

**ME 460 Spring 2017
The Back-Up Linemen
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Problem Statement:

In order to enhance lineman's ability to generate leverage, a training tool is used to provide feedback as to when a lineman has crossed a horizontal plane set at a predetermined elevation. The tool in use today consists of a fabric plane that is stretched and fastened to a rectangular frame made of steel pipe. The fabric plane is a rectangle approximately 10 feet wide and 20 feet long. The frame that supports it has a leg at each corner that sits on the ground. The size of the fabric plane and the placement of the legs limit the effective blocking drill area to the size of the fabric plane. During blocking drills, the opposing linemen position themselves under the fabric plane and go at each other. Whenever either lineman rises up too much (reducing his leverage) he comes in contact with the fabric letting him know any advantage he had over his opponent is gone. The desired design would be capable of providing an effective blocking drill area 40'x10' or roughly twice the size of the existing tool. If supported by legs, the legs would be positioned so as to enhance the effective blocking drill area above the 40'x10' size. The goal is to remove the legs to maximize the blocking area and allow the entire offensive line to be under the feedback plane at once. The football coaches requested the new lineman chute be designed so that it could be stationary and anchored to the ground in a specified area on the football practice field.

Background:

The Physics of Football: Lineman Leverage

If you've ever been around the game of football, there's a good chance you've heard someone say "the lowest man wins" when talking about linemen. You may have also heard that defensive coaches preach "low tackles". It turns out that both sayings are backed up by physics. In fact, they both work using the same mechanical relationship: torque.

A torque, sometimes called a moment, is the outcome of a force being delivered outside of an object's center of mass. When a moment is applied to an object, it produces a rotation about the center of mass. For example, one person on a seesaw will simply drop their side of the seesaw to the ground, because their weight is the only outside force on the seesaw, and it rotates the object around the fixed center point. But if another person sits on the other end, their weight will work against the first person's, and with some assistance from person one's legs, together they can rotate the seesaw back and forth.

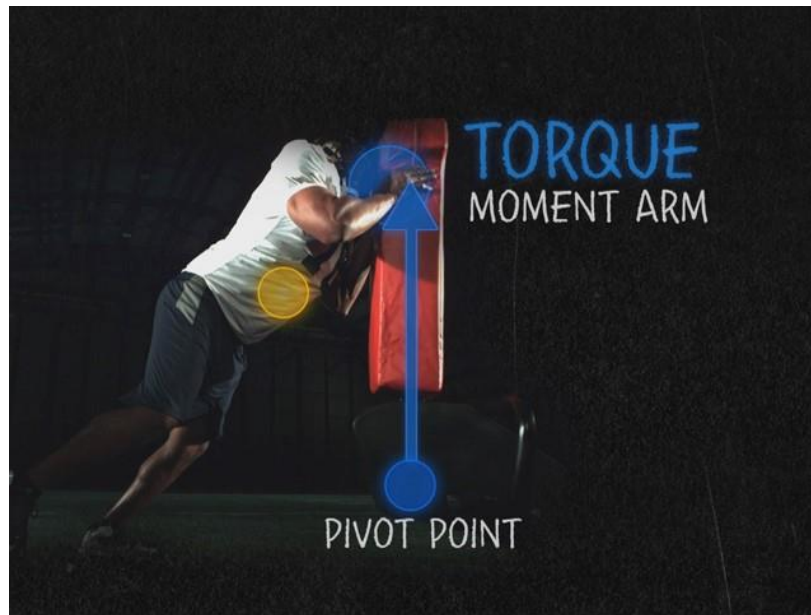


Figure 1: A Lineman pushing a football dummy

In Figure 1, an offensive lineman is shown pushing against the top of a football dummy. By pushing against the top of the dummy, he is giving himself the best leverage, i.e. producing the biggest moment. So why is it important for a lineman to stay low during the block? When a lineman gets low, his center of mass lowers with him. A man's center of mass is usually located around the navel, and by keeping the upper half of his body lower, he decreases the maximum distance of his body from his center of mass. This means that when two linemen run into each other and push on each other's chests, the lineman who is lower has created a mechanical advantage for himself. If he can produce the same force as his opponent, he will be producing a larger moment, and will win the matchup.

Similarly, if a defensive player is trying to tackle a running back, they are told to tackle the player low. When you deliver a force to the lower part of a player, you create a rotation around the running back's center of mass. If the defense tackles higher, they decrease the magnitude of the resulting moment, and may have to tackle the player using only their force. This action may simply push the running back sideways, and his practiced balance may allow him to break free. In conclusion, a well-coached team uses any mechanical advantage they can, and a lineman's low stance certainly creates one.

Present Designs in Use

Various leverage trainers, also called chutes, are on the market and are currently used by the football team. The primary mobility chute the football team uses is manufactured by Rogers Athletics and measures 20' by 10' at 230 pounds. The football team also has a number of 10' by 10' mobility chutes also made by Rogers that are 190 pounds and used less frequently. Features that both of these chutes include are 4 legs with casters for easy mobility, 40"-69" height adjustability via pins in legs, and mesh netting tops as non-scratch height barriers. The price of these chutes are \$1200 for the 10' by 10' and \$2065 for the 20' by 10'.

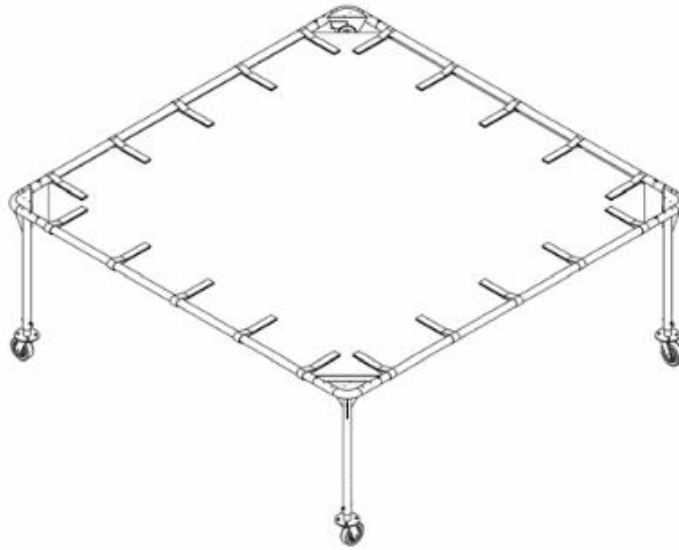


Figure 2: Rogers 10' by 10' Mobility Chute

As will be discussed a little later in the Approach section, another type of leverage trainer called a trap chute was also considered in our design process. This type of chute is typically longer and narrower in design when compared to mobility chutes. The football team also possesses a Rogers 24' by 5' trap chute that weighs 664 pounds that is used less frequently than the mobility chutes. This trap chute features two "T" shaped legs with casters on either short end of the structure and a two point 24" height adjustable plane with 90° optional angle adjustments. This model costs \$2470.

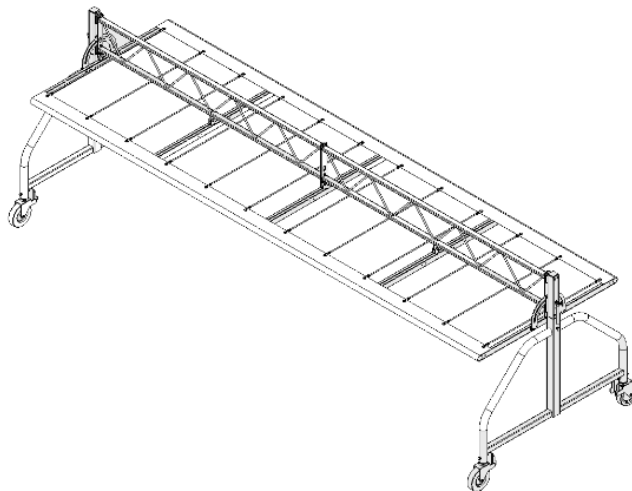


Figure 3: Rogers 24' by 5' Trap Chute

Approach and Methodology:

We began the Fall semester by creating a Gantt chart which would act as a guide throughout the semester to keep us on track with our project and to keep us accountable for any deadlines we needed to meet.

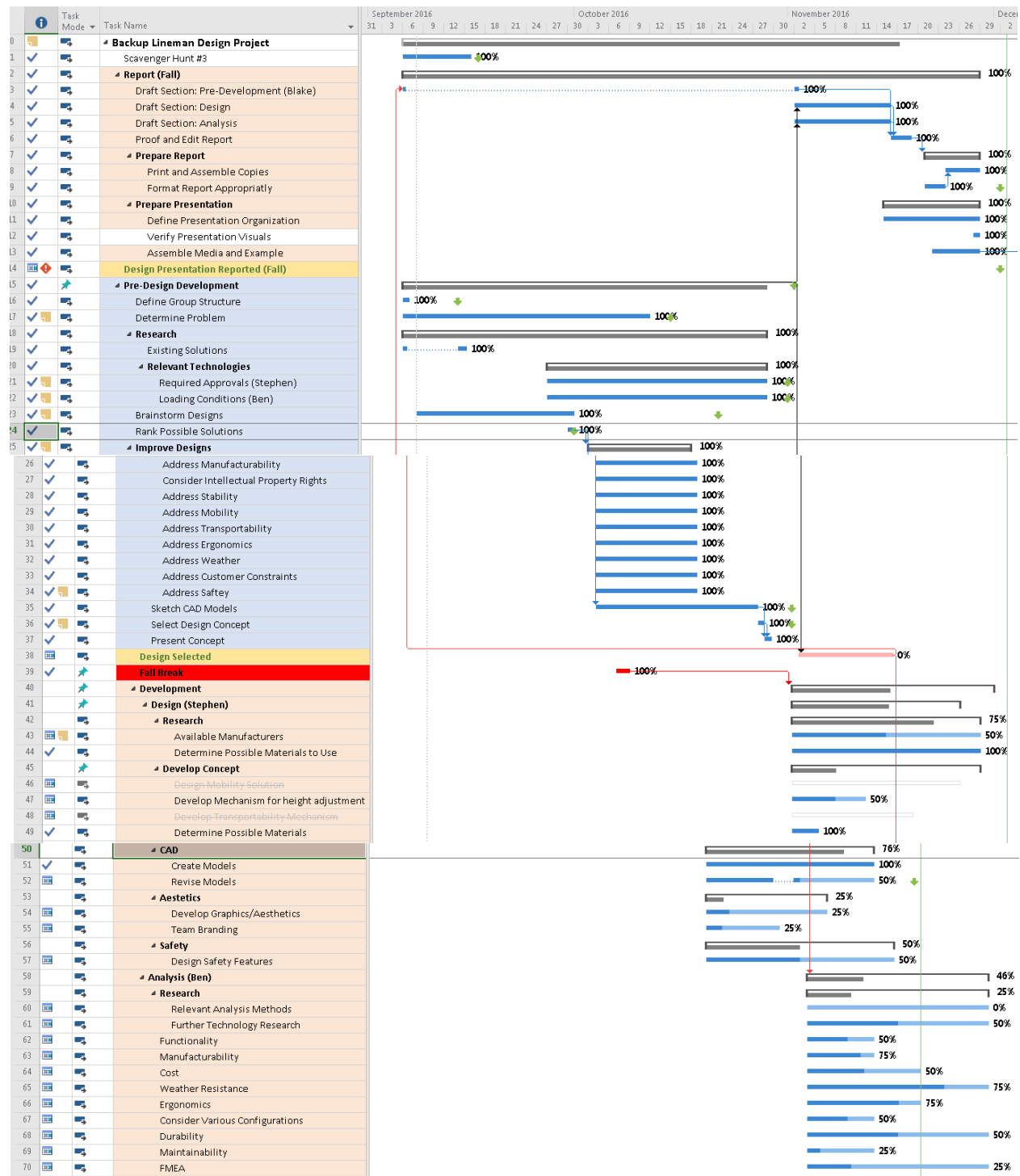


Figure 4: Fall Semester Gantt Chart

Our initial design approach focused on developing ideas to move the legs out of the way and to make the height adjustment more efficient. Some of the design sketches are shown in the Appendix A.

In designing and synthesizing concepts for this project we initially wanted to address concerns of the following: durability, overall cost, weather resistance, safety, ease of use by athletes, functionality and performance, weight, transportability, capacity to design, manufacturability, aesthetics, legal constraints, disposal, athlete capabilities, and ease of installation. Given these factors and the criteria of the problem statement we determined to design the tool in sections, that is separate concepts for the support structure, the feedback plane which athletes interface with, and the mechanism for adjusting the height.

