SlipperyRock University

Structural Engineering

CIVIL 310

Department of Physics and Engineering

Slippery Rock University

Prepared By:

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Executive Summary

The objective presented was to model and create a structure out of wood, steel, and concrete whether these three materials would be combined into one structure or if three different structures would be created was free of choice. This particular project uses the materials separately and so the same structure was created three times once out of wood, once out of steel and once out of concrete. The structure created was made to be a warehouse that is 100 feet wide, 180 feet long and 50 feet high, including two indoor soccer courts, a small office space and a bathroom for each gender. The structure could be made with all three materials with wood being the cheapest of the three structures made followed by concrete and then steel being the most expensive at $589367. Each structure had dead loads and live loads applied to it with concrete undergoing the least deflection making it the most stable and wood undergoing the most deflection making it the least stable. Comparing the stability and cost effectiveness of each structure it was found that concrete would be best choice of material as it provided the most stability and a price that seems reasonable for a building such as the one chosen.

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Introduction

The purpose of this project was to design a structure in AutoCAD and then model the structure in Risa. Through this a warehouse with two indoor soccer fields, a men's and women's bathroom and a small office and front desk area was designed. The design for this project was based on an indoor soccer arena in Australia, the majority are designed like this and that is what sparked this idea. The structure was then modelled in Risa three times using different materials each time, one made from wood, one out of steel and one out of concrete. The structure was designed to be 100 feet wide by 180 feet long and 50 feet high, with a flat roof. Columns were to be placed every 20 feet to support the structure. The designed plans for the structure can be seen below and a separate plan for where the columns will be placed. Each of these structures comes with a cost analysis describing the estimated cost of how much one of these buildings would cost with their chosen materials.

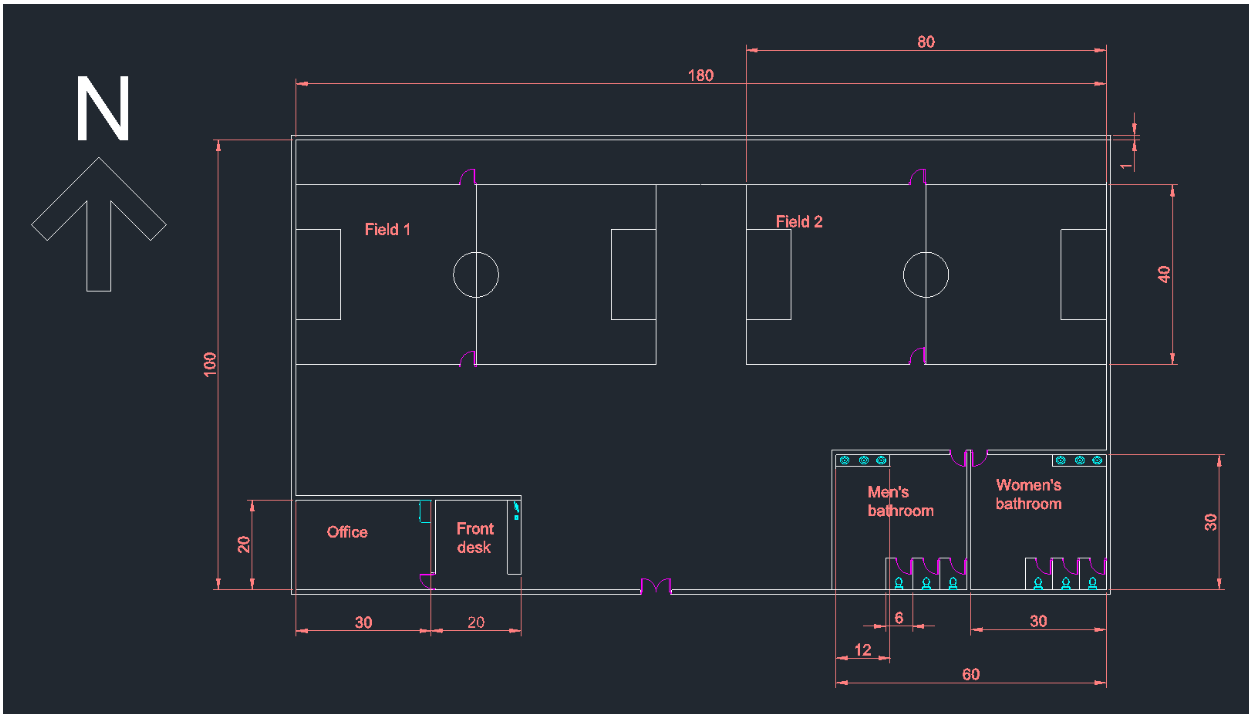


Figure 1: Structure layout

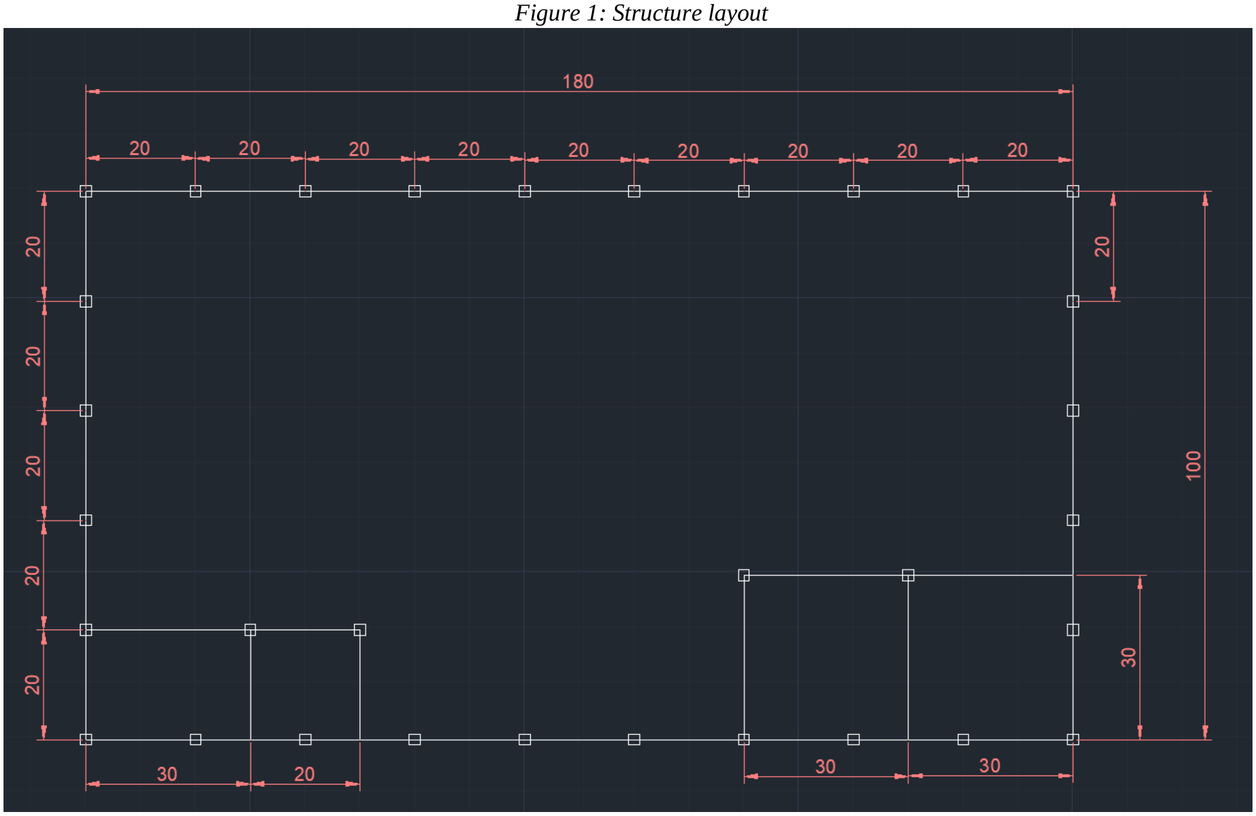


Figure 2: Placement of columns

Designed Structures

There are three structures shown and described below the first being made of wood, followed by one made of steel and then one made of concrete. Each structure was placed under a 0.1 ksf area load, a 3 k nodal load and 0.1 ksf wind load on all of the walls to test the stability of the structure and which all of these results are calculated from.

1. Wood design

The first structure that was designed was made from wood with 20 x 20 Douglas fir columns, 4 x 10 Douglas fir beams and 6 x 8 Douglas fir girders. Between the columns wood walls were placed which were also made from Douglas fir. In the figures below the model of the structure made from wood can be seen and the forces that were placed on it. There is also an analysis of each member and how the members act when they are under a force. The wood structure undergoes the most deflection which can be seen in the diagrams below for each element, this is primarily due to wood being a weaker material than steel and concrete. The entire structure would be stable if it would be created out of wood so this would be a suitable design.

