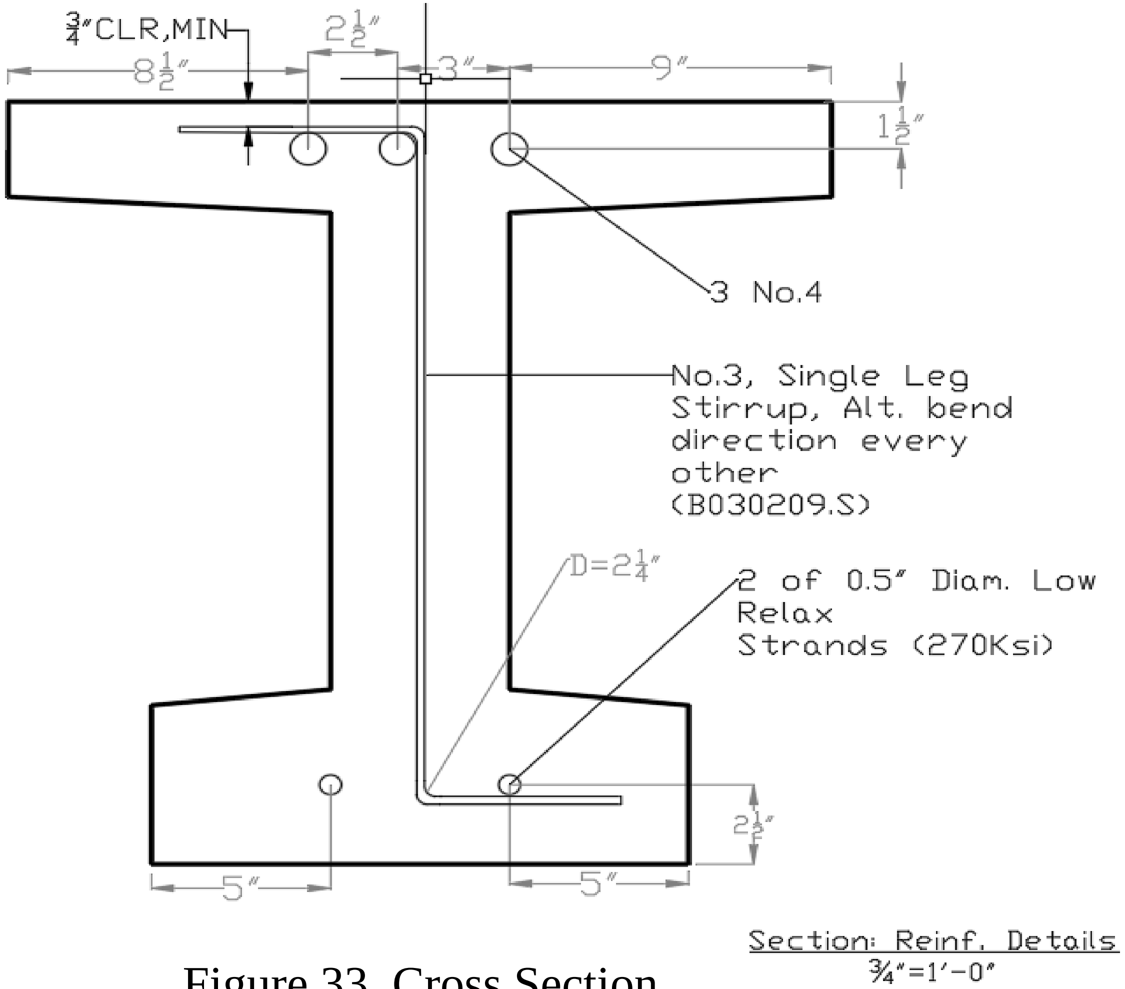


Figure 33. Cross Section

TASK 5.1.3: PROFILE VIEW

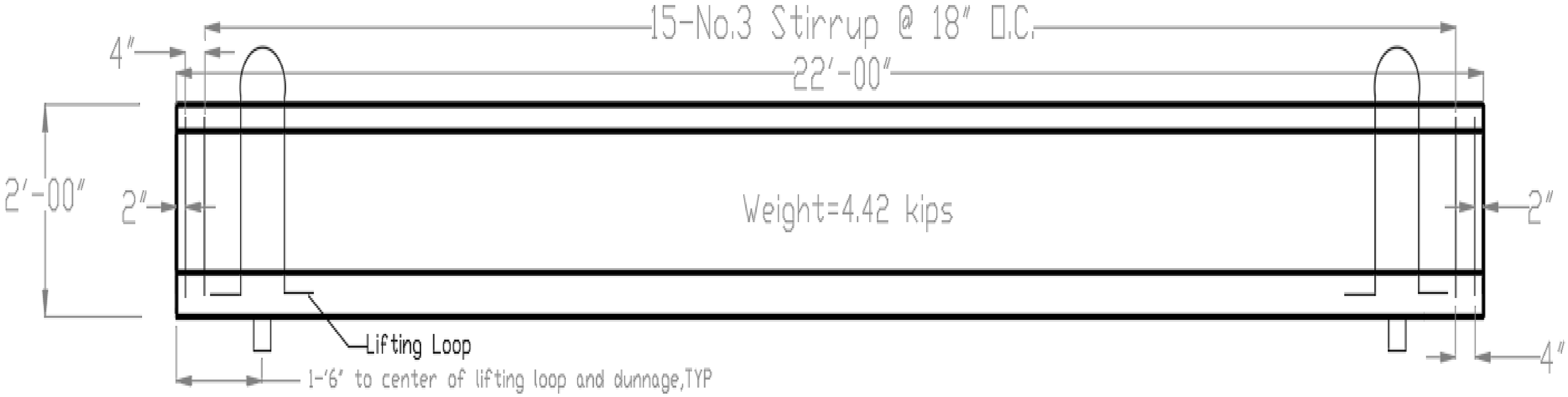


Figure 34. Profile View

TASK 6: CASTING OF BEAM

Figure 35. Beam at TPAC facility

Casting Info:

- Poured on 3/23 at 9am in Phoenix
- The Beam should be approaching 8,000 psi

TASK 7: TESTING OF BEAM

Figure 36. Last Year's Beam at NAU Lab

Current Status of Beam:

- The beam is still at TPAC facility because of COVID-19
- The beam will be tested early May if the “stay at home” order is lifted

TASK 8: PROJECT MANAGEMENT

Reports

Website

Meetings

- Team
- Grading Instructor
- Technical Advisor

Figure 37. Team Website

TASK 9: PROJECT IMPACTS

- Regulatory: Competition rules
- Environmental: Mining of cement is the 3rd largest CO2 emissions in the world.
- Social: Winning can bring NAU more students by showing potential students that NAU can beat top ranked schools in competitions
- Economic: Increases the demand of jobs for getting the materials for the concrete and casting the beam

WHAT WE WOULD DO DIFFERENT

- Build more float into schedule
- Weekly calendar updates
- More TA meetings
- Better communication with TPAC
- Start design earlier
- Stay on top of design work

Figure 38. The Big Beam Theory Logo

ANY QUESTIONS?

THANK YOU FOR LISTENING

REFERENCES

- [1] R. Tuchscherer, *Lecture Slides*, Flagstaff: NAU, 2019.
- [2] "2019-2020 PCI Competition".
- [3] ACI 318-19 Code
- [4] PCI Design Handbook 7th Edition