Initially, for designs of the support structure there were two general concepts; the first being a truss that spans the major length of the feedback plane and is supported on either end by free-standing legs. The legs on either end could either be two separate legs or one legs with a T-shaped base. The second of the two designs is a cantilevered design; the structure consists of vertical posts positioned along the major length of the feedback plane. At the base of these posts there is a base that is either weighted or fixed, and at the top posts that extend out over the feedback plane.

Concepts for the feedback plane were quite varied; there were many types of designs that each focused on a different type of sensory feedback. For types of feedback that provides a sensory feedback by constructing a solid surface from either mesh, sheet metal, rubber, or some mass-loaded polymer sheeting. For visual and auditory means of feedback we considered an array of light beams or pressure switches which would trigger events of sirens and flashing lights to show that an athlete had exceeded the selected height restriction. Additionally, the concept of having a series of padded, cantilevered bars extending out over the area, such that when the athlete stands up the bars would rotate and show that the height had been exceeded in addition to the sensory feedback to the player.

In terms of the height adjustment mechanism there are multiple designs ranging from set of concentric tubes with an array of holes that would accept a pin to allow for the feedback to rest at some pre-selected interval of heights to a 3-bar mechanism that constrains the height depending upon the length of one of the mechanism links. For the array of holes, ideas of placing the extension in the vertical legs of the support structure were considered; alternatively, we considered make the adjustment at the connection point between the feedback plane and the overhead supporting structure. Some components that allow for a mechanism include a tensioned cable that when allowed to change lengths via a winch assembly, the height of the feedback plane would change, a power screw that when rotated allows for a changing length, and a rack and pinion which as a gear rotates (pinion) the rotational motion is translated into to linear movement of the rack.

In order to determine which designs were the best, we compared each component to a datum design using a Pugh Chart. We assigned a plus one to a design that was better than the datum, a minus one to a design that was worse than the datum, and a zero if the design was the same as the datum. The designs were compared to the datum for each of the criteria for success, and the scores for each design were summed. The Pugh charts can be seen in Figure 5.

Pugh Chart : Height Adjustment										
		Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7	Design 8	Design 9
Durability	D	0	0	0	0	I	0	I	0	0
Cost	A	0	0	-1	-1	N	-1	N	-1	-1
Weather Resistance	T	0	0	1	-1	A	-1	A	-1	0
Ease of Use	U	1	1	0	1	C	1	C	1	1
Functionality	M	0	0	0	1	T	1	T	1	1
Weight		0	1	0	0	I	-1	I	0	0
Ease of Design		0	0	-1	-1	E	-1	E	-1	-1
Aesthetic		0	0	0	1	I	1	I	0	1
Safety		0	0	0	0	N	0	N	0	0
Marketing		0	0	0	0	A	0	A	0	0
Legal	D	0	0	0	0	C	0	C	0	0
Manufacturability	A	0	0	0	0	T	0	T	-1	0
Disposal	T	0	0	0	0	I	0	I	0	0
Customer	U	0	0	0	1	V	1	V	1	0
Ease of Assembly	M	1	1	1	1	E	1	E	1	1
Total		2	3	0	2	0	1	0	0	2
Datum Description	Four individual legs extend from structure and is supported by an array of holes with inserted pin.									
Design 1 Description	Two extending legs from structure and an array of holes, stopped by inserting pin.									
Design 2 Description	Two connections hang down from frame to feedback plane.									
Design 3 Description	Two extending legs from structure consist of telescoping members that provide support from locking, cam-lever mechanism. * Research *									
Design 4 Description	A cable is attached at every corner of feedback plane and are all connected to some pulley/tensioning mechanism which dependent upon force changes feedback plane height.									
Inactive Design 5 Description	Two extending legs have pneumatic /hydraulic actuators similar to pallet jacks with foot lever									
Design 6 Description	Two extending legs have a mechanical crank attached to rack and pinion allowing structure to travel up and down.									
Design 7 Description	Two extending legs form a scissor crank mechanisms allowing structure to travel up and down.									
Design 8 Description	Two extending legs are fitted with a thread and fixed nut so when the leg is rotated the structure can travel up and down.									
Design 9 Description	Two connections hang down from feedback plane with mechanism connected to operate both supports simultaneously.									

Figure 5a: Pugh Chart for Height Adjustment

Pugh Chart : Feedback Plane								
		Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7
Durability	D	0	0	1	1	0	1	I
Cost	A	0	0	0	-1	-1	0	N
Weather Resistance	T	0	0	0	0	-1	1	A
Ease of Use	U	1	1	1	1	0	0	C
Functionality	M	0	0	1	1	1	1	T
Weight		0	0	0	-1	0	-1	I
Ease of Design		0	0	0	-1	-1	0	E
Aesthetic		0	1	0	1	0	1	I
Safety		0	0	0	0	0	0	N
Marketing		0	0	0	0	0	0	A
Legal	D	0	0	0	0	0	0	C
Manufacturability	A	0	0	0	-1	-1	-1	T
Disposal	T	0	0	1	-1	-1	0	I
Customer	U	0	0	0	0	0	0	V
Ease of Assembly	M	1	1	-1	-1	-1	-1	E
Total		1	2	3	-2	-5	1	0
Datum Description	Solid, rectangular net that is stretched between structure frame.							
Design 1 Description	Solid, rectangular net is stretched in a separate frame which is supported by the structure by some connections.							
Design 2 Description	Solid, elliptical net is stretched in a separate frame which is supported by the structure by some connections.							
Design 3 Description	An array of multiple nets are stretched in "lanes" in a separate frame which is supported by the structure by some connections.							
Design 4 Description	An array of multiple panels consisting of some solid material which acts as a switch for when closed triggers a visual, audio alarm per the panel triggered.							
Design 5 Description	Solid rectangular net that is stret in a separate frame with an array of strain gauges attached to tensioned parts of net. When strain increases a visual, audio alarm per the nearest strain gauge is triggered.							
Design 6 Description	An array of flexible bars are cantilevered across plane.							
Design 7 Description	An array of planar laser beams are projected at a set height to an array of sensor, if a beam is broken a visual, audio alarm is triggered.							

Figure 5b: Pugh Chart for Feedback Plane

	Pugh Chart : Structure									
		Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7	Design 8	Design 9
Durability	D	0	1	0	0	0	-1	1	0	0
Cost	A	0	0	0	-1	0	0	0	0	0
Weather Resistance	T	0	0	0	-1	0	-1	0	0	0
Ease of Use	U	0	0	0	0	0	0	0	0	1
Functionality	M	-1	0	1	1	1	0	0	1	1
Ease of Design		-1	-1	-1	-1	0	-1	-1	0	1
Aesthetic		1	1	1	1	0	1	1	0	1
Safety		0	0	0	0	0	0	0	0	0
Marketing		0	0	0	0	0	0	0	0	0
Legal	D	0	0	0	0	0	0	0	0	0
Manufacturability	A	-1	-1	-1	0	0	-1	-1	0	0
Disposal	T	0	0	0	0	0	0	0	0	0
Customer	U	0	0	0	0	0	0	0	0	0
Ease of Assembly	M	1	1	1	-1	1	1	1	1	-1
Total		-1	1	1	-2	2	-2	1	2	3
Datum Description	Rectangular frame with an extending leg at each corner.									
Design 1 Description	A tripod frame consisting of two arches meeting at the center of structure above feedback plane.									
Design 2 Description	A double arch frame simply supporting a beam above the feedback plane connecting both arches on both ends of feedback plane.									
Design 3 Description	Single arch support transverses feedback plane; the ends of the arch create a fixed, T-connection at the feet. The feedback plane is suspended below structure.									
Design 4 Description	An accordion type, rectangular structure is pinned together at each folding panel. When not in use the panels can be folded together. Top is to be light and base is to be heavy.									
Design 5 Description	A rectangular frame with two extending legs at either end. The feed back plane is suspended from a transversing beam. One side of the plane has connections allowing training									
Design 6 Description	A double arch frame transverses the feedback plane with the end of each arch creating a foot. The feedback plane has an array of ledges to simply support a separate frame which contains the feedback plane; similar to a bench for a set of free gym weights.									
Design 7 Description	A double arch frame transverses the feedback plane with the end of each arch creating a foot. The feedback plane is suspending by connections on either ends of the arches, simply supporting the feedback plane.									
Design 8 Description	Single square support traverse feedback plane; the ends of the frame create a fixed, T-connection at the feet. The feedback plane is suspended below structure.									
Design 9 Description	A cantilevered overhead support that suspends the feedback plane below structure.									

Figure 5c: Pugh Chart for Structure

Selected Concept Design:

After our Pugh Chart analysis was complete, it was decided that the best design option included a cantilevered overhead support that suspends the feedback plane from above. Figure 6 shows the CAD model of our selected concept.

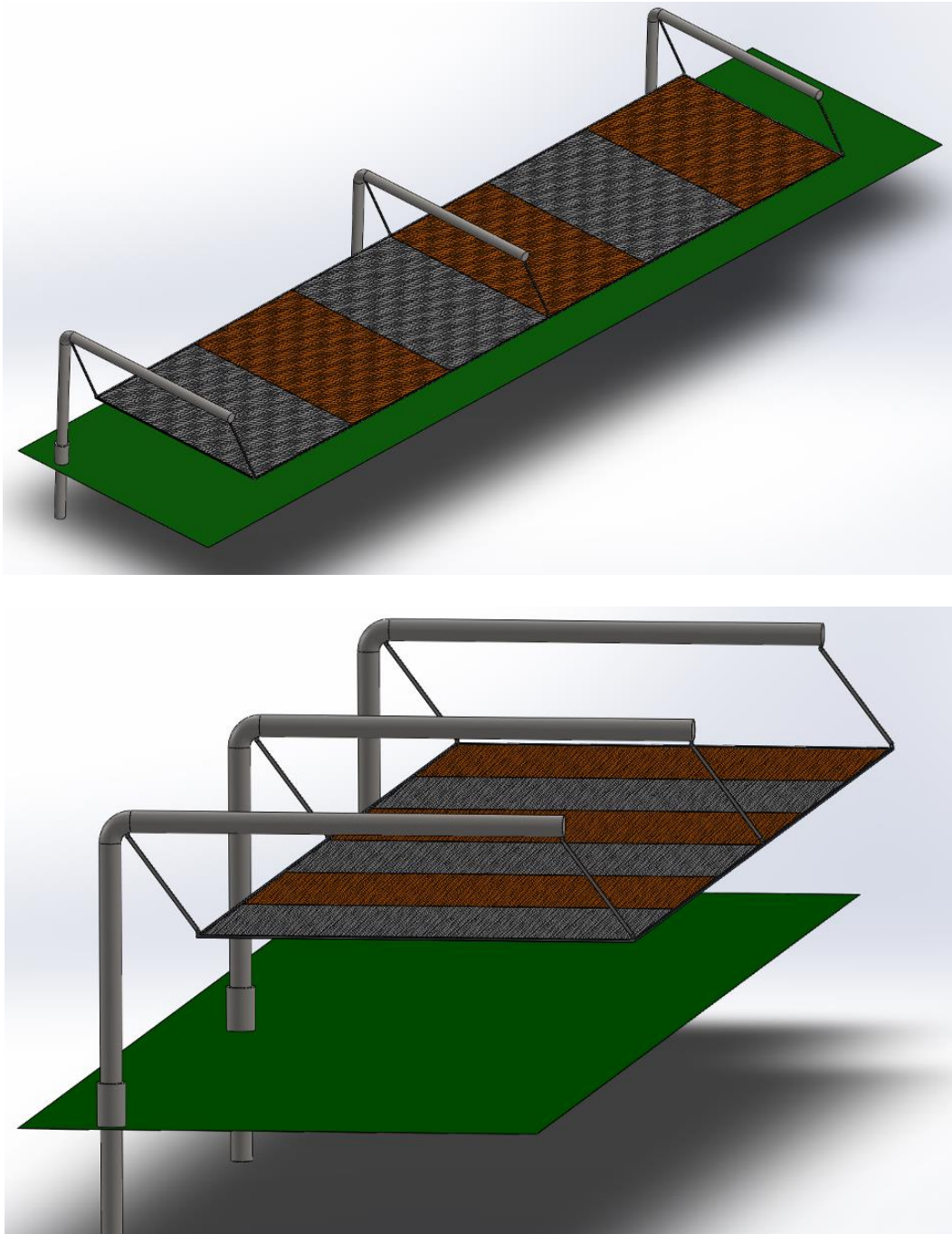


Figure 6: Selected Cantilever Design Concept

Initial Analysis:

Feedback Plane:

In determining the design of the feedback plane, the selected concept of the mesh lanes was analyzed on a basis that the mesh would span a length of 10' between the feedback plane framing, and have a width of 80" such that separate lanes to drill under would exist under the feedback plane. Based on existing use of the Rogers Athletics mesh and extensive use in the Marine construction industry — within these too similar applications the mesh selected could demonstrate similar weather resistance — a vinyl-covered, thermoplastic polyester was selected for analysis. Additionally, from suppliers such as McMaster-Carr a net made of such material could be sourced with a thickness of 0.016" and 60% fill, i.e. 60% of the area covered by the mesh would have a fiber covering it. With this in mind, a mass of about 2.50 kg, a second-moment of area, I , of $1.137 \times 10^{-11} \text{ m}^4$, and Young's Modulus, E , of 2.49 GPa was determined.