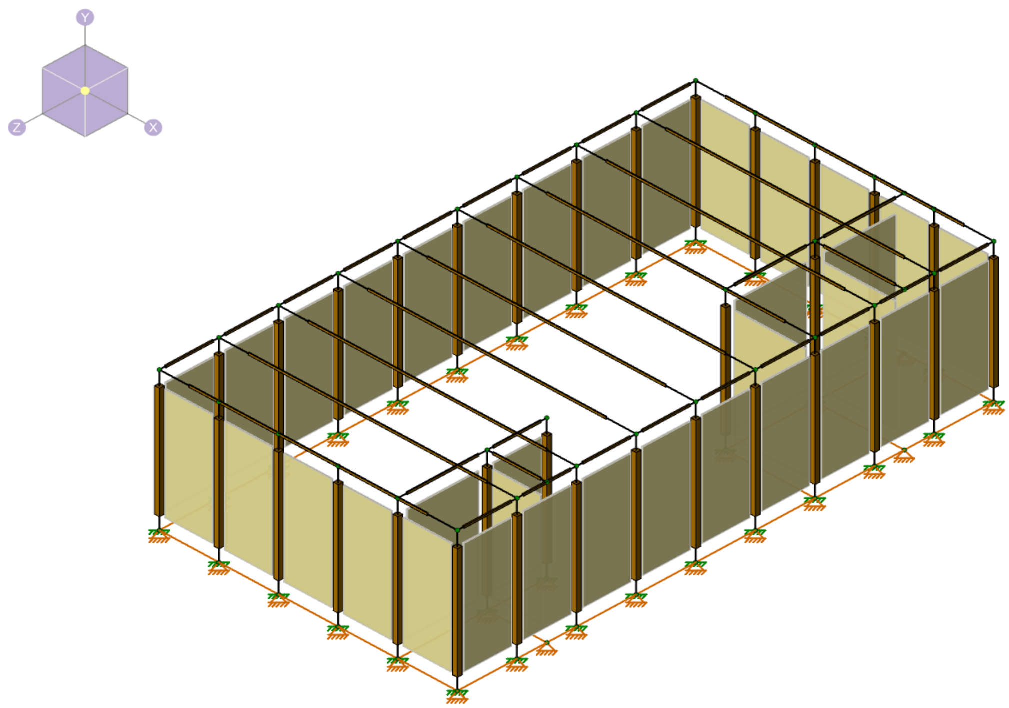


Figure 3: Wood Structure

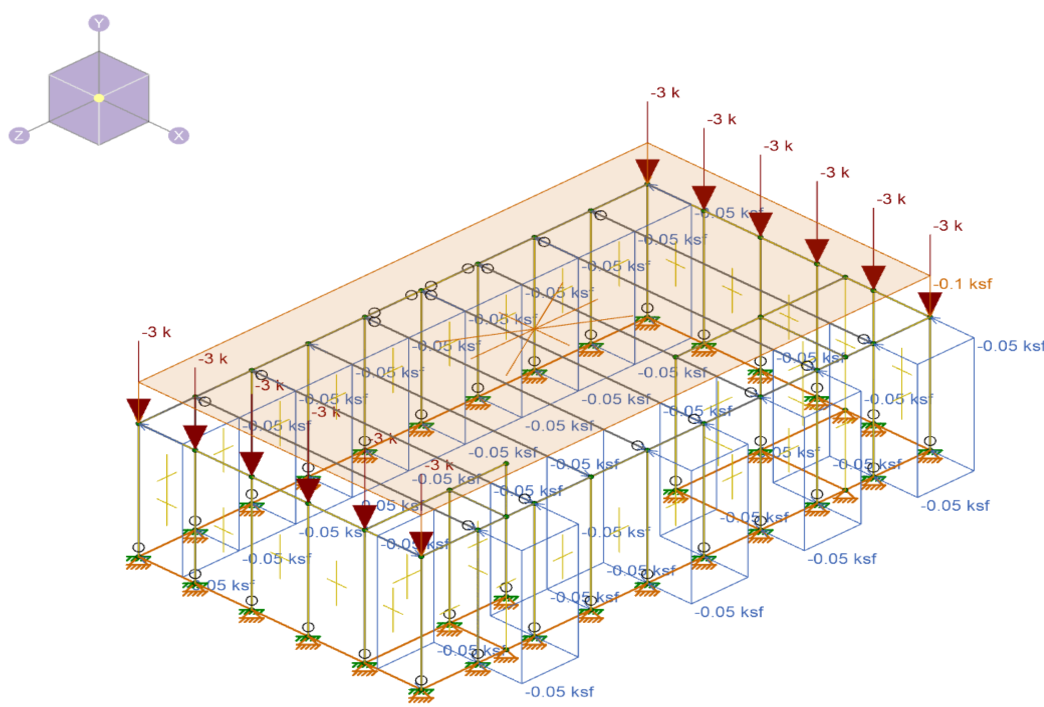


Figure 4: Loads applied to wood Structure

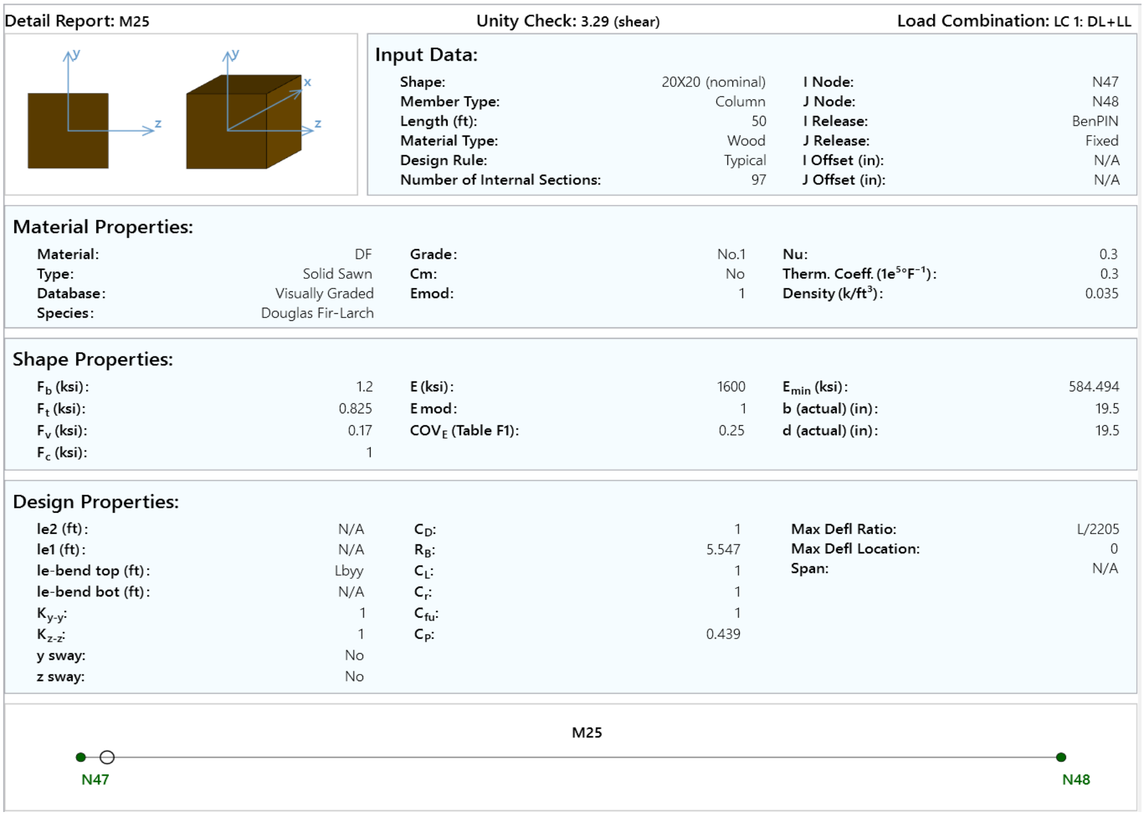


Figure 5: Wood column design

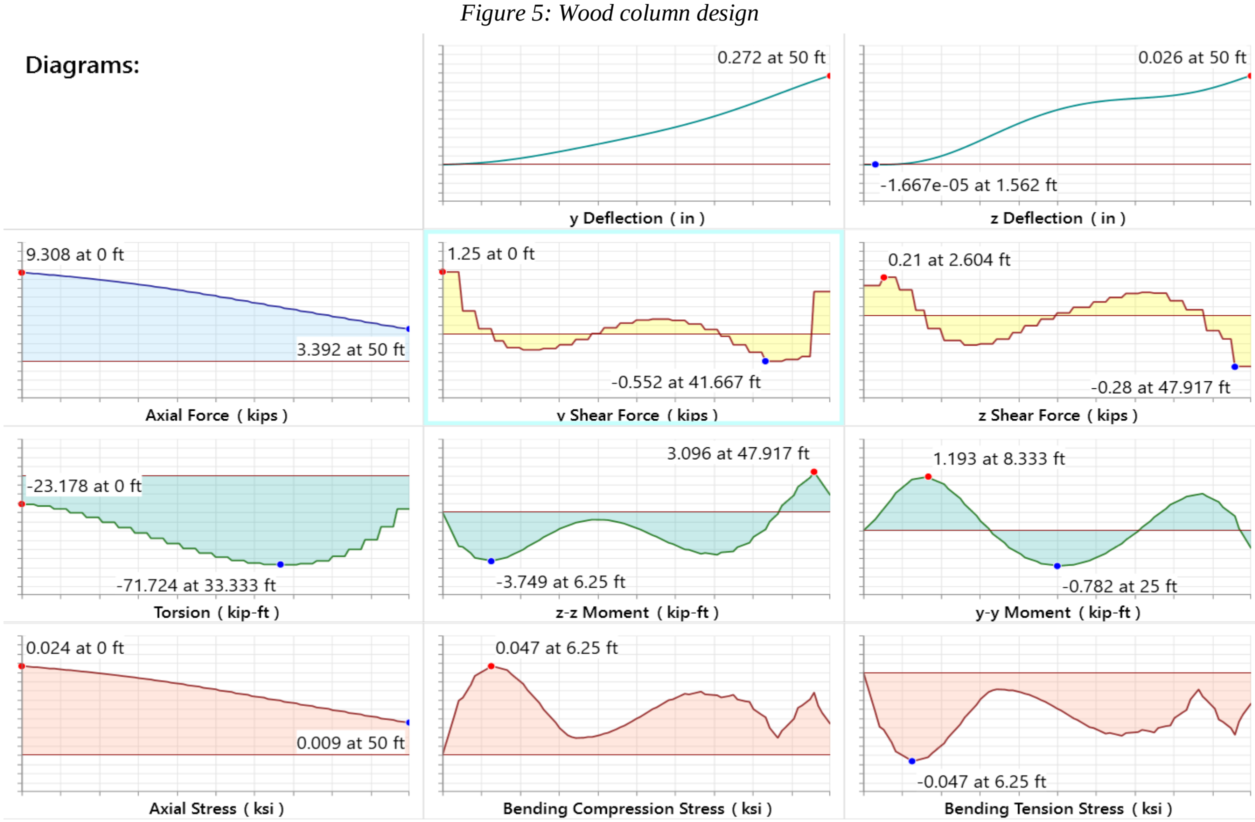


Figure 6: Wood column diagrams

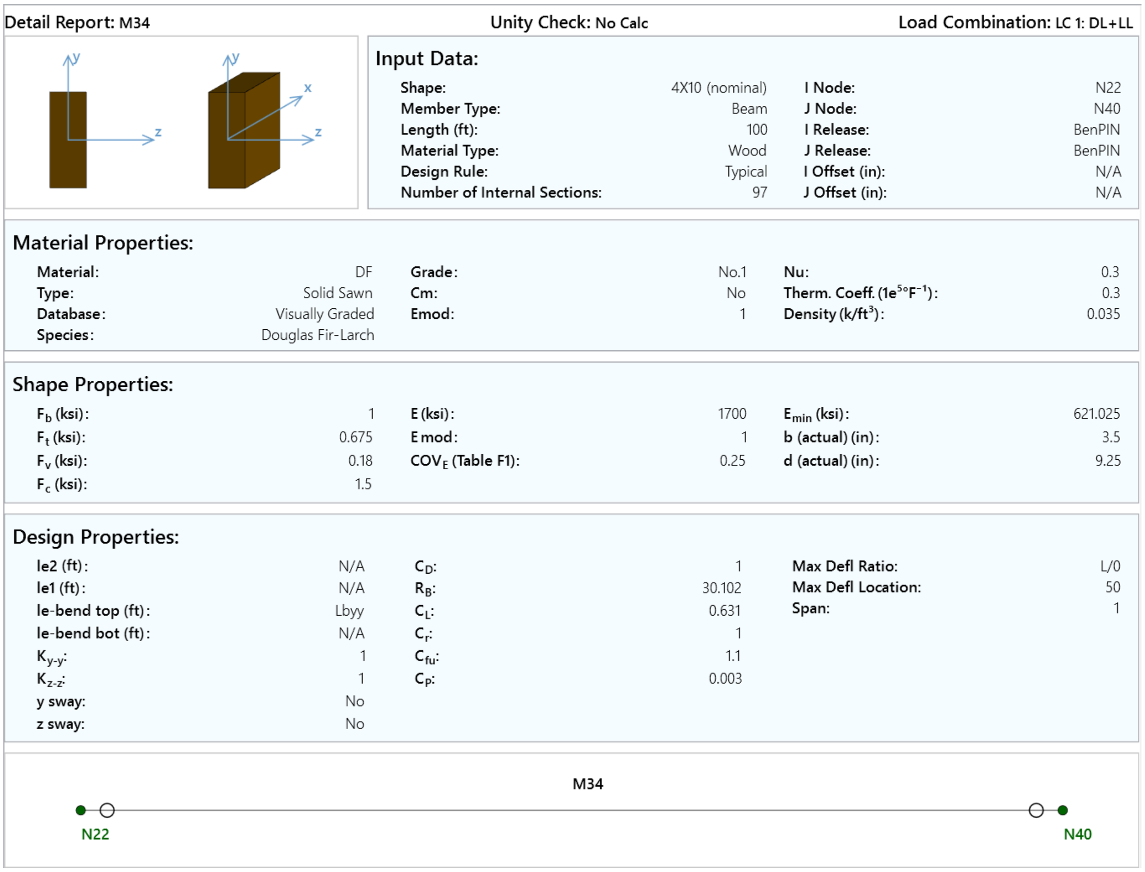


Figure 7: Wood beam design

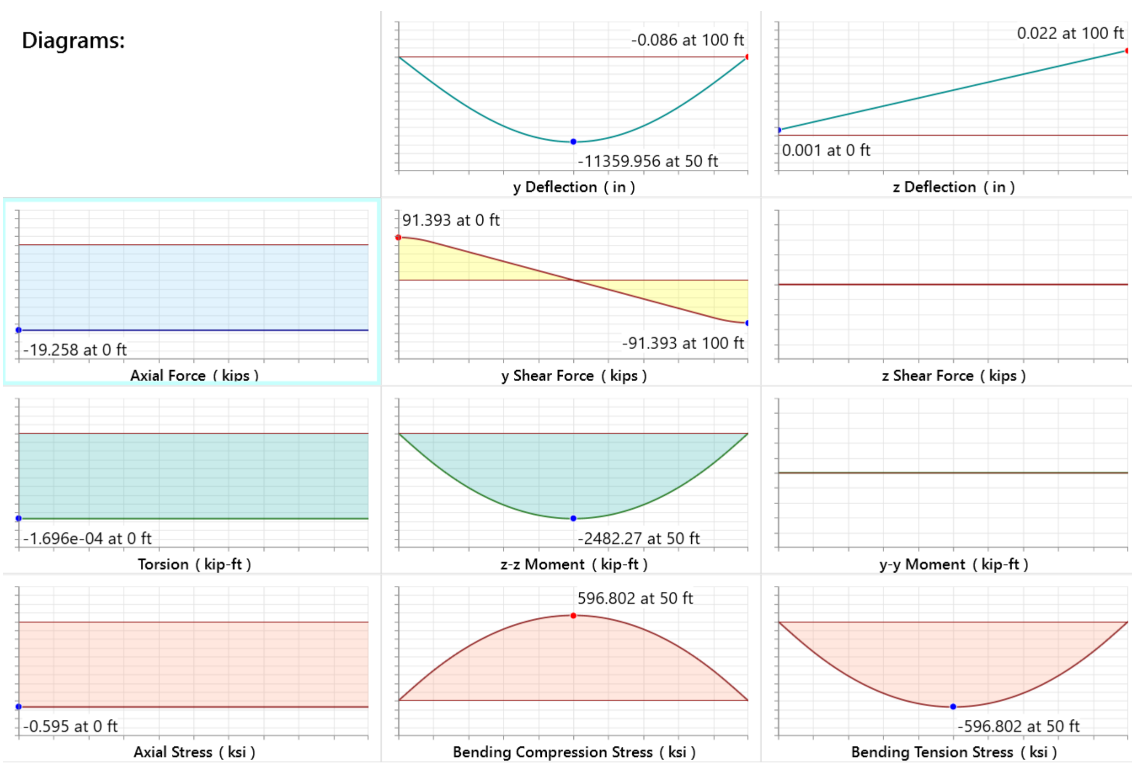
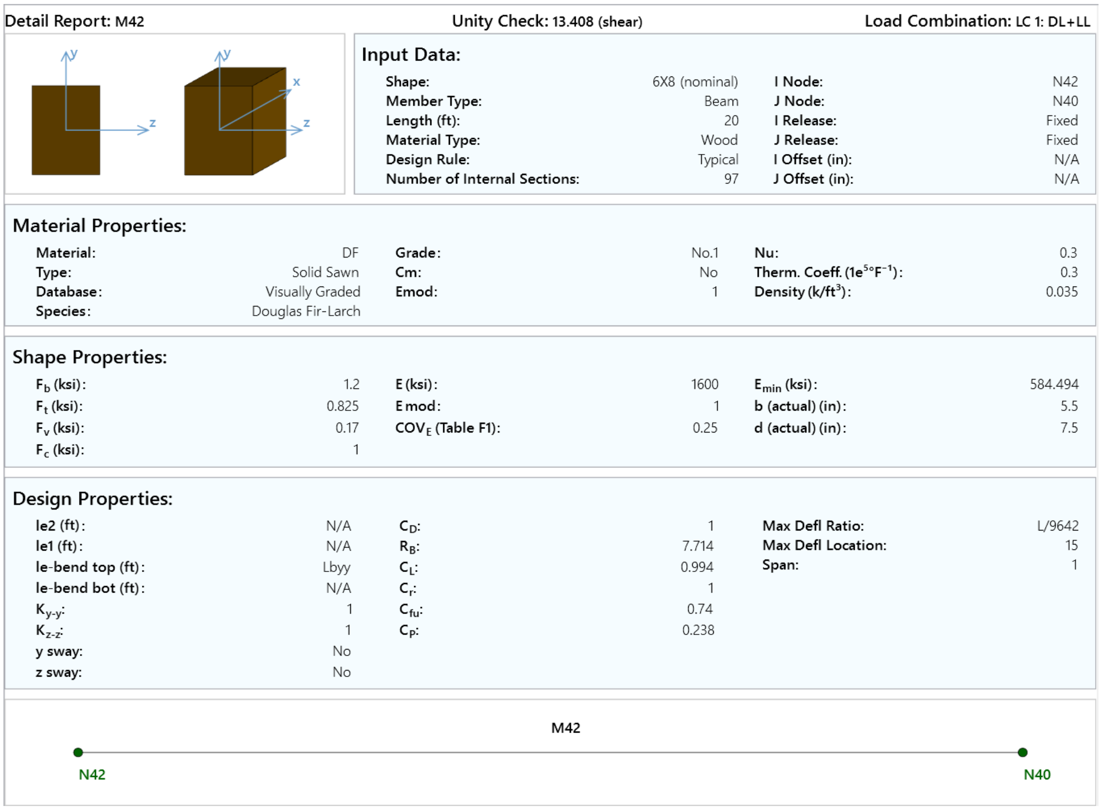


Figure 8: Wood beam diagrams



Detail Report: M42 | Unity Check: 13.408 (shear) | Load Combination: LC 1: DL+LL

Input Data:

Shape:	6X8 (nominal)	I Node:	N42
Member Type:	Beam	J Node:	N40
Length (ft):	20	I Release:	Fixed
Material Type:	Wood	J Release:	Fixed
Design Rule:	Typical	I Offset (in):	N/A
Number of Internal Sections:	97	J Offset (in):	N/A

Material Properties:

Material:	DF	Grade:	No.1	Nu:	0.3
Type:	Solid Sawn	Cm:	No	Therm. Coeff. ($1e^5 °F^{-1}$):	0.3
Database:	Visually Graded	Emod:	1	Density (k/ft^3):	0.035
Species:	Douglas Fir-Larch				

Shape Properties:

F_b (ksi):	1.2	E (ksi):	1600	E_{min} (ksi):	584.494