Further, the stress and deflection of the net was then determined using equations of superposition. To first see how much the net deflected under its own weight the following equation modeled the net's behavior assuming it is simply supported by the frame.

The resulting design would deflect at the center length a theoretical distance of 318.3 m which is impossible; it would simply fall off the frame. A further iteration was determined that the net would have to be placed into tension. Given that polyester is a polymer it is susceptible to the mechanism of creep — given a load over some time depending mainly on magnitude of load and operating temperature the polymer will rupture or fail. In the case of polyester with a maximum operating temperature of 125°F the design could survive about 100,000 hours (about 11.5 years) as long as the strain in the fiber is below 2.4%. Given this the net could be loaded in tension by about 11 N or 2.5 lbs. The stress in the net would come from the load of the tension through the net and shear forces of the net keeping itself from deflecting. The resulting max force in the net would then occur at the edges of the net with 55.09 MPa since the cross-sectional area is so small (Note the estimate yield point is 57.1 MPa for polyester), the deflection then decreases to 0.141 m or 5.6" at the center.

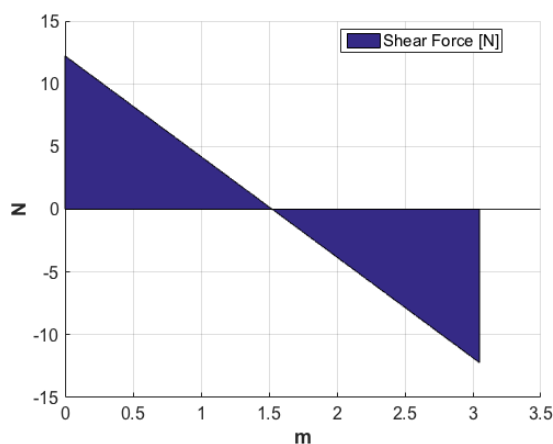


Figure 7a: Shear Stress in Net along length

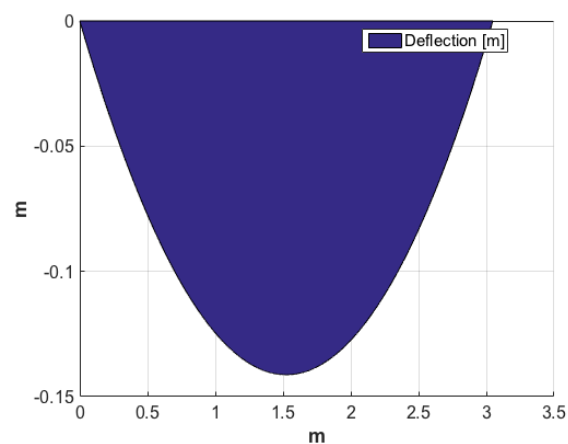


Figure 7b: Deflection of Net along length

This height can be further reduced by driving the tension up to 65 N or 15 lb in the net to a maximum of 4.1% strain; the design could then survive about 10,000 hours (about 1 year). The deflection however would reduce to 3" at the center.

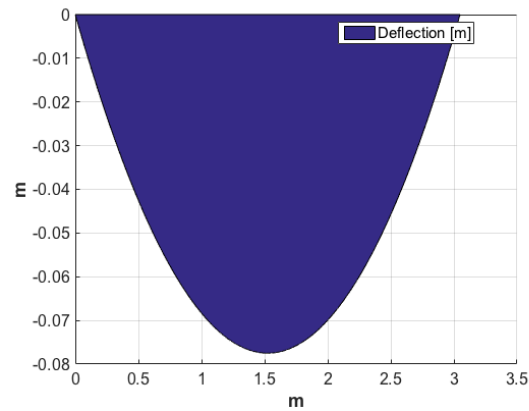


Figure 8: Deflection of Net along length

Due to the creep of the net this would change and drop over time the net would either have to be re-tensioned as the net elongates and drops, or add support that is not susceptible to the mechanism of creep and higher modulus of elasticity, i.e. steel cables. Under those terms the net could last as long as it is not deteriorated by weather or damaged by some other means not accounted for.

Analysis of Required Force to Push Feedback Plane:

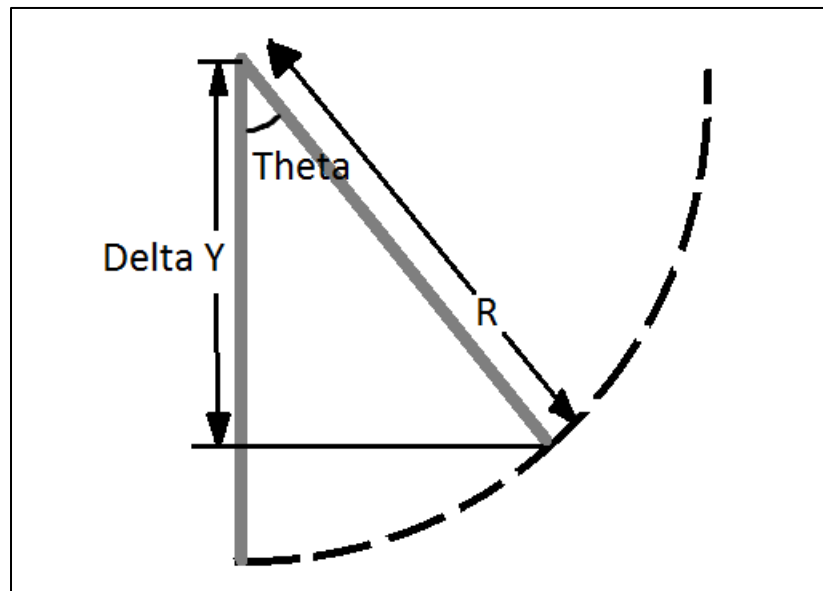


Figure 9: Arc with radius R and height Y from which theta is derived

If R is the length of the links connecting the feedback plane to the legs, θ is the angle of those links from their vertical position, and ΔY is the change in height of the feedback plane, then they are connected by the following relationships:

$$R - R * \cos(\theta) = \Delta Y$$

$$\theta = \cos^{-1}\left(1 - \frac{\Delta Y}{R}\right)$$

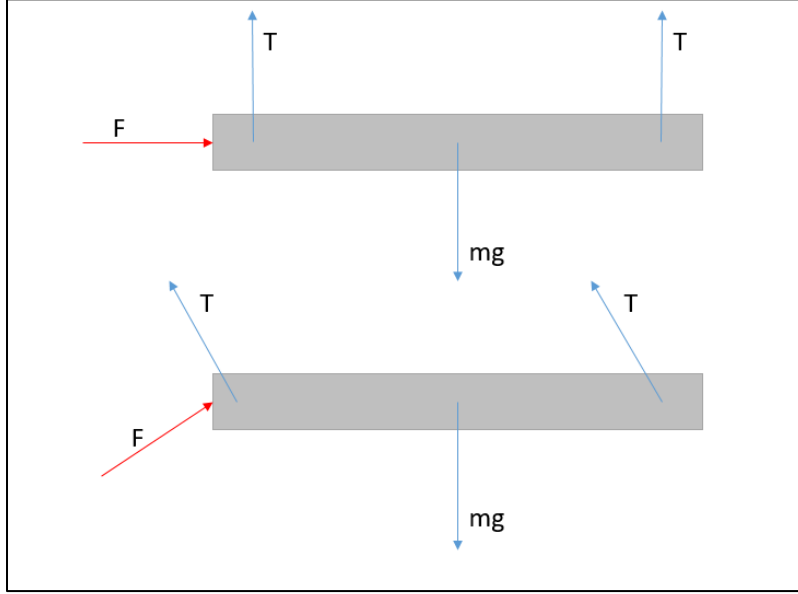


Figure 10: Free body diagram of feedback plane

A free body diagram of the feedback plane is shown in Figure 10 for two different positions: the connecting links in the vertical position, and the connecting links at an angle of θ from their vertical position. For the first position, the horizontal force F is equal to 0 pounds, because it doesn't require a force to keep the feedback plane at its natural resting position. The following analysis is done for the second position, where all values except (mg) will be dependent on the angle θ .

$$\sum F_x \xrightarrow{\text{yields}} F * \cos(\theta) = 2 * T * \sin(\theta) \xrightarrow{\text{yields}} F = 2 * T * \tan(\theta)$$

$$\sum F_y \xrightarrow{\text{yields}} F * \sin(\theta) + 2 * T * \cos(\theta) = 2 * T * \sin(\theta) * \cos(\theta) + 2 * T * \cos(\theta) = mg$$

$$T(\sin\theta \tan\theta + 2\cos\theta) = mg$$

$$T = \frac{mg}{2\sin\theta \tan\theta + 2\cos\theta}, F = 2 * T * \tan\theta = \frac{mg * \tan\theta}{\sin\theta \tan\theta + \cos\theta}$$

$$F = \frac{mg * \tan\theta}{\sin\theta \tan\theta + \cos\theta} = \frac{mg * \tan\theta}{\tan\theta(\sin\theta + \frac{(\cos\theta)^2}{\sin\theta})} = \frac{mg}{\frac{(\sin\theta)^2}{\sin\theta} + \frac{(\cos\theta)^2}{\sin\theta}} = \frac{mg * \sin\theta}{(\sin\theta)^2 + (\cos\theta)^2}$$

$$F = mg * \sin\theta$$

Table 1 shows various inputs, the outputted Θ values, and the outputted F values.

R (ft)	ΔY (ft)	Θ (degrees)	Mg (lbs)	F (lbs)
3	2	70.5	500	471
3	1	48.2	500	373
3	0.5	33.6	500	277
4	2	60	500	433
4	1	41.4	500	329
4	0.5	29.0	500	242

Table 1: Calculated forces at each angle theta

Analysis of Bending Stress on the Upper Leg Corner

Weight of Feedback Plane	$W = 500 \text{ lbs}$
Moment Arm Length (Maximum)	$X = 10 \text{ ft} = 120 \text{ in.}$
Thickness of Legs	$T = 4 \text{ in.}$
Number of Legs	$N = 4$
Max Moment on Each Leg Corner	$M = (W/N) * X = (500/4) * 120$ $= 15000 \text{ in-lbs}$
Second Moment of Area of Each Leg's Cross-Section	$I_x = (\pi/4) * (T/2)^4$ $= (\pi/4) * (4/2)^4$ $= 12.57 \text{ in.}^4$
Bending Stress	$\sigma = (M * (T/2)) / I_x$ $= (15000 * (4/2)) / 12.57$ $= 2386.7 \text{ psi}$
Yield Strength (T304 Stainless Steel)	$FY = 31200 \text{ psi}$
Factor of Safety	$FoS = (FY / \sigma) = (31200 / 2386.7)$ $= \mathbf{13.1}$

The Factor of Safety is a quantity that defines the factor that the current stress could be multiplied by to reach the Yield Strength of the structure material.

Spring Semester Gantt Chart:

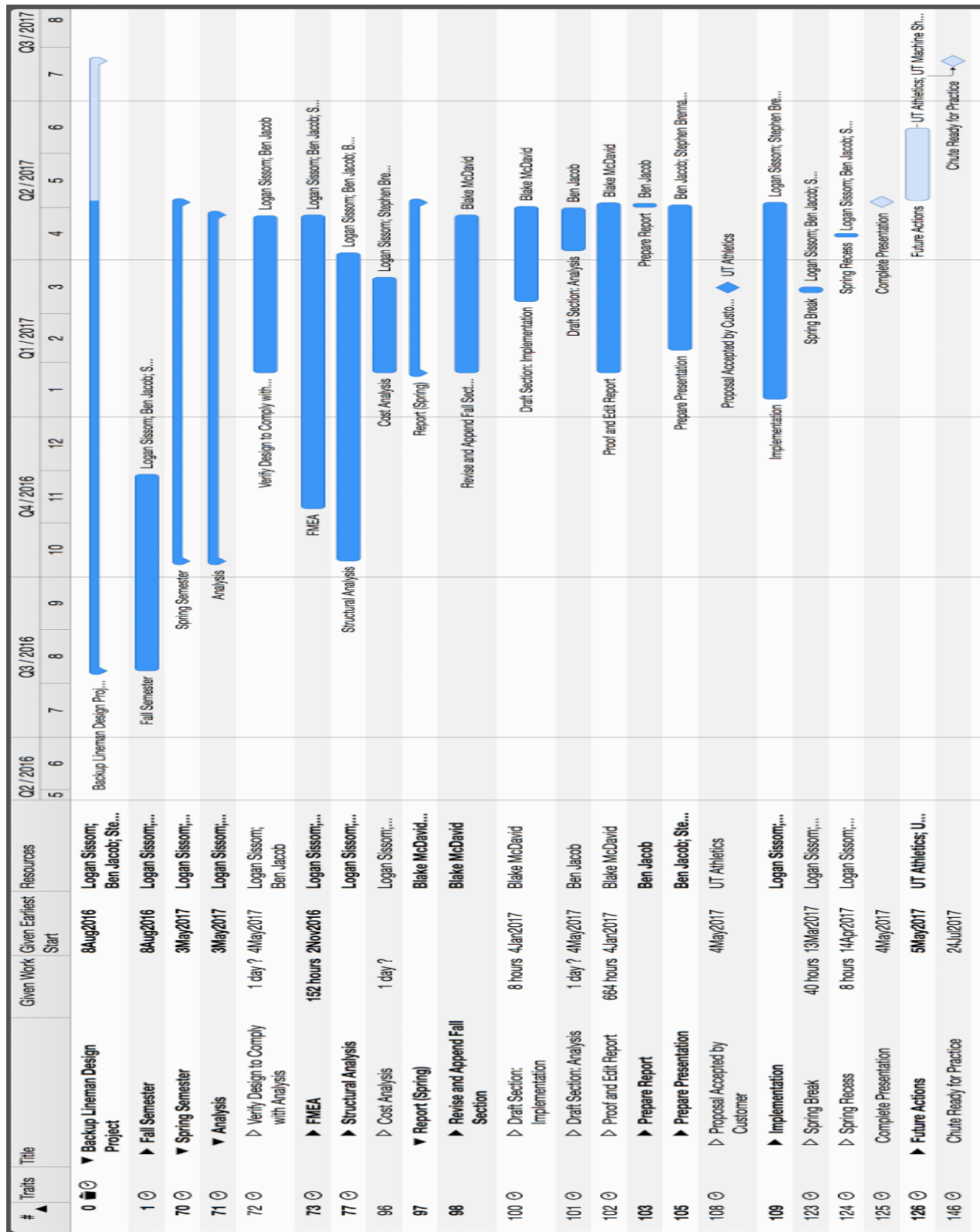


Figure 11: Spring semester Gantt chart

In-Depth Analysis:

Safety is a vital component of any design, but is especially important when the failure of that design could result directly in injuries. To prevent structural failure, many calculations were performed. In order to understand the importance of each calculation, a Failure Mode Effects Analysis (FMEA) was written. A summary of the FMEA is shown in Figure 12.

Ranking Scale										
	1	2	3	4	5	6	7	8	9	10
Severity	None	Very Minor	Minor	Very Low	Low	Moderate	High	Very High	Hazardous with warning	Hazardous without warning
Occurrence	Very Low	Low	Low	Moderate	Moderate	Moderate	High	High	High	Very High
Detection	Almost Certain	Very High	High	Moderately High	Moderate	Low	Very Low	Remote	Very Remote	Almost Impossible

Failure Mode & Effect Analysis Item Identification					
Item	Function	Potential Failure Mode	SEV	OCC	DET RPN
Support Structure Base	Anchors the entire structure	Base and Structure interface is broken	9	7	7 441
Feedback Plane Assembly	Signal when an athlete has moved outside the specified height range	Net rips	6	8	8 384
Height Adjustment System	Changes elevation of feedback plane.	Cable breaks	8	4	7 224
Support Structure	Holds feedback plane in place	Structure fails under load	9	7	3 189
Pulleys	Guide the cable from winch to feedback plane	Pulley fails - breaks off, disk stops rotating, etc	7	3	4 84
Connecting Rods	Connects feedback plane to support structure	Rods fail and no longer suspends feedback plane	9	2	3 54
Feedback Plane Assembly	Signal when an athlete has moved outside the specified height range	Suspension fails	9	2	2 36

Failure Action Item Identification						
Potential Failure Mode	Recommended Action	Responsibility and Target Completion Date	Action Taken	Updated SEV	Updated OCC	Updated DET RPN
Net rips	Reinforce and Reduce Stress concentrations	—	Replace Net under Manufacturer Warranty	5	5	8 200
Cable breaks	Reduce effects of corrosion	Design Team during Product Development	Implement Galvanized Cable and Hardware	8	4	4 128
Structure fails under load	Increase Number of Supports to Distribute the Load	Design Team during Product Development	Add Additional Center Leg to Two Support Legs	9	4	2 72
Base and Structure interface is broken	Add Reinforcement and Increase Factor of Safety.	Design Team during Product Development	FEA and Addition of Gusset Plates	9	3	2 54
Rods fail and no longer suspends feedback plane	Increase Reliability of Connecting Rods	Design Team during Product Development	Apply Redundant Connecting Rods	9	2	2 36
Pulley fails - breaks off, disk stops rotating, etc	Minimize Exposure to Failure Mechanisms	Design Team during Product Development	Increase Grade of Fastening Hardware, Mount Pulley with Sealed Bearings	7	3	1 21

Figure 12: Summary of FMEA performed on design

Below is a summary of the analysis calculations done for the project.

Feedback Plane – Bending (Deflection and Stress), Shear in the part interactions

Links – Tensile Stress, Shear Stress, Deflection

Support Legs – Bending (Deflection and Stress), Shear, Buckling, Compression, Stress Concentrations

Redundancy Brackets – Shear, Shear Tear-Out

Cable – Tensile Strength

Pulleys – Loads from Cable System were compared to part allowance

Winch – Loads from Cable system were compared to part allowance

Concrete Base – Concrete Base was sized based from knowledge of soil mechanics and concrete pier strength

Anchor Bolts – Axial Stress and Pull-Out Strength

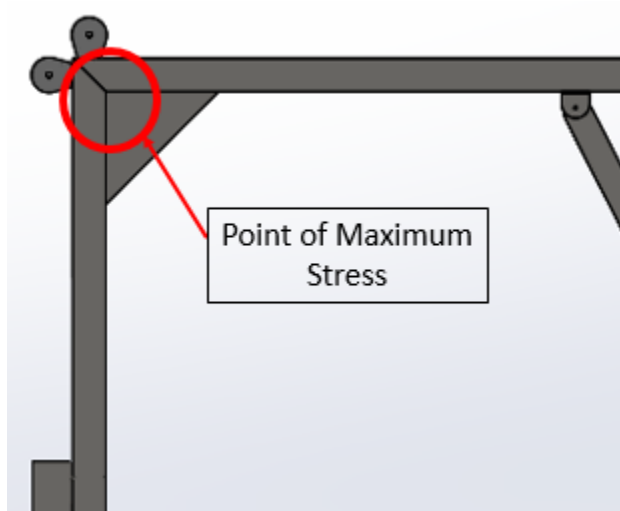
Brackets – Brackets were analyzed for strength in their respective loads

Fasteners – All fasteners were checked for strength in their respective load paths

Tolerance Stack-Up was checked for all parts, as well as the overall system reliability.

It is important to note that when calculating factors of safety, stress calculations were checked against the respective yield strength, and some parts were checked against the maximum loading values listed on their vendor websites. Below is a summary of the critical factors of safety for each designed part, along with the critical stress/load state, and supporting equations for calculation (See Appendix B for detailed MATLAB code). A factor of safety is considered critical if it is the lowest factor of safety for that respective part.

1. Legs: 2.13 (Bending + Handling)



$$\sigma_b = \frac{Mc}{I}$$
$$I = \frac{R^4}{12} - \frac{r^4}{12}$$
$$M = \int_0^L V(x) dx = \int_0^L \int_0^L Q(x) dx dx$$