F_t (ksi):	0.825	E mod:	1	b (actual) (in):	5.5
F_v (ksi):	0.17	COV_E (Table F1):	0.25	d (actual) (in):	7.5
F_c (ksi):	1				

Design Properties:

le2 (ft):	N/A	C_D:	1	Max Defl Ratio:	L/9642
le1 (ft):	N/A	R_B:	7.714	Max Defl Location:	15
le-bend top (ft):	Lbyy	C_L:	0.994	Span:	1
le-bend bot (ft):	N/A	C_r:	1		
K_{y-y}:	1	C_{fu}:	0.74		
K_{z-z}:	1	C_P:	0.238		
y sway:	No				
z sway:	No				

Figure 9: Wood girder design

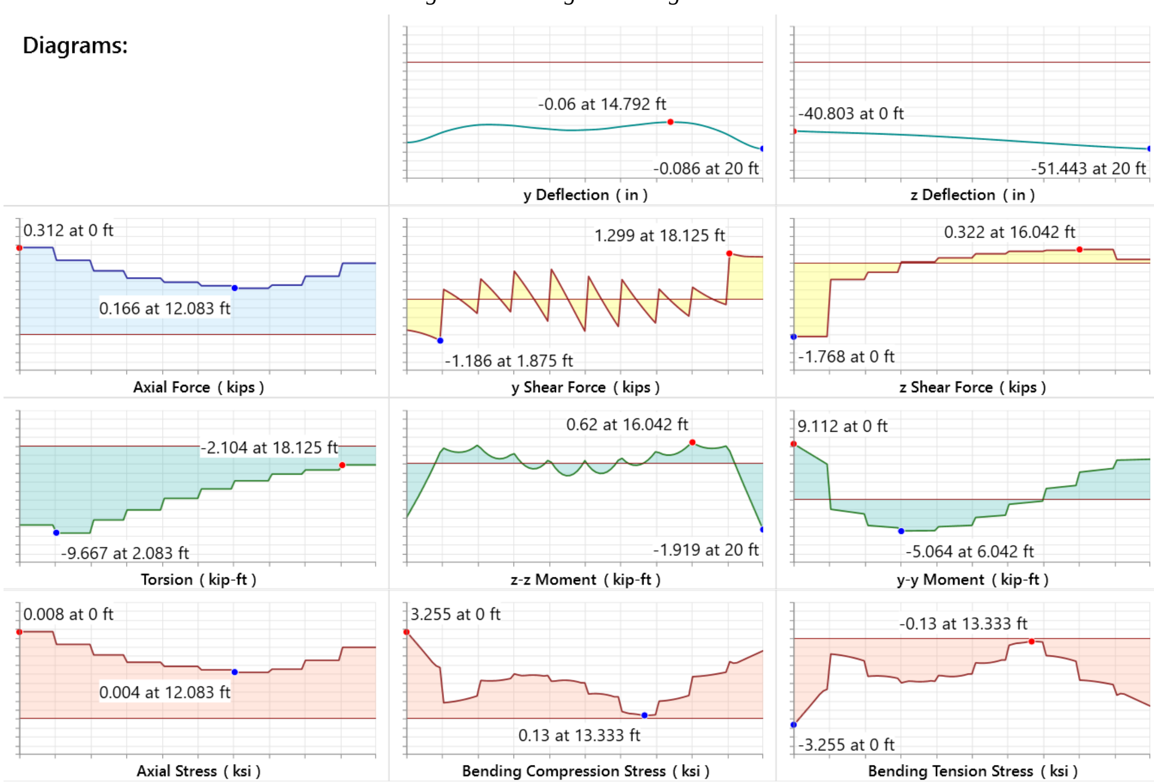


Figure 10: Wood girder diagrams

2. Steel Design

The second structure that was designed was made from Steel with W32 x 652 wide flanged hot rolled steel columns, W12 x 30 wide flanged hot rolled beams and W14 x 132 wide flanged hot rolled girders, all the hot rolled steel was made from A992 steel. Between the columns masonry walls were placed. In the figures below an analysis of each member can be seen of how the members act when a force is placed on them. The entire structure would be stable if it would be created out of steel so this would be a suitable design.