Figure 13: Point of maximum stress on Legs and supporting equations

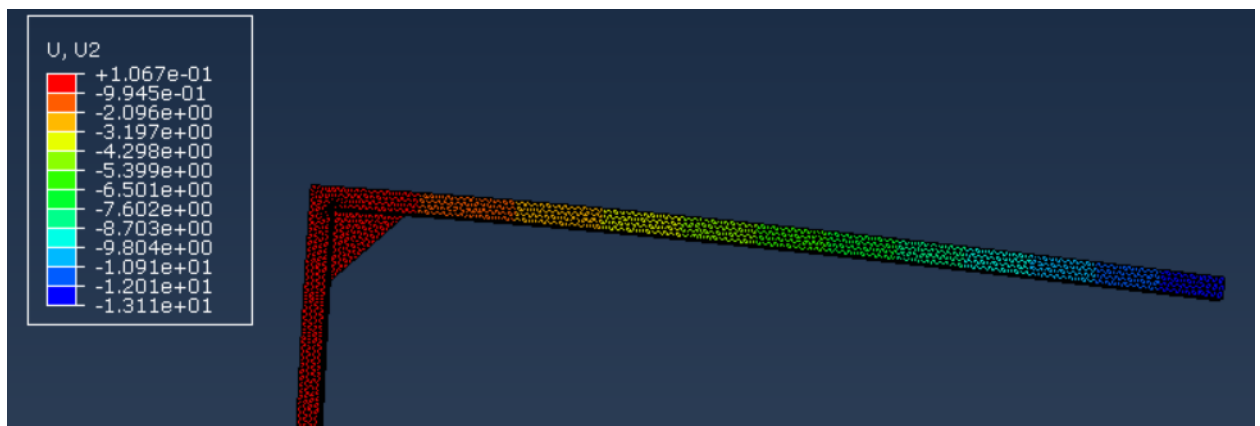


Figure 14: FEA displacement analysis of Leg

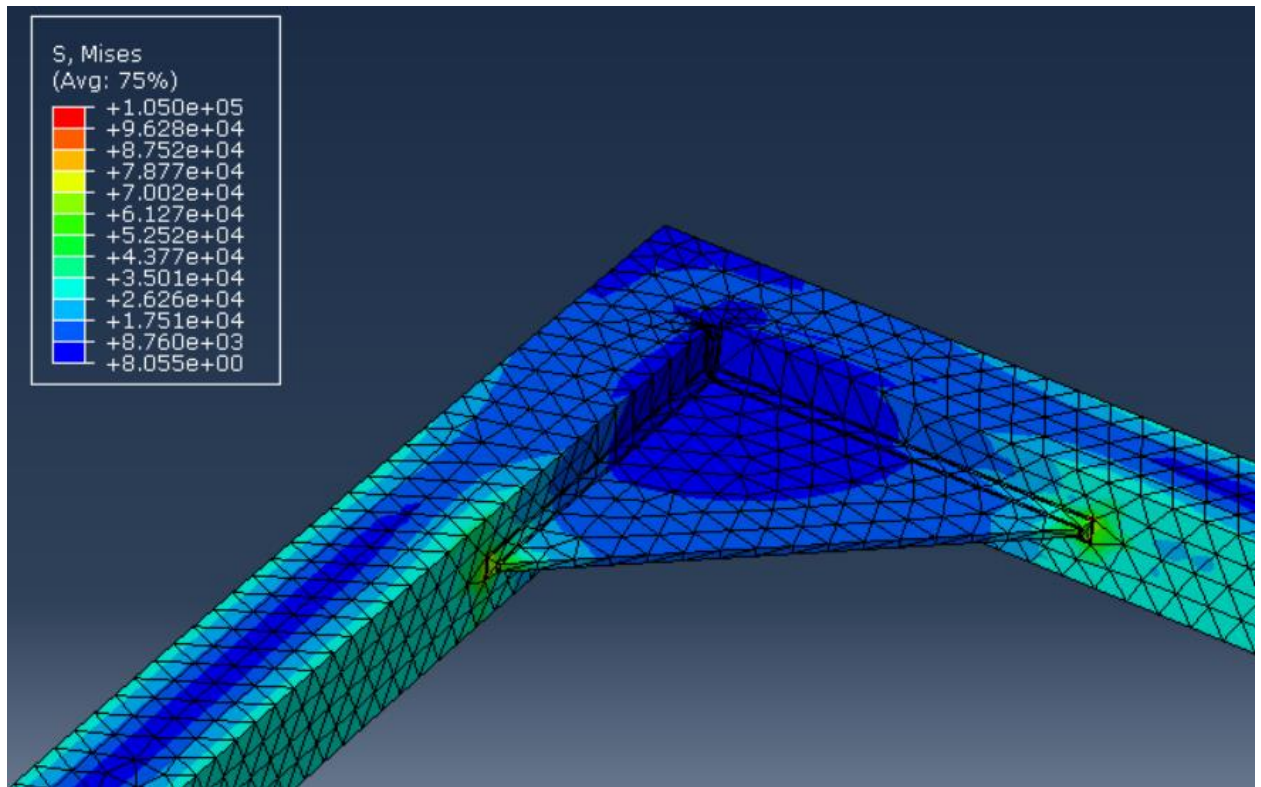
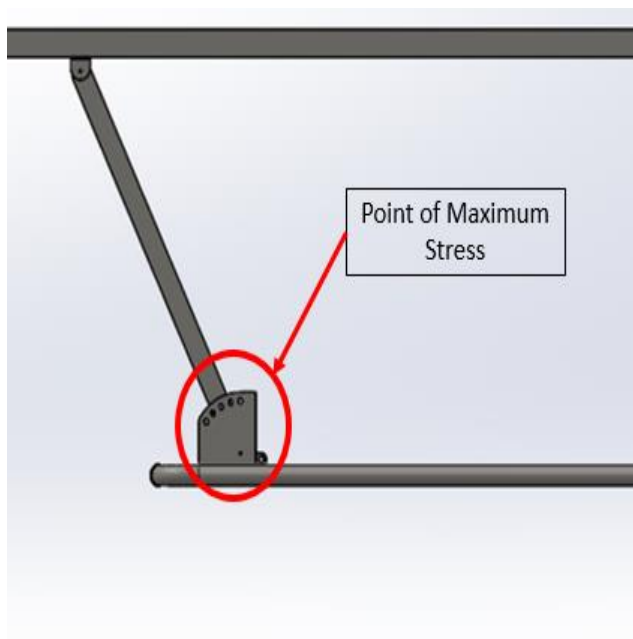


Figure 15: FEA Mises analysis of Upper Gusset Plate

2. Links: 1.81 (Bending + Tension)



$$\sigma_b = \frac{Mc}{I}$$

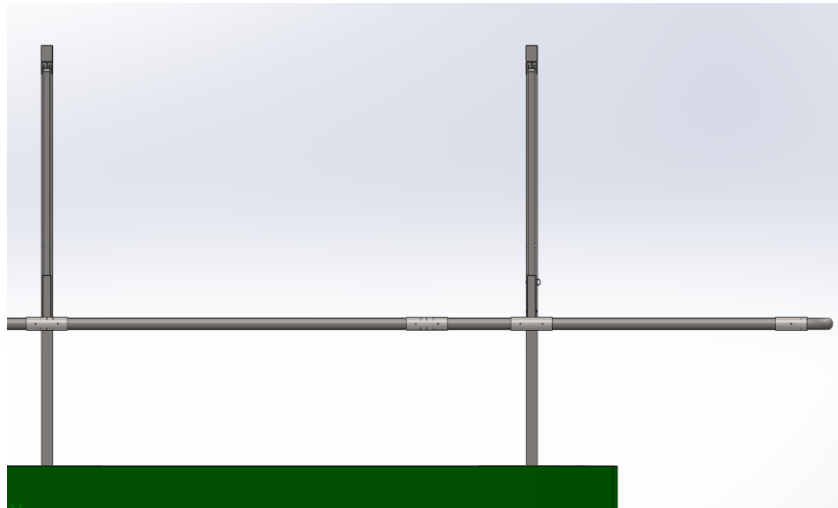
$$I = \frac{R^4}{12} - \frac{r^4}{12}$$

$$M = \int_0^L V(x) dx = \int_0^L \int_0^L Q(x) dx dx$$

$$\sigma = \frac{F}{A}$$

Figure 16: Point of maximum stress and supporting equations

3. Feedback Plane: 4.54 (Stress on Perimeter Frame)

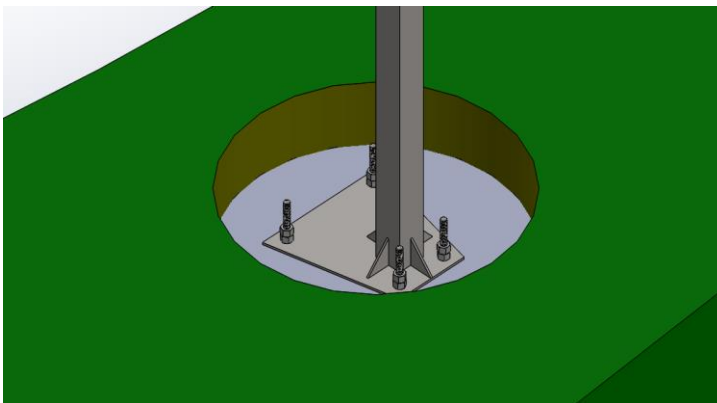


$$M = \int_0^L V(x) dx = \int_0^L \int_0^L Q(x) dx dx$$

$$\sigma_b = \frac{Mc}{I}$$

Figure 17: Stress on perimeter frame and supporting equations

4. Anchor Bolts: 4.27 (Pull-Out)

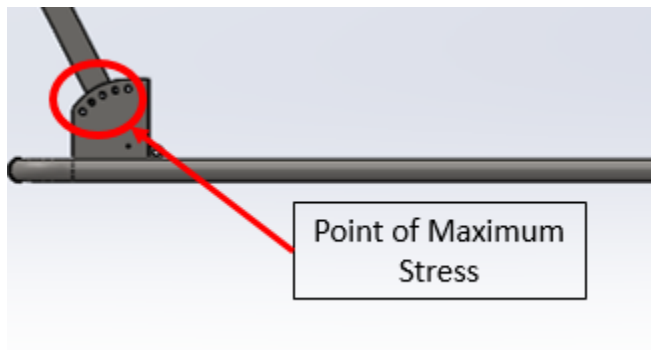


$$M = Fd$$

$$\sigma = \frac{F}{A}$$

Figure 18: Anchor bolt pull out and supporting equations

5. Lower Brackets: 2 (Shear Tear-Out)



$$\sigma_b = \frac{Mc}{I}$$

$$I = \frac{R^4}{12} - \frac{r^4}{12}$$

$$M = \int_0^L V(x) dx = \int_0^L \int_0^L Q(x) dx dx$$

$$\sigma = \frac{F}{A}$$

Figure 19: Lower bracket maximum stress and supporting equations

6. Safety Pin: 3.5 (Shear)

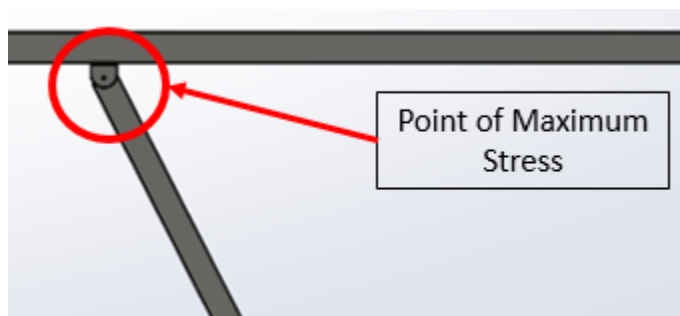


$$\sigma_{shear} = \frac{2P}{\pi d^2}$$

$$\sigma_b = \frac{8P(2B_o + B_i + 6g)}{3\pi d^3}$$

Figure 20: Safety Pin shear tear-out and supporting equations

7. Upper Brackets: 13 (Shear Tear-Out + Handling)



$$\sigma = \frac{F}{A}$$

Figure 21: Upper Bracket point of maximum stress and supporting equation

8. Cable System: Maximum Tension of 1250 lbs

9. Upper Bracket Bolts: 1.14 (Bending, Shear, Handling)

10. Concrete Pier Design

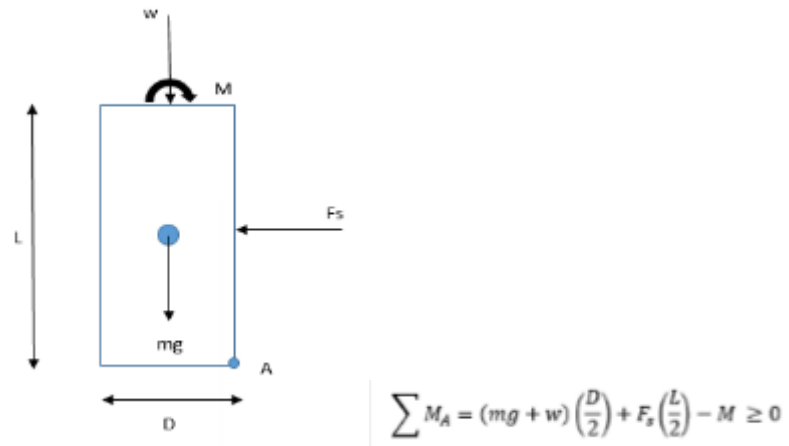


Figure 22: Concrete pier FBD and supporting equation

Future Actions & Conclusion

Although the design is complete, we do not yet have a working prototype. The biggest reason for this is because the customer was not sure if actually building the device was going to occur. Once we got approval from the football team, it was already too late to be able to complete the prototype by the end of the semester. We have been working very hard to order parts, refine drawings, and schedule time with Danny to get everything as close to done as possible.

Some tasks that still need to be completed going forward are:

- Cut and drill legs, feedback plane, and plates to spec
- Weld parts together
- Assemble the entire structure
- Map out area best for installation
- Transport parts to the field
- Install prototype on site via work instructions

We have learned a lot throughout this process and hopefully it will make us better engineers moving forward.

Figure 13 shows the Gantt chart moving forward into the summer months when we hope to complete the project.

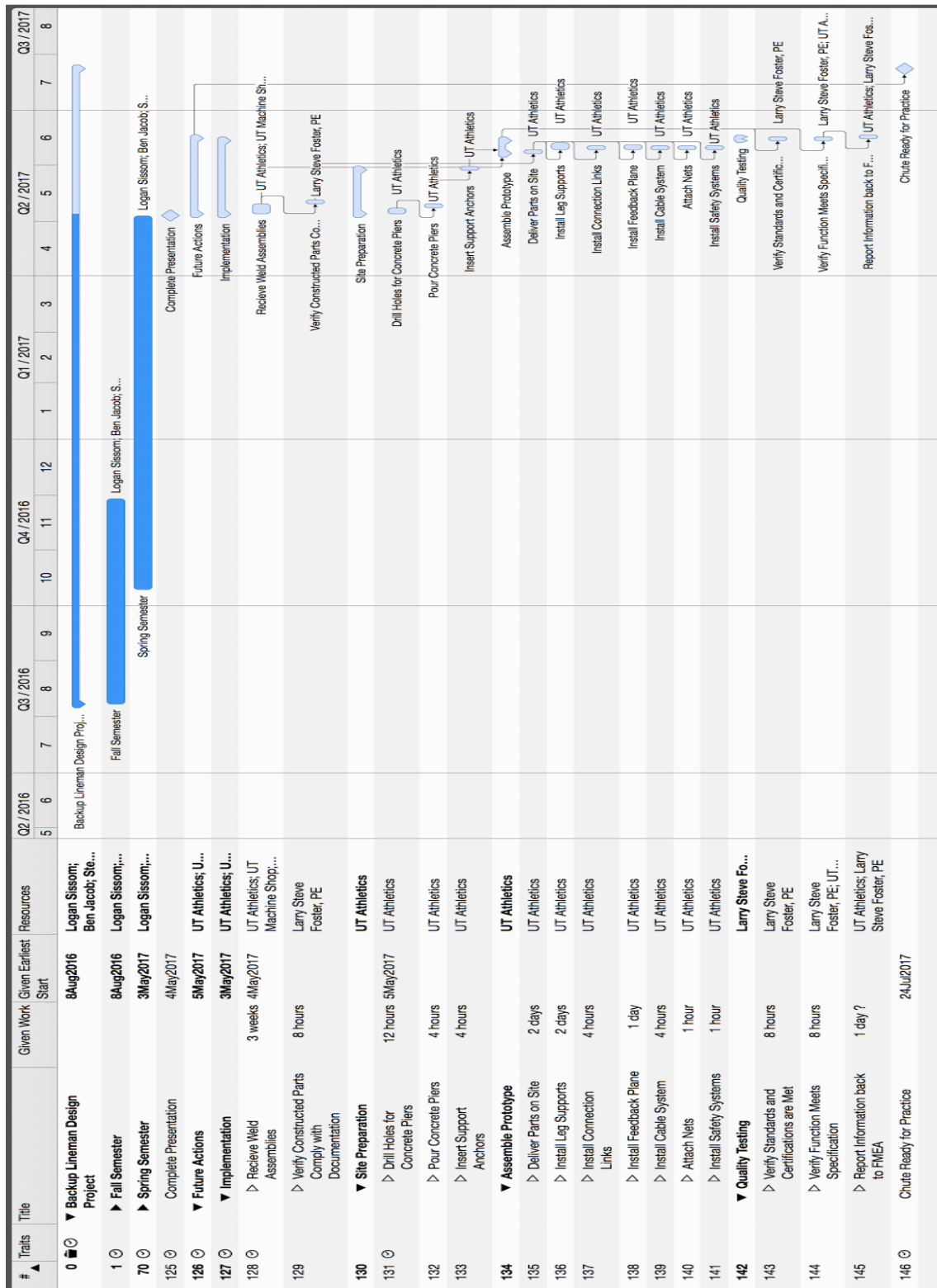
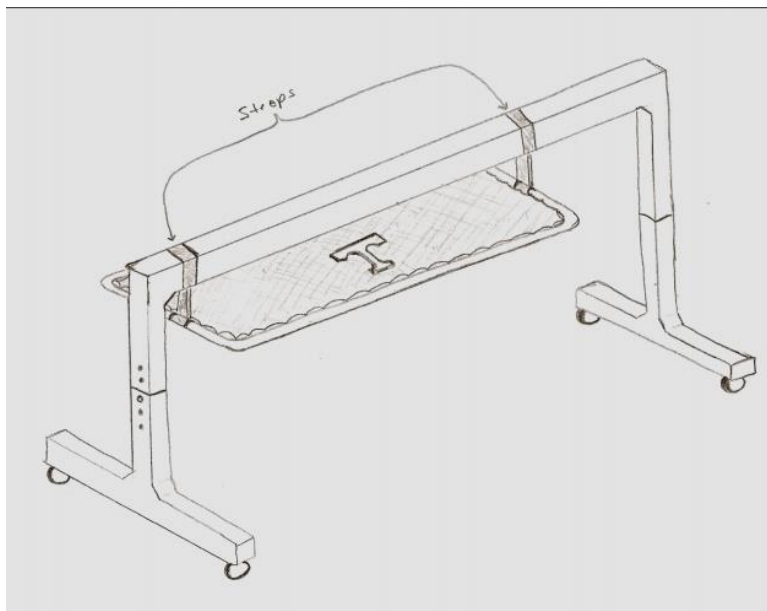
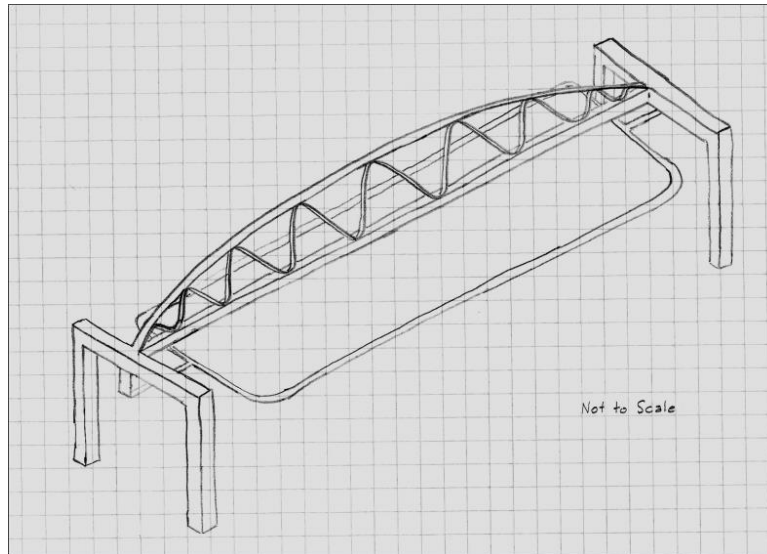
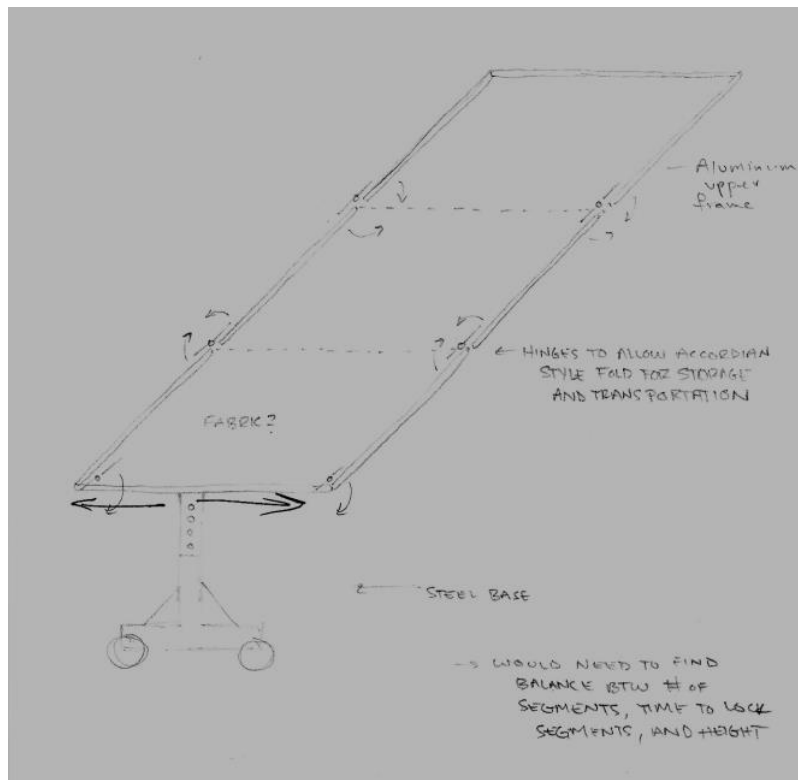
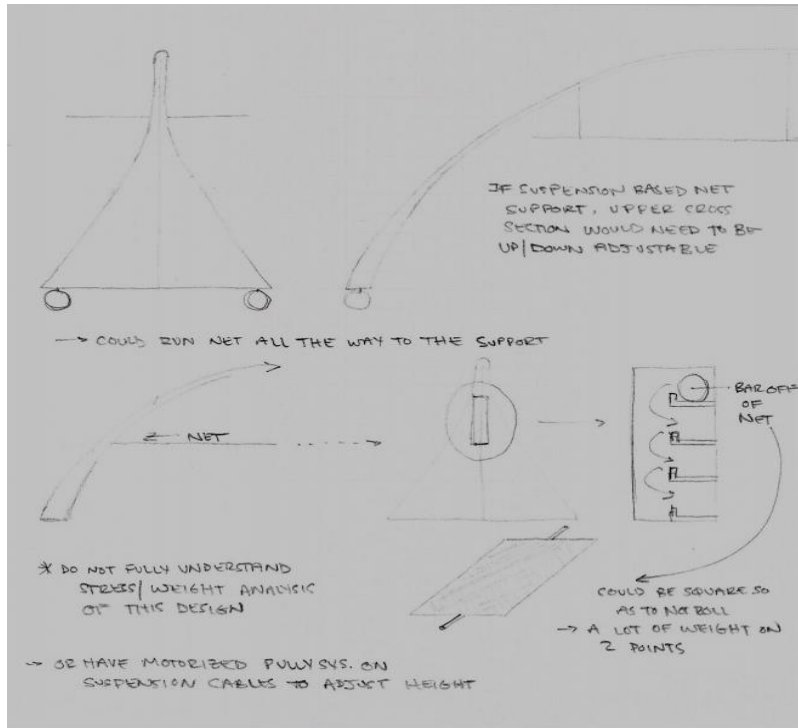


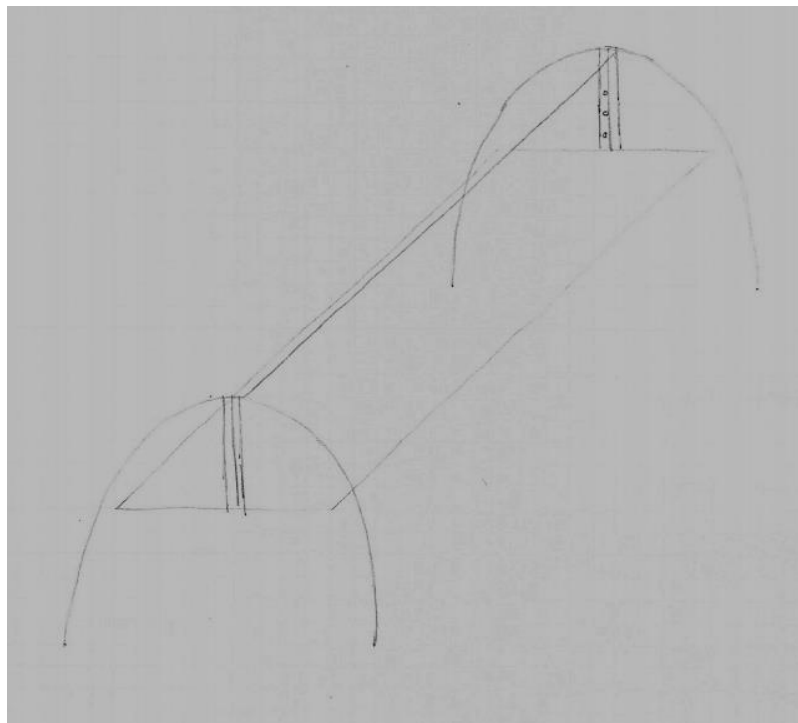
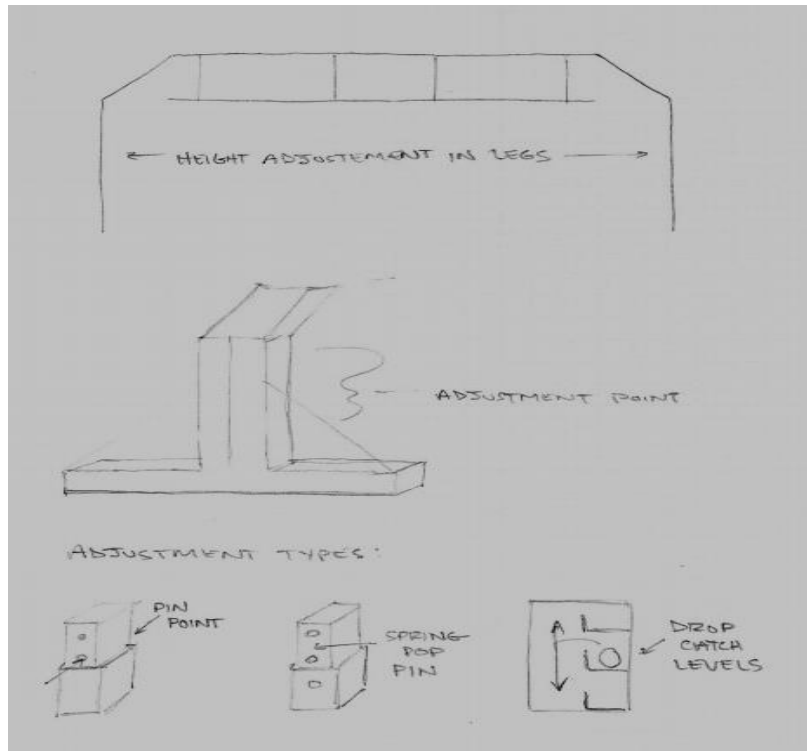
Figure 13: Future Actions Gantt Chart