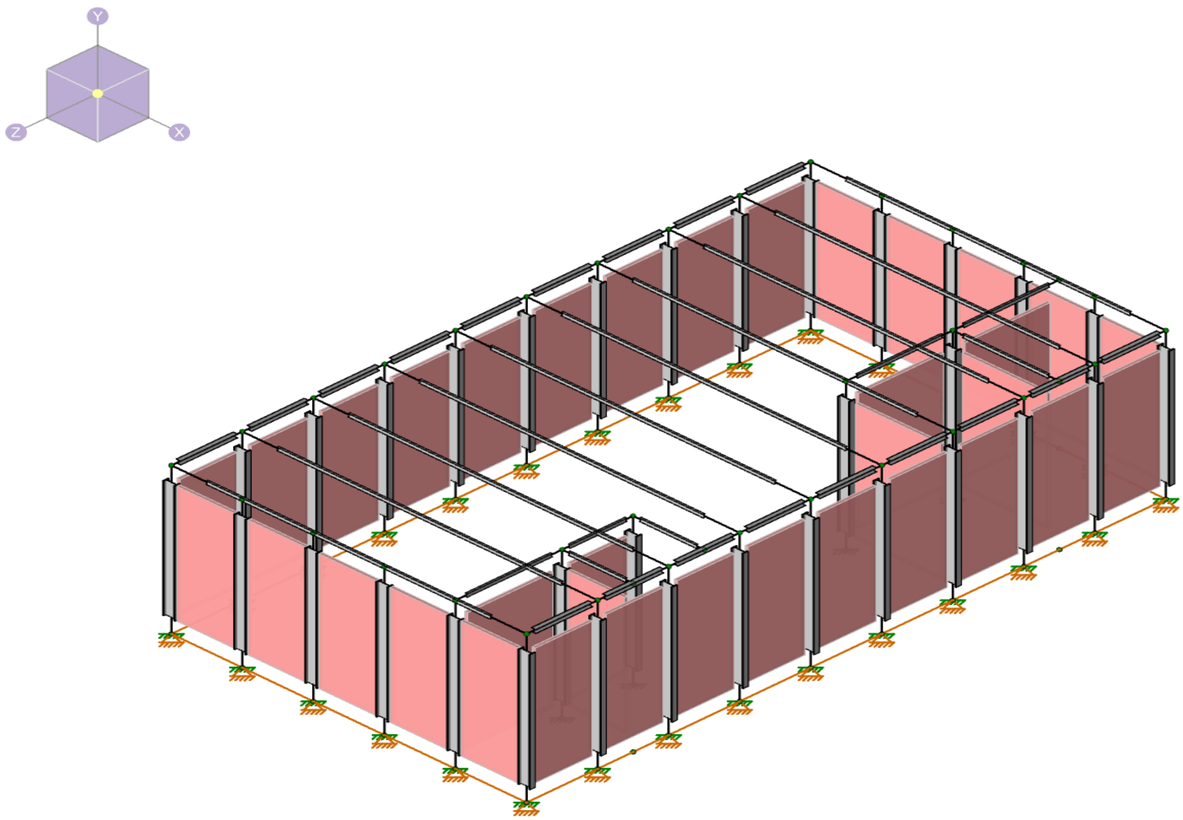


Figure 11: Steel structure

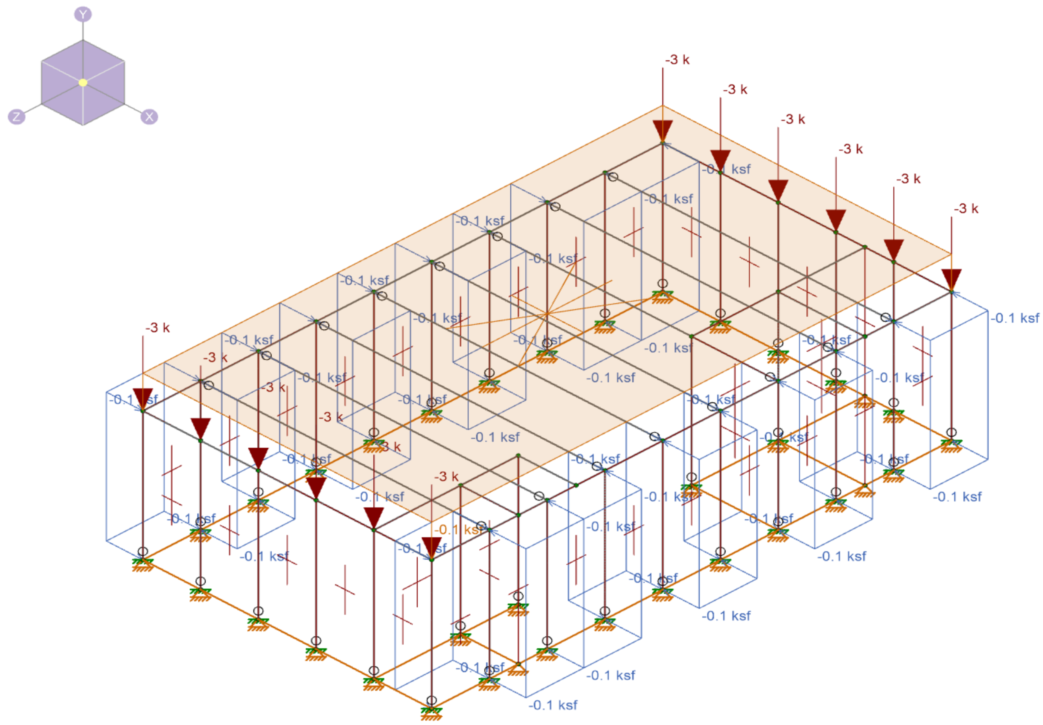
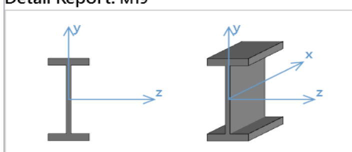


Figure 12: Loads applied to steel structure

Detail Report: M19 | **Unity Check:** 0.119 (axial/bending) | **Load Combination:** LC 1: DL+LL+WL



Input Data:

Shape:	W36X652	**I Node:**	N38
Member Type:	Column	**J Node:**	N37
Length (ft):	50	**I Release:**	Fixed
Material Type:	Hot Rolled Steel	**J Release:**	BenPIN
Design Rule:	Typical	**I Offset (in):**	N/A
Number of Internal Sections:	97	**J Offset (in):**	N/A

Material Properties:

Material:	A992	**Therm. Coeff. ($1e^{5}$°F^{-1}):**	0.65	**R_y:**	1.1
E (ksi):	29000	**Density (k/ft^3):**	0.49	**F_u (ksi):**	65
G (ksi):	11154	**F_y (ksi):**	50	**R_t:**	1.1
Nu:	0.3				

Shape Properties:

d (in):	41.1	**Area (in^2):**	192	**S_w (in^4):**	2560
b_f (in):	17.6	**Z_{yy} (in^3):**	581	**r_T (in):**	4.684
t_f (in):	3.54	**Z_{zz} (in^3):**	2910	**J (in^4):**	593
t_w (in):	1.97	**C_w (in^6):**	1.13e+6	**k_{det} (in):**	4.812
I_{yy} (in^4):	3230	**W_{no} (in^2):**	165	**k_{des} (in):**	4.49
I_{zz} (in^4):	50600				

Design Properties:

$L_{b\ y\text{-}y}$ (ft):	N/A	**$K_{y\text{-}y}$:**	1	**Max Defl Ratio:**	L/10000
$L_{b\ z\text{-}z}$ (ft):	N/A	**$K_{z\text{-}z}$:**	1	**Max Defl Location:**	0
$L_{comp\ top}$ (ft):	Lbyy	**y sway:**	No	**Span:**	N/A
$L_{comp\ bot}$ (ft):	N/A	**z sway:**	No		
L_{torque} (ft):	N/A	**Function:**	Lateral		
		Seismic DR:	None		

Figure 13: Steel column design

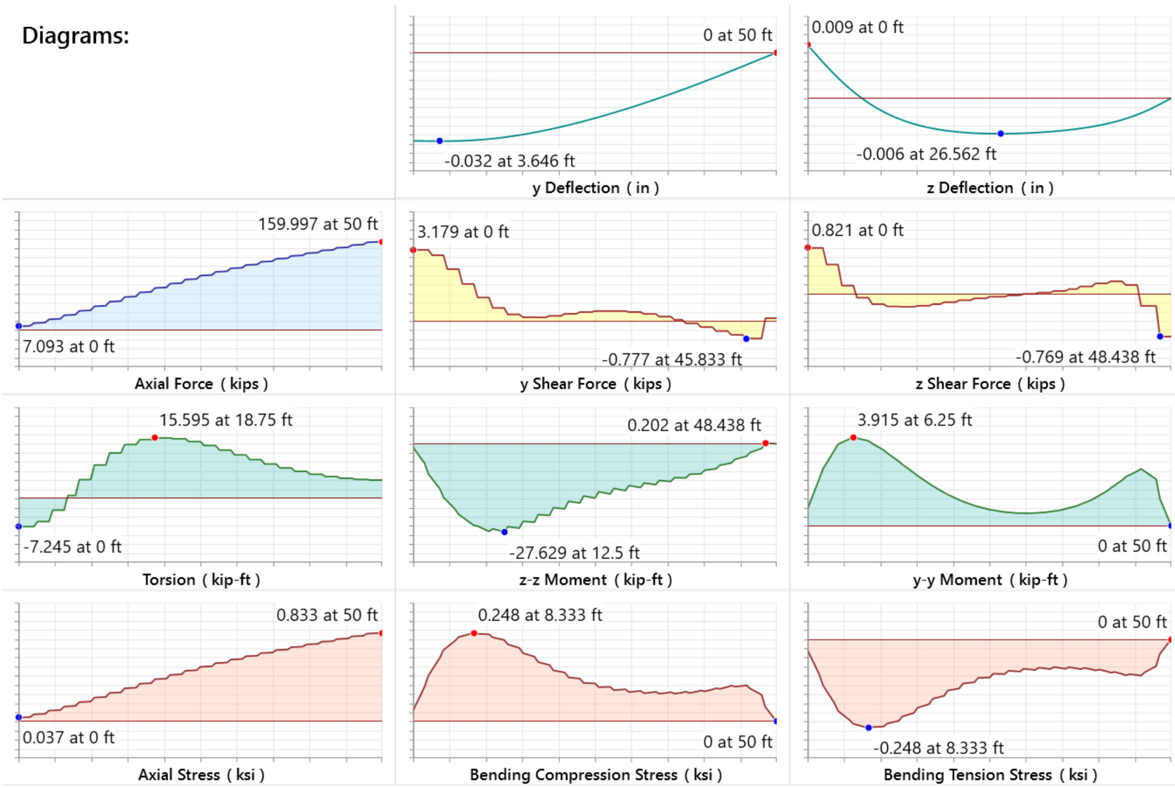
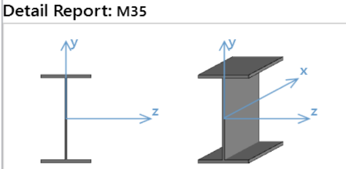


Figure 14: Steel column diagrams

Detail Report: M35 **Unity Check:** No Calc **Load Combination:** LC 1: DL+LL+WL



Input Data:

Shape:	W12X30	I Node:	N25
Member Type:	Beam	J Node:	N44
Length (ft):	100	I Release:	BenPIN
Material Type:	Hot Rolled Steel	J Release:	BenPIN
Design Rule:	Typical	I Offset (in):	N/A
Number of Internal Sections:	97	J Offset (in):	N/A

Material Properties:

Material:	A992	Therm. Coeff. ($1e^{5\circ}F^{-1}$):	0.65	R_y:	1.1
E (ksi):	29000	Density (k/ft³):	0.49	F_u (ksi):	65
G (ksi):	11154	F_y (ksi):	50	R_t:	1.1
Nu:	0.3				

Shape Properties:

d (in):	12.3	Area (in^2):	8.79	S_w (in^4):	13.9
b_f (in):	6.52	Z_{yy} (in^3):	9.56	r_T (in):	1.73
t_f (in):	0.44	Z_{zz} (in^3):	43.1	J (in^4):	0.457
t_w (in):	0.26	C_w (in^6):	720	k_{det} (in):	1.125
I_{yy} (in^4):	20.3	W_{no} (in^2):	19.3	k_{des} (in):	0.74
I_{zz} (in^4):	238				

Design Properties:

$L_{b\ y\text{-}y}$ (ft):	N/A	$K_{y\text{-}y}$:	1	Max Defl Ratio:	L/6
$L_{b\ z\text{-}z}$ (ft):	N/A	$K_{z\text{-}z}$:	1	Max Defl Location:	34.375
$L_{comp\ top}$ (ft):	Lbyy	y sway:	No	Span:	1
$L_{comp\ bot}$ (ft):	N/A	z sway:	No		
L_{torque} (ft):	N/A	Function:	Lateral		
		Seismic DR:	None		

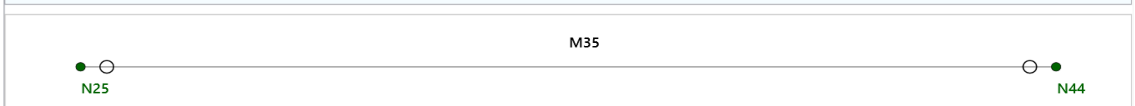


Figure 15: Steel beam design

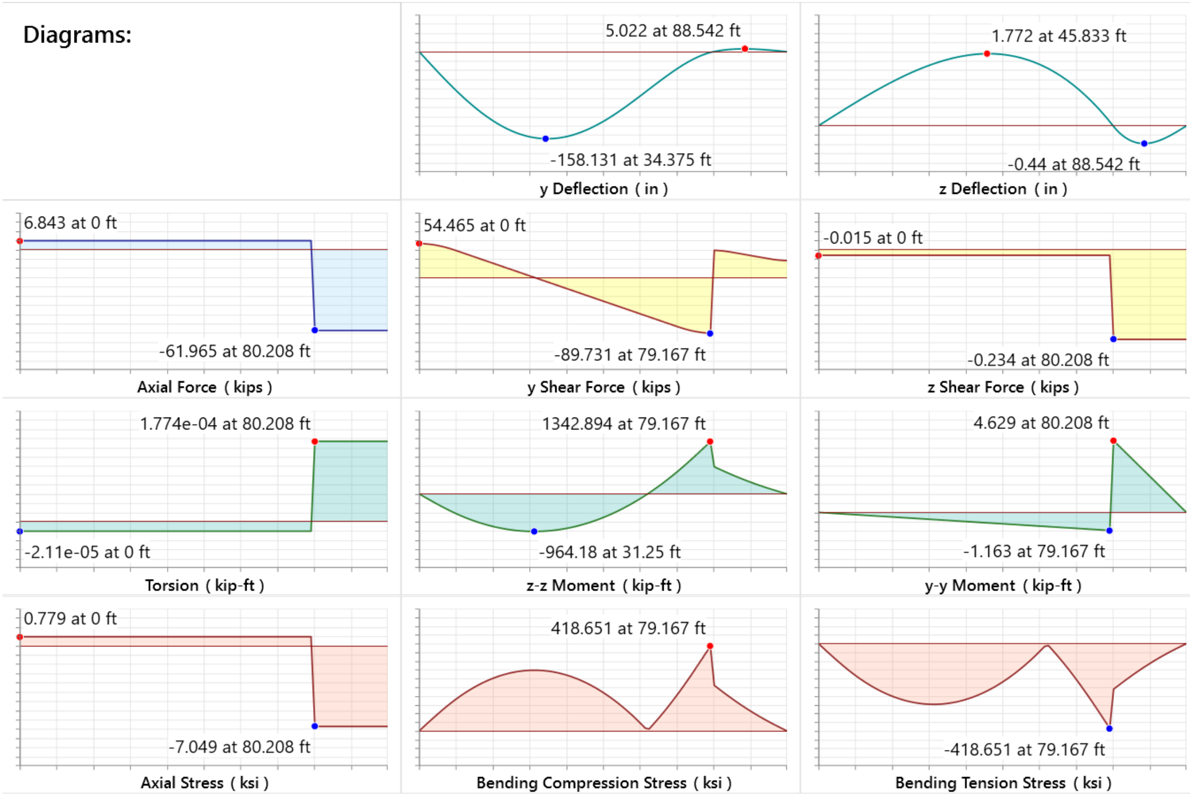
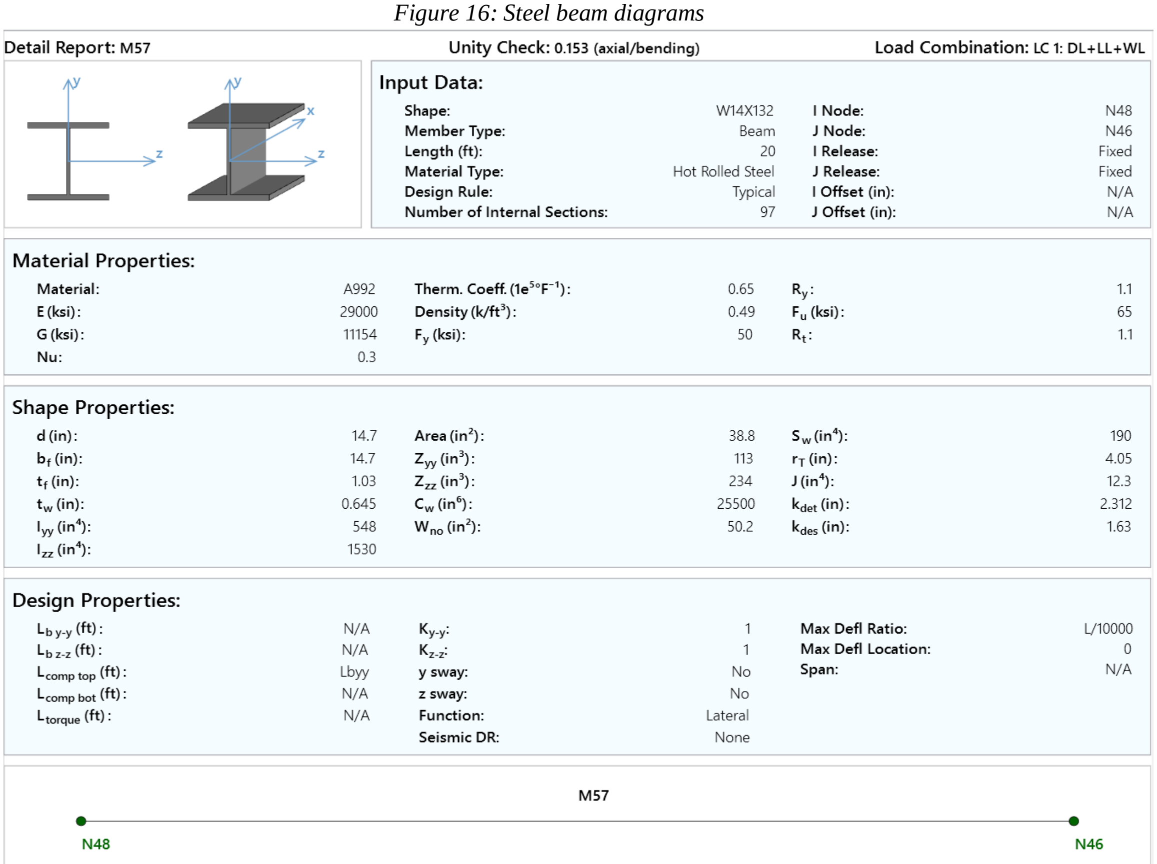


Figure 16: Steel beam diagrams



Detail Report: M57 — Unity Check: 0.153 (axial/bending) — Load Combination: LC 1: DL+LL+WL

Input Data:

Shape:	W14X132	I Node:	N48
Member Type:	Beam	J Node:	N46
Length (ft):	20	I Release:	Fixed
Material Type:	Hot Rolled Steel	J Release:	Fixed
Design Rule:	Typical	I Offset (in):	N/A
Number of Internal Sections:	97	J Offset (in):	N/A

Material Properties:

Material:	A992	Therm. Coeff. ($1e^{5}$°F^{-1}):	0.65	R_y:	1.1
E (ksi):	29000	Density (k/ft^3):	0.49	F_u (ksi):	65
G (ksi):	11154	F_y (ksi):	50	R_t:	1.1
Nu:	0.3				

Shape Properties:

d (in):	14.7	Area (in^2):	38.8	S_w (in^4):	190
b_f (in):	14.7	Z_{yy} (in^3):	113	r_T (in):	4.05
t_f (in):	1.03	Z_{zz} (in^3):	234	J (in^4):	12.3
t_w (in):	0.645	C_w (in^6):	25500	k_{det} (in):	2.312
I_{yy} (in^4):	548	W_{no} (in^2):	50.2	k_{des} (in):	1.63
I_{zz} (in^4):	1530				