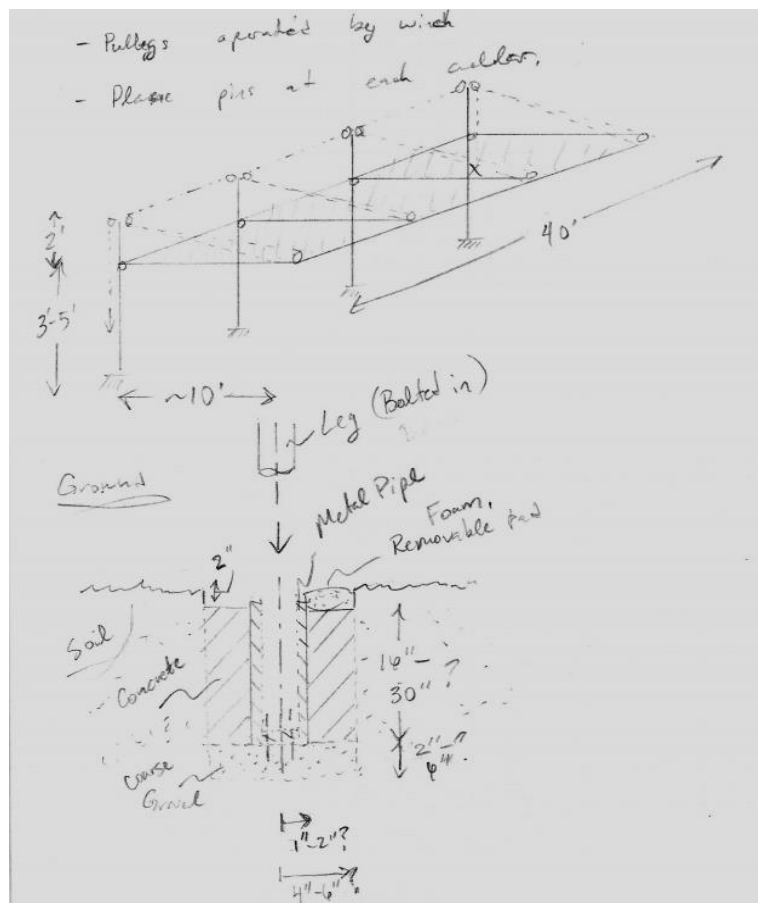
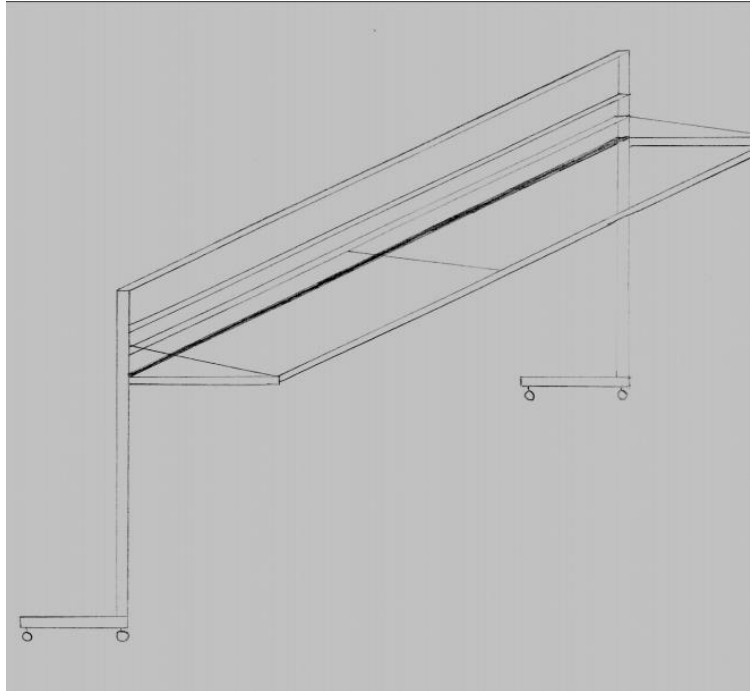
Appendix A

Pre-Design Sketches:









Appendix B

Analysis Calculations:

The stress calculations for the support leg are shown below, as well as the loading for the cable. The cable analysis calculates the load at different feedback plane heights, so that the maximum value could be accounted for. The cable was then purchased to be strong enough to handle the load.

Bending Stress at the Support Leg Bend

```
N = 3; % number of legs (unitless)
W = 900; % total weight in pounds
R = 13; % moment arm length in feet (maximum distance of application)
M = R*W; % magnitude of total weight moment in ft-lbs
h2 = (3.5/12); % outer height of support leg piping in feet
h1 = (3.25/12); % inner height of support leg piping in feet
b2 = (3.5/12); % outer radius of support leg piping in feet
b1 = (3.25/12); % inner radius of support leg piping in feet
I = (1/12)*((b2*h2.^3)-(b1*h1.^3)); % second moment of area of leg pipe in ft^4
Sig = (((M*h2)/(2*I))*(1/144))/N; % b-stress in psi (1 leg, total weight)
YS = 35000; % approximate yield strength of steel in psi
FoS = YS/Sig
% This bending moment is equal to the moment at the fixed connection of the
% support leg because these are the only acting moments on the leg
% structure
```

FoS =

1.3709

Axial Stress on the Support Cable(s)

```
WC = 670; % moving load (pounds) on one cable, only in y direction
FPL = 8.5; % feedback plane length with pulley in feet
LL = 5; % link length in feet
Del_Y = [0 0.5 1 1.5 2]; % change in height matrix in feet
Theta1 = acosd(1-(Del_Y./LL)); % angle between link and vertical
Del_X = sind(Theta1).*LL; % change in horizontal position of plane in feet
Theta2 = atand((FPL-Del_X)./(LL-Del_Y)); % angle between cable and vertical
Load = WC./(cosd(Theta2)) % maximum axial load in cable in lbs

% cable should be rated above the calculated load.
```

Load =

1.0e+03 *

1.3214 1.1552 1.1391 1.1573 1.2079

Below is the analysis for the buckling and compressive strength of the support leg.

Buckling and Compressive Strength

```
clear all
close all
clc

L = (8*12); % Length (Height of Vertical Support above ground) (in)
           % Height measured from bottom of bent tube to top of ground

E = 30*(10^6); % Modulus of Elasticity (1026 Low Carbon Steel)

a = 3.5; % Outer Length Square (in)
b = a-(0.125*2); % Inner Length Square (in)

I = ((a^4)-(b^4))/12; % Center Moment of Inertia (Square Shape)
A = a^2-b^2; % Area of the vertical support bar
K = sqrt(I/A); % radius of gyration

% The vertical bar is in a fixed-free configuration, so a C value of (1/4)
% will be used to calculate the critical force.
C = 0.25; % end-condition constant C
Pcr = (C*(pi^2)*E*A)/((L/K)^2); % critical force for buckling in pounds
Weight = 900; % weight of feedback plane and total load in lbs
FoS = Pcr/Weight % factor of safety (buckling)
```

FoS =

28.6293

Compressive Strength

```
% 1020 Cold Rolled Steel (Low Carbon)
% Yield Strength - 51,000 psi (CD)
%                - 43,000 psi (annealed)
%                - 30,000 psi (HR)
```

```
% Formula Used: sigma = F/A

F = 1000; % Max force on a leg (lb)

ao = a.^2; % Outer Length Square (in^2)
bi = b.^2; % Inner Length Square (in^2)

A = (ao)-(bi);

sigma = F/A; % Applied stress to vertical tube cross section (psi)
YS = 35000; % steel yield strength (psi)
FoS2 = YS/sigma

FoS2 =
```

59.0625

Below is the analysis code for the feedback plane.

Revised Feedback Plane Analysis

Created by L. Sissom Date : 15 April 2017 Modified :

```
%{
PURPOSE:
    The purpose of this script is to help compute the expected loads on
    possible configurations of the senior design project.

REFERENCE:

LOCATION:
pathDir00 = '';
addpath(pathDir00);

FUNCTIONS:

%}

close all; clear all; clc; format compact; format long g;
```

Add Function Paths

Use below to locate directory:

```
%{
[fileName00, pathDir00] = uigetfile();
```

```

addpath(pathDir00);
completeName00 = fullfile(pathDir00,fileName00)
%}

```

Plotting Properties

```

psname = ('Helvetica');      % Plot Font Style
pawt = 'bold';               % Plot Label font weight
pftxt = 15;                  % Plot Text font size, [pts]
patxt = 18;                  % Plot Label font size, [pts]
pstxt = 16;                  % Plot Axis Ticks font size, [pts]

strU01 = ('in');
strU02 = ('Lb_f');
strU03 = ('Lb_f-in');
strU04 = ('°');
strU05 = ('psi');

```

Initializations

Load of Netting

```

T = 58.1358;      % Tension per Net [lbf]
aT = 2.8108;      % Angle from horizontal of net connection [°]
Tnetz = T*sind(aT);
Tnety = T*cosd(aT);
lT = 120;         % Length of Net Section
% Positions Netting attaches to Feedback Plane [in]
cT = sort([(246-2) (246+2) (246-120+2) (246+120-2) (246-2*120+2) ...
          (246+2*120-2) (246-120-2) (246+120+2)]);

% Load of Person
n = 3;            % Worst Case Number of Persons on Plane
P = 320;          % Weight of single Person [lbf]
aP = 00;          % Angle from vertical person is leaning [°]

% Framing Properties
% Framing [0 93 126 246 366 399 492]
E = 30000000;     % Modulus of Elasticity
YS = 36*10^3;     % Yield Strength [psi]
den = 0.285;      % Density of Carbon Steel [lbf/in^3]

Li = 492;         % Length of Major Section [in]
xi = linspace(0,Li,1000);
Lj = 122.5;       % Length of Minor Section [in]
xj = linspace(0,Lj,1000);

D = 2.5;          % Diameter of Tubing [in]
t = [(1/8) (3/16) (1/4)]; % Thickness of Framing Tube [in]
R = D/2;          % Outer Radius of Framing [in]

```

```

r = R*ones(1,length(t)) - t;      % Inner Radius of Framing [in]

A = pi.*((R*ones(1,length(r))).^2 - r.^2);      % Area of Framing Cross-Section [in^2]
I = (pi.*((R*ones(1,length(r))).^4 - r.^4))./4;  % Second moment of area of tubing [in^4]

% Load of Feedback Plane
fS = 1;      % Identifier to Determine Weight of Feedback Plane
fD = ([3 1 1]); % Design for Feedback Plane Sections ([End, Center, Cross-Members])
                % Wall Thickness Identifier: 1 = 1/8" ; 2 = 3/16" ; 3 = 1/4"
chw = 1000;   % Estimated Load of Feedback Plane [lbf]; Current Design = 820 lbf
fW = A*den;    % Weight per length of Frame [lbf/in]
if fS == 2
    fL = chw;   % Load of Feedback Plane from Estimated Weight [lbf]
elseif fS == 1
    % Load of Feedback Plane from Framing Dimensioning [lbf]
    fL = 4*(82.5*fW(fD(1))) + 4*(153*fW(fD(2))) + 7*(122.5*fW(fD(3))) ...
        + 6*5.6 + 4*4.5 + 10*6.75;
end

```

Minor Length YZ Plane

```

Ljyz = ([0 10.238 112.262 122.5]);

spp1 = ([[1 1 0 0];[-51.012 51.012 0 0];...
    [(1/6)*(Ljyz(3)-Ljyz(2))^3 0 Ljyz(3) 1];...
    [0 0 Ljyz(2) 1]]);
spp2 = ([[(fL+n*P)/3];[n*P*61.25/3];...
    [(fL/36)*(Ljyz(3)-Ljyz(1))^3+(fW(fD(3))/24)*(Ljyz(3))^4];...
    [(fL/36)*(Ljyz(2)-Ljyz(1))^3+(fW(fD(3))/24)*(Ljyz(2))^4]]);
spp3 = spp1\spp2;
R1 = spp3(1);    R2 = spp3(2);    % Connection Reactions [lbf]
P1 = fL/6;        P2 = P1 + (n*P/3);    bcS = spp3(3);    bcD = spp3(4);

% Shear
Vjyz = -(P1/1)*(xj > Ljyz(1)).*(xj - Ljyz(1)).^(0) + ...
    (R1/1)*(xj > Ljyz(2)).*(xj - Ljyz(2)).^(0) + ...
    (R2/1)*(xj > Ljyz(3)).*(xj - Ljyz(3)).^(0) - ...
    (P2/1)*(xj > Ljyz(4)).*(xj - Ljyz(4)).^(0) - ...
    fW(fD(3))*(xj > 0).*(xj - 0).^(1);

% Moment
Mjyz = -(P1/1)*(xj > Ljyz(1)).*(xj - Ljyz(1)).^(1) + ...
    (R1/1)*(xj > Ljyz(2)).*(xj - Ljyz(2)).^(1) + ...
    (R2/1)*(xj > Ljyz(3)).*(xj - Ljyz(3)).^(1) - ...
    (P2/1)*(xj > Ljyz(4)).*(xj - Ljyz(4)).^(1) - ...
    (fW(fD(3))/2)*(xj > 0).*(xj - 0).^(2);

% Slope
S = -(P1/2)*(xj > Ljyz(1)).*(xj - Ljyz(1)).^(2) + ...