Design Properties:

$L_{b\ y\text{-}y}$ (ft):	N/A	$K_{y\text{-}y}$:	1	Max Defl Ratio:	L/10000
$L_{b\ z\text{-}z}$ (ft):	N/A	$K_{z\text{-}z}$:	1	Max Defl Location:	0
$L_{comp\ top}$ (ft):	Lbyy	y sway:	No	Span:	N/A
$L_{comp\ bot}$ (ft):	N/A	z sway:	No		
L_{torque} (ft):	N/A	Function:	Lateral		
		Seismic DR:	None		

Figure 17: Steel girder design

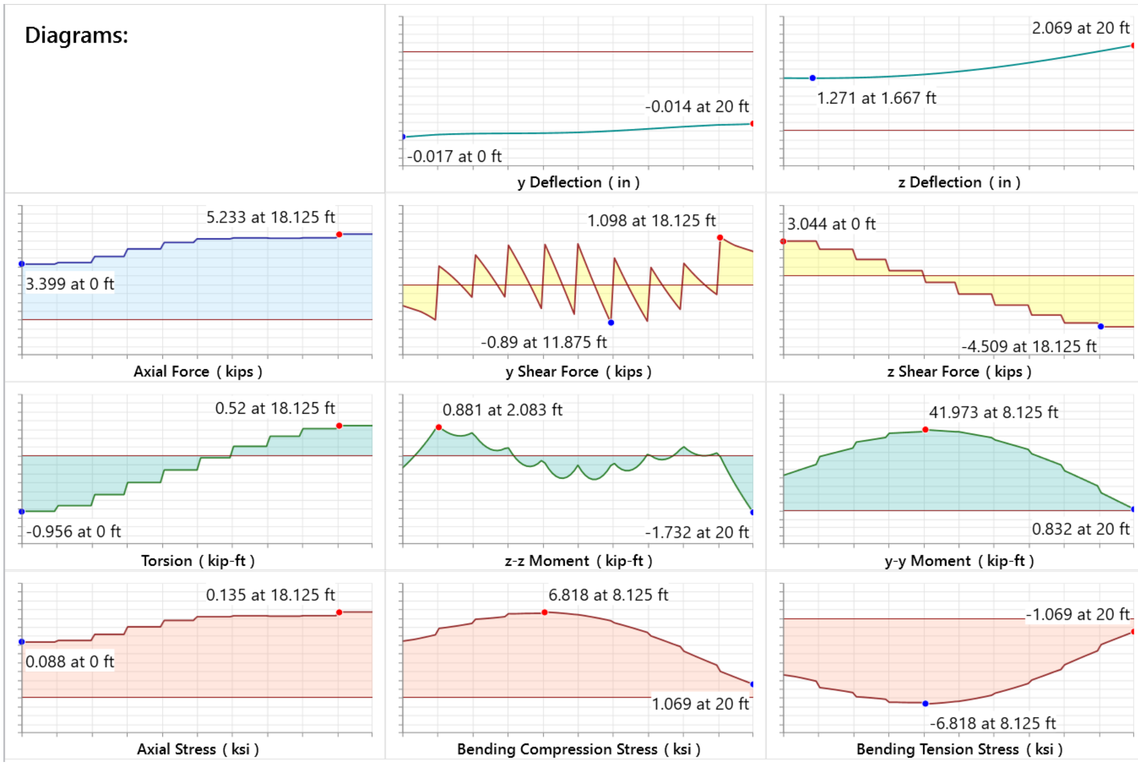


Figure 18: Steel girder diagrams

3. Concrete Design

The third structure that was designed was made from Concrete with 25in x 25in thick concrete columns, 13in x 13in thick concrete beams and 10in x 10in thick concrete girders, all the concrete was made from 3000NW concrete. Between the columns 18in thick concrete walls were placed which passed all the design tests. In the figures below an analysis of each member can be seen of how the members act when a force is placed on them, and the concrete structure looks and where the forces were placed. This structure made from concrete deflects the least out of the three as can be seen by all of the diagrams for each element. The entire structure would be stable if it would be created out of steel so this would be a suitable design.

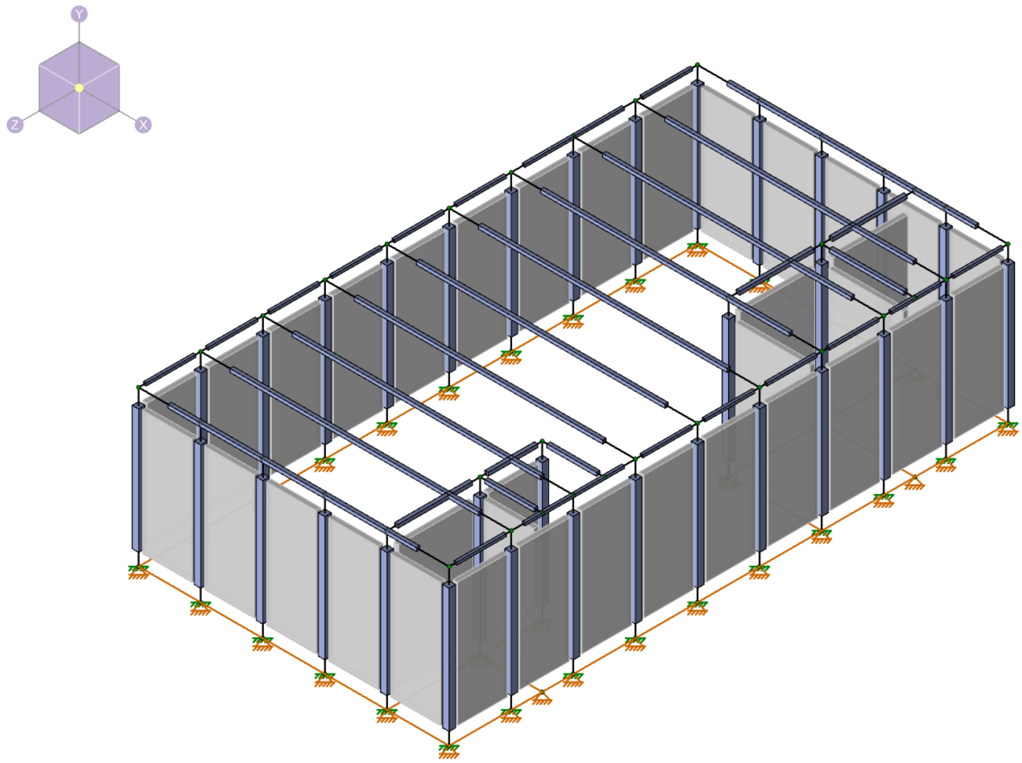


Figure 19: Concrete structure

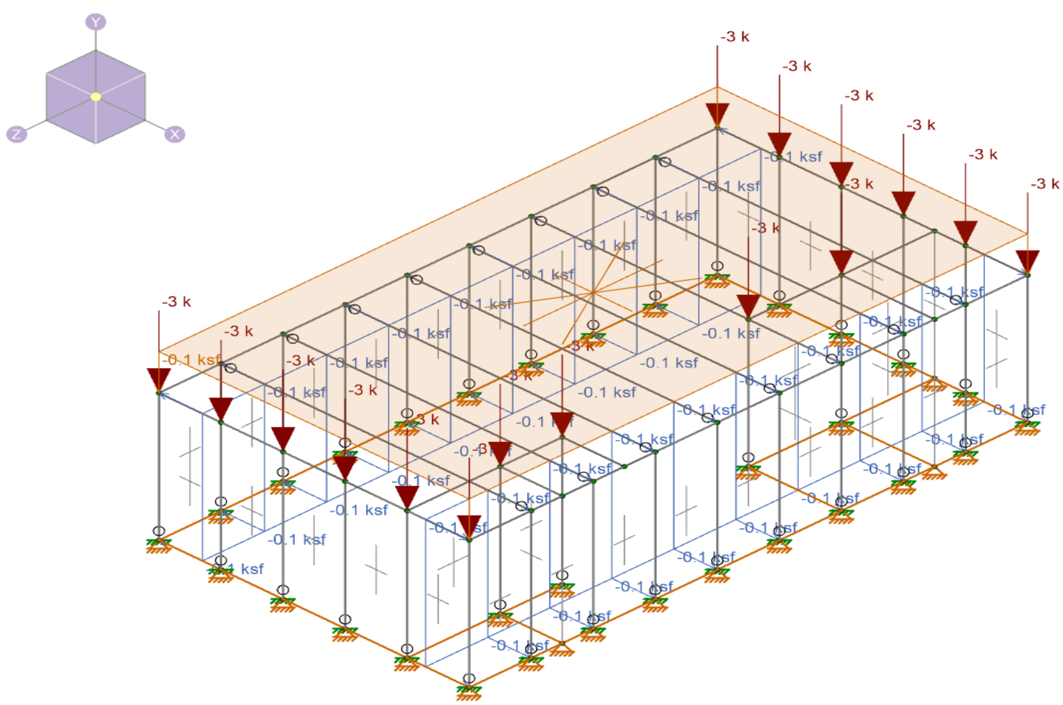
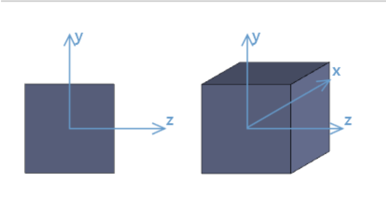


Figure 20: Loads applied to concrete structure



Input Data:

Shape:	CRECT25X25	I Node:	N37
Member Type:	Column	J Node:	N38
Length (ft):	50	I Release:	BenPIN
Material Type:	Concrete	J Release:	Fixed
Design Rule:	Typical	I Offset (in):	N/A
Number of Internal Sections:	5	J Offset (in):	N/A
Design Code:	ACI 318-19		

Material Properties:

Material:	Conc3000NW	Therm. Coeff. $(1e^{5}°F^{-1})$:	0.6	Lambda:	1
E (ksi):	3156	Density (k/ft^3):	0.145	Flex Steel (ksi):	60
G (ksi):	1372	f'c (ksi):	3	Shear Steel (ksi):	60
Nu:	0.15				

Shape Properties:

D (in):	25	W (in):	25

Design Properties:

$C_{m\ y\text{-}y}$:	N/A	Concrete Stress Block:	Rectangular	Flex Rebar Set:	ASTM A615
$C_{m\ z\text{-}z}$:	N/A	Cracked Sections Used:	Yes	Shear Rebar Set:	ASTM A615
$K_{y\text{-}y}$:	1	Cracked "I" Factor:	0.7	Top Cover (in):	1.5
$K_{z\text{-}z}$:	1	Effective "I" (in^4):	22786.458	Bottom Cover (in):	1.5
y sway:	No	Effective "I" (Service) (in^4):	32584.635	Side Cover (in):	1.5
z sway:	No			Legs/Stirrup:	2

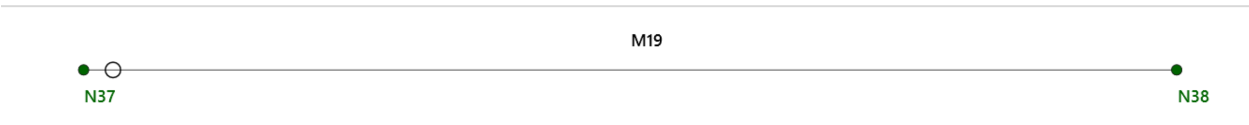


Figure 21: Concrete column design

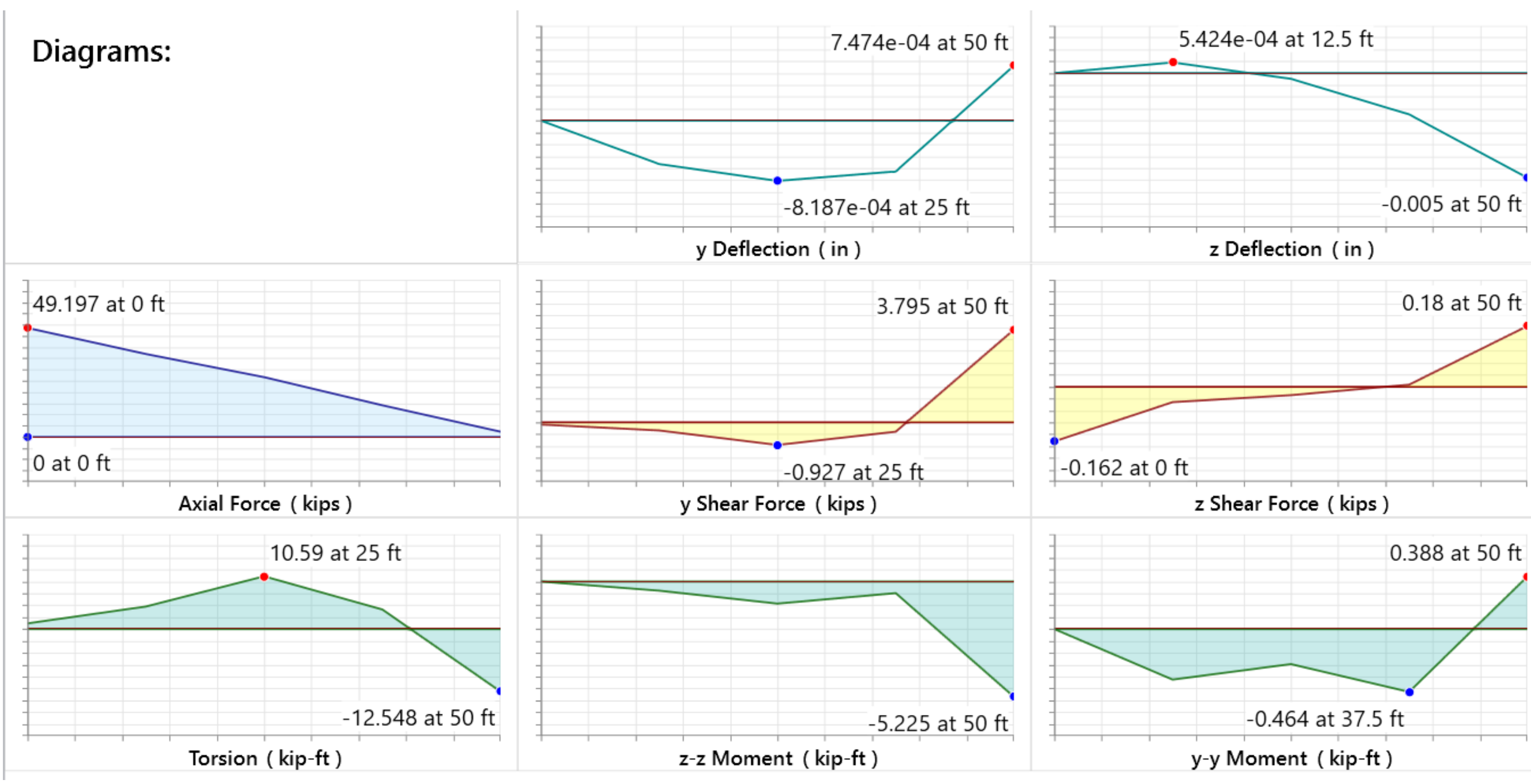
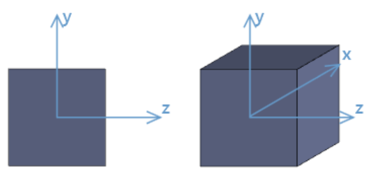


Figure 22: Concrete column diagrams



Input Data:

Shape:	CRECT13X13	**I Node:**	N44
Member Type:	Beam	**J Node:**	N26
Length (ft):	100	**I Release:**	BenPIN
Material Type:	Concrete	**J Release:**	BenPIN
Design Rule:	Typical	**I Offset (in):**	N/A
Number of Internal Sections:	5	**J Offset (in):**	N/A
Design Code:	ACI 318-19		

Material Properties:

Material:	Conc3000NW	**Therm. Coeff. $(1e^{5}{}^{\circ}F^{-1})$:**	0.6	**Lambda:**	1
E (ksi):	3156	**Density (k/ft^{3}):**	0.145	**Flex Steel (ksi):**	60
G (ksi):	1372	**f'c (ksi):**	3	**Shear Steel (ksi):**	60
Nu:	0.15				

Shape Properties:

D (in):	13	**W (in):**	13

Design Properties:

B-eff Left (in):	N/A	**Concrete Stress Block:**	Rectangular	**Flex Rebar Set:**	ASTM A615
B-eff Right (in):	N/A	**Cracked Sections Used:**	Yes	**Shear Rebar Set:**	ASTM A615
Slab Thk Left (in):	N/A	**Cracked "I" Factor:**	0.35	**Top Cover (in):**	1.5
Slab Thk Right (in):	N/A	**Effective "I" (in^{4}):**	833.029	**Bottom Cover (in):**	1.5
		Effective "I" (Service) (in^{4}):	1191.232	**Side Cover (in):**	1.5
				Legs/Stirrup:	2

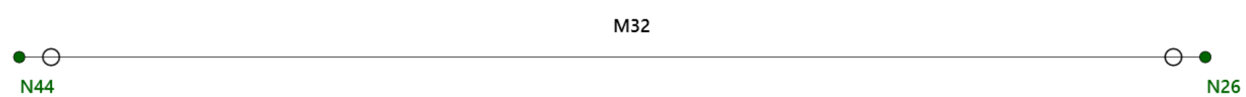


Figure 23: Concrete beam design

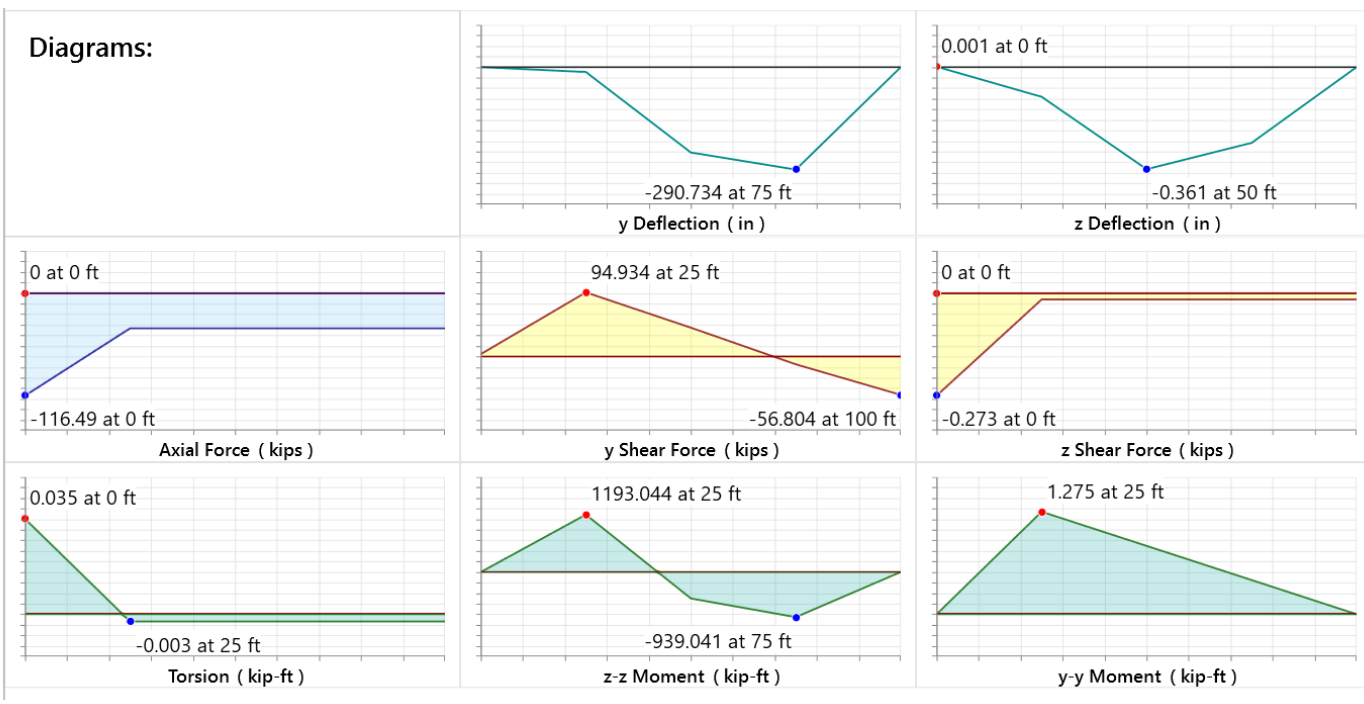
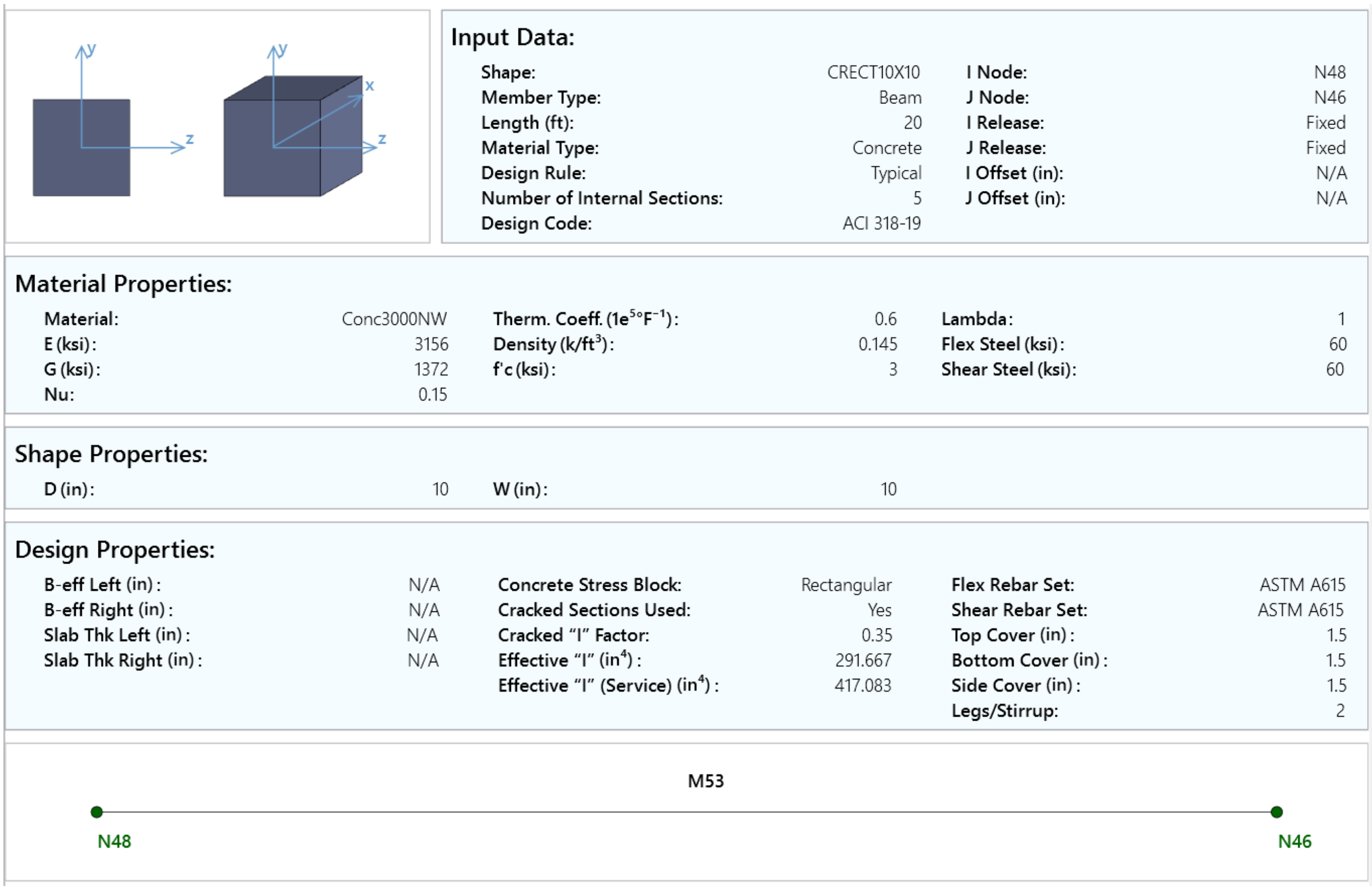


Figure 24: Concrete beam diagrams



Input Data:

Shape:	CRECT10X10	I Node:	N48
Member Type:	Beam	J Node:	N46
Length (ft):	20	I Release:	Fixed
Material Type:	Concrete	J Release:	Fixed
Design Rule:	Typical	I Offset (in):	N/A
Number of Internal Sections:	5	J Offset (in):	N/A
Design Code:	ACI 318-19		

Material Properties:

Material:	Conc3000NW	Therm. Coeff. ($1e^{5}\,°F^{-1}$):	0.6	Lambda:	1
E (ksi):	3156	Density (k/ft^3):	0.145	Flex Steel (ksi):	60
G (ksi):	1372	f'c (ksi):	3	Shear Steel (ksi):	60
Nu:	0.15				

Shape Properties:

D (in):	10	W (in):	10

Design Properties:

B-eff Left (in):	N/A	Concrete Stress Block:	Rectangular	Flex Rebar Set:	ASTM A615
B-eff Right (in):	N/A	Cracked Sections Used:	Yes	Shear Rebar Set:	ASTM A615
Slab Thk Left (in):	N/A	Cracked "I" Factor:	0.35	Top Cover (in):	1.5
Slab Thk Right (in):	N/A	Effective "I" (in^4):	291.667	Bottom Cover (in):	1.5
		Effective "I" (Service) (in^4):	417.083	Side Cover (in):	1.5
				Legs/Stirrup:	2

Figure 25: Concrete girder design

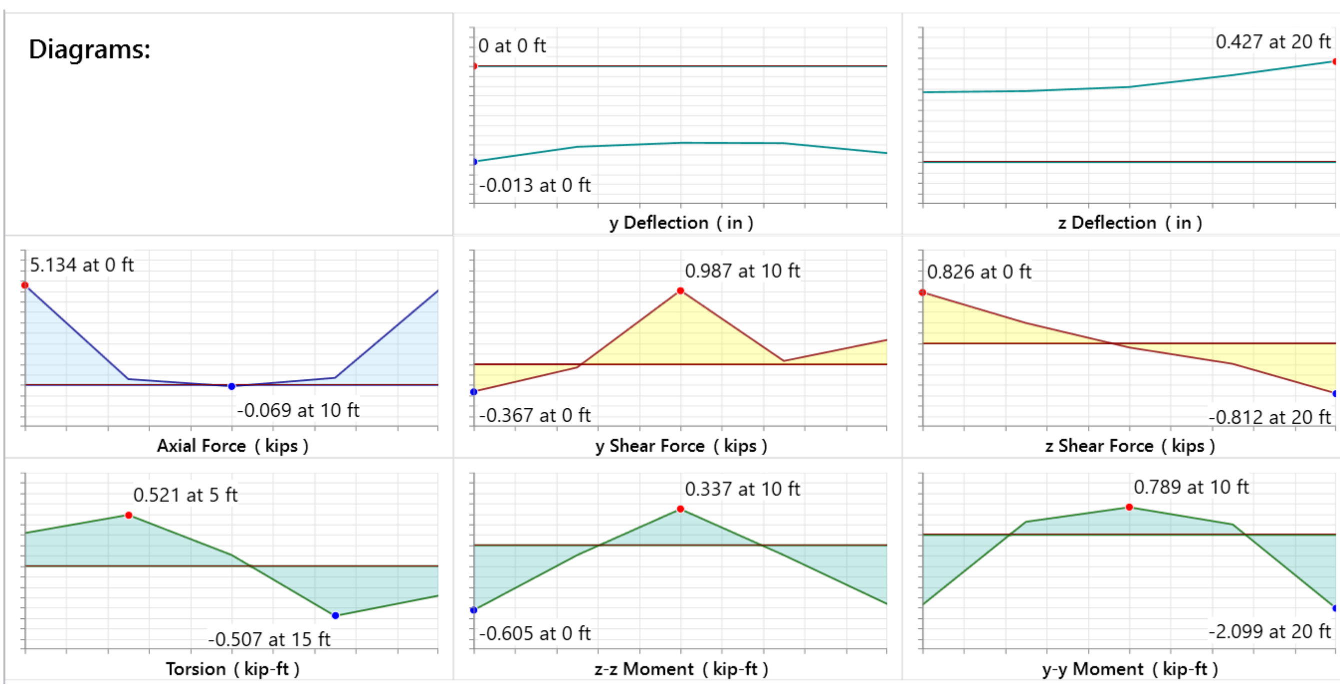


Figure 26: Concrete girder diagrams

4. Cost Analysis

4.1 Wood Design

The prices for the wood pieces are from Lowe's [1] where the price was multiplied by the length of the required wood pieces. The cost of 2x8 per foot was $1.09, the cost of 20x20 was $19.5 per foot, the cost of 2x6 was $0.885 per foot, the cost of 4x10 was $8.70 per foot and for 6x8 the cost was $12.6 per foot. The total cost for the wood structure equaled to $54367 which was by far the cheapest for any of the three structures. Since it is made completely out of wood it might also not be the strongest of structures and therefore might need to be reinforced which would increase the price of the final structure.

Table 1: Wood structure cost analysis

wood	Size	Pieces	Length (ft)	Price
Douglas fir	2x8	140	5000	$5457
Douglas fir	20x20	32	1600	$31200
Douglas fir	2x6	70	2500	$2212
Douglas fir	4x10	17	1260	$10962
Douglas fir	6x8	18	360	$4536
Total		304	17560	$54367

4.2 Steel Design

According to Midwest steel and aluminum [2] the price for one foot of W12x30 is $58.92, the price for one foot of W14x132 is $108.73 and the price for one foot of W36x652 is $300. The total cost for the structure made completely out of steel the total cost would be $589367 making it the most expensive of the three structures. The price of the structure could be reduced if a different material or size was used for the columns making the entire structure more affordable. The cost breakdown of the entire structure can be seen in table 2 below where all parts of structures cost can be seen.

Table 2: Steel structure cost analysis

Hot rolled steel	Size	Pieces	Length (ft)	Price
A992	W12x30	17	1180	$69525
A992	W14x132	18	360	$39142
A992	W36x652	32	1600	$480700
Total		67	3140	$589367

4.3 Concrete Design

According to concrete network [3] for a yard of concrete is about $125 however there can be other fees or the region the concrete is needed can change the price. For this price the $125 estimate has been used. Making the structure out of concrete would make the final cost $300136 which would be the second most expensive out of the wood, steel, and concrete options. The piece of the structure that adds the most cost on is the concrete walls, since there is a large area for them to cover. If the walls could be replaced with a different material, it would make the structure more affordable.

Table 3: Concrete structure cost analysis

Concrete	Size	Pieces	Length (yd's)	Price
Conc3000NW	10x10	16	9.3	$1162.5
Conc3000NW	13x13	17	51.3	$6412.5
Conc3000NW	25x25	32	257.2	$32150
Conc300NW	walls	35	2083.3	$260412
Total		100	2401.1	$300136

Summary

The project was a success as three structures were created one out of wood, one out of steel and one out of concrete and all three of them are stable and can be constructed. With steel being the most expensive of the three at $589367 followed by the concrete structure at $300136 and the cheapest of the three being the wood structure at $54367. All three of the structures could become cheaper or more expensive if certain modifications are made that could greatly benefit each structure by replacing certain parts with other materials. All three structures have deflection diagrams showing how they react under the forces they were placed with wood being the weakest of the three materials and therefore deflecting the most and concrete being the strongest material and deflecting the least. In terms of the best option, it would be concrete if one looks at affordability and its ability to resist deflection.

References

[1] Reliabilt 2-in x 8-in x 12-ft douglas fir . Lowes. (n.d.). Retrieved November 27, 2021, from https://www.lowes.com/pd/Top-Choice-2-in-x-8-in-x-12-ft-Douglas-Fir-Lumber-Common-1-562-in-x-7-5-in-x-12-ft-Actual/1000009776.

[2] Hot Roll Steel I Beam. Midwest Steel & Aluminum. (n.d.). Retrieved November 27, 2021, from https://www.midweststeelsupply.com/store/hotrollsteelbeam.

[3] Concrete Network. (2021, July 26). *Concrete prices 2021 - how much does concrete cost?* The Concrete Network. Retrieved November 27, 2021, from https://www.concretenetwork.com/concrete-prices.html.