```

```

(R1/2)*(xj > Ljyz(2)).*(xj - Ljyz(2)).^(2) + ...
(R2/2)*(xj > Ljyz(3)).*(xj - Ljyz(3)).^(2) - ...
(P2/2)*(xj > Ljyz(4)).*(xj - Ljyz(4)).^(2) - ...
(fW(fD(3))/6)*(xj > 0).*(xj - 0).^(3) + bcS;

Sjyz = (E*I(fD(3)))^(-1).*S;

% Deflection
D = -(P1/6)*(xj > Ljyz(1)).*(xj - Ljyz(1)).^(3) + ...
(R1/6)*(xj > Ljyz(2)).*(xj - Ljyz(2)).^(3) + ...
(R2/6)*(xj > Ljyz(3)).*(xj - Ljyz(3)).^(3) - ...
(P2/6)*(xj > Ljyz(4)).*(xj - Ljyz(4)).^(3) - ...
(fW(fD(3))/24)*(xj > 0).*(xj - 0).^(4) + bcS.*xj + bcD;

Djyz = (E*I(fD(3)))^(-1).*D;

% Beam Diagrams
% Shear Force Diagram Figure
strSV01 = ('Cross-Strut Shear Force Diagram YZ');
strSV02 = (['Shear Force [' strU02 ']]');
SVf = figure('Name',strSV01,'Resize','On','Visible','on');
hold on;
%axis([x min} {x max} {y min} {y max}]);
grid on;
hSF = area(xj,Vjyz);
hlegSF = legend([hSF],{strSV02});
set(hlegSF,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01;
strYlab = strU02;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;

% Bending Moment Diagram Figure
strSM01 = ('Cross-Strut Bending Moment Diagram YZ');
strSM02 = (['Bending Moment [' strU03 ']]');
SMf = figure('Name',strSM01,'Resize','On','Visible','on');
hold on;
%axis([x min} {x max} {y min} {y max}]);
grid on;
hSM = area(xj,Mjyz);
hlegSM = legend([hSM],{strSM02});
set(hlegSM,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01;
strYlab = strU03;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);

```

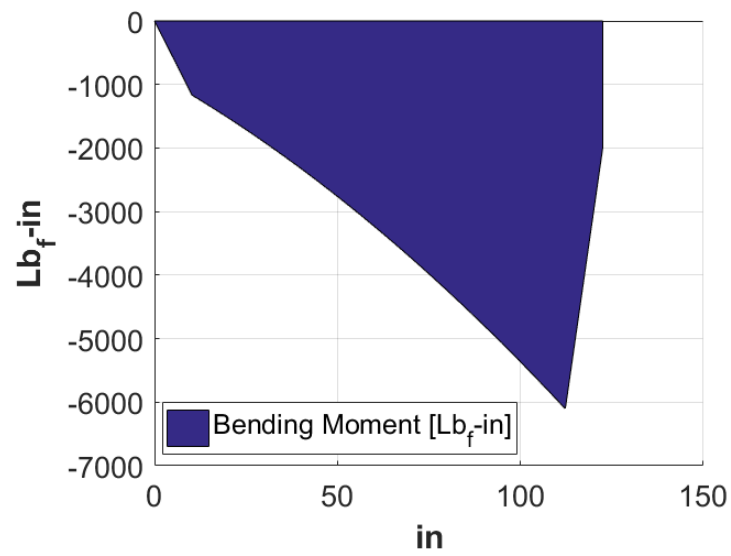
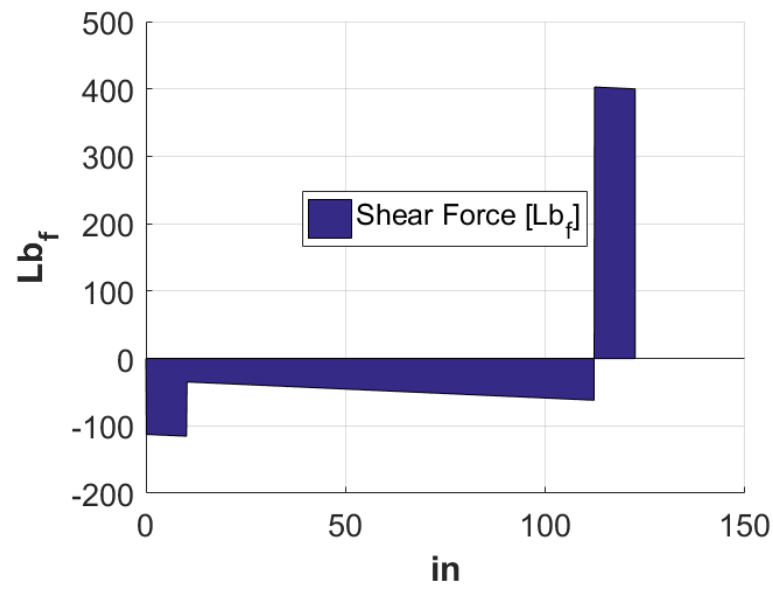
```

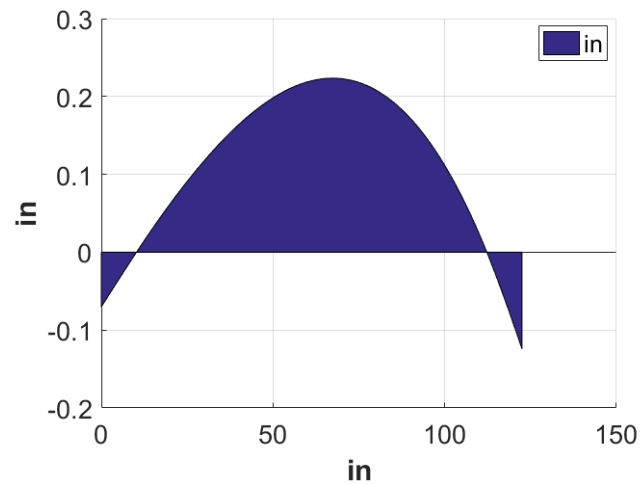
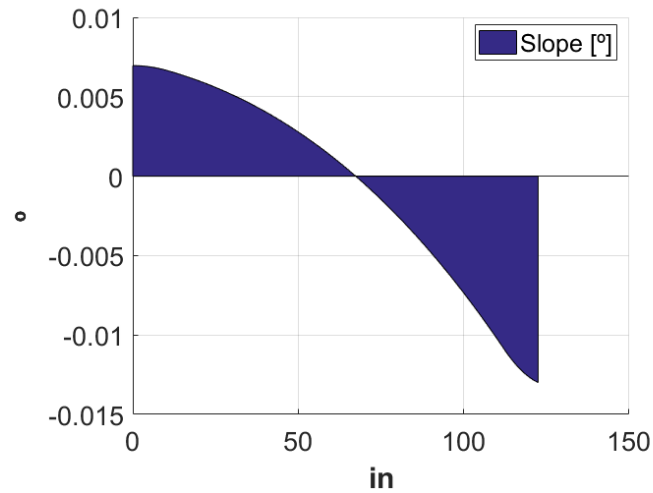
hold off;

% Slope Diagram Figure
strSS01 = ('Cross-Strut Slope Diagram YZ');
strSS02 = (['Slope [' strU04 ']]');
SSf = figure('Name',strSS01,'Resize','On','Visible','on');
hold on;
%axis([x min] [x max] [y min] [y max]));
grid on;
hSS = area(xj,Sjyz);
hlegSS = legend([hSS],{strSS02});
set(hlegSS,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01;
strYlab = strU04;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;

% Deflection Diagram Figure
strD01 = ('Cross-Strut Deflection Diagram YZ');
strD02 = (['Deflection [' strU01 ']]');
Df = figure('Name',strD01,'Resize','On','Visible','on');
hold on;
hD = area(xj,Djyz);
grid on;
hlegD = legend([hD],{strU01});
set(hlegD,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01; strYlab = strU01;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;

```





Major Length XZ Plane

Beam Diagrams

```
Lixz = ([93 246 399]);

spp1 = ([[1 1 1 0 0];[0 0 0 -Lixz(1) -1];...
        [-(1/6)*(Lixz(2) - Lixz(1)).^(3)) 0 0 -Lixz(2) -1];...
        [-(1/6)*(Lixz(3) - Lixz(1)).^(3)) -(1/6)*(Lixz(3) - Lixz(2)).^(3)) 0 -Lixz(3) -
1];...
        [-(1/2)*(Lixz(2) - Lixz(1)).^(2)) 0 0 -1 0]]);
spp2 = ([[186*fW(fD(1))+306*fW(fD(2))+n*P];[-(fW(fD(1))/24)*(Lixz(1) - 0)^(4)];...
        [-(fW(fD(1))/24)*(Lixz(2) - 0)^(4)+(fW(fD(1))/24)*(Lixz(2) - 93)^(4)-
(fW(fD(2))/24)*(Lixz(2) - 93)^(4)];...
        [-(fW(fD(1))/24)*(Lixz(3) - 0)^(4)+(fW(fD(1))/24)*(Lixz(3) - 93)^(4)-
(fW(fD(2))/24)*(Lixz(3) - 93)^(4)-(n*P/6)*(Lixz(3) - Lixz(2))^(3)];...
        [-(fW(fD(1))/6)*(Lixz(2) - 0)^(3)+(fW(fD(1))/6)*(Lixz(2) - 93)^(3)-
(fW(fD(2))/6)*(Lixz(2) - 93)^(3)]]);
spp3 = spp1\spp2;
```

```

R1 = spp3(1);    R2 = spp3(2);    R3 = spp3(3);    % Connection Reactions [lbf]
bcS = spp3(4);  bcD = spp3(5);

% Shear
Vixz = -(fW(fD(1))/1)*(xi > 0).*(xi - 0).^1 + (fW(fD(1))/1)*(xi > 93).*(xi - 93).^1 ...
        -(fW(fD(2))/1)*(xi > 93).*(xi - 93).^1 + (fW(fD(2))/1)*(xi > 399).*(xi - 399).^1 ...
        -(fW(fD(1))/1)*(xi > 399).*(xi - 399).^1 ...
        +(R1/1)*(xi > Lixz(1)).*(xi - Lixz(1)).^0 ...
        +(R2/1)*(xi > Lixz(2)).*(xi - Lixz(2)).^0 ...
        +(R3/1)*(xi > Lixz(3)).*(xi - Lixz(3)).^0 ...
        -(n*P/1)*(xi > Lixz(2)).*(xi - Lixz(2)).^0;

% Moment
Mixz = -(fW(fD(1))/2)*(xi > 0).*(xi - 0).^2 + (fW(fD(1))/2)*(xi > 93).*(xi - 93).^2 ...
        -(fW(fD(2))/2)*(xi > 93).*(xi - 93).^2 + (fW(fD(2))/2)*(xi > 399).*(xi - 399).^2 ...
        -(fW(fD(1))/2)*(xi > 399).*(xi - 399).^2 ...
        +(R1/1)*(xi > Lixz(1)).*(xi - Lixz(1)).^1 ...
        +(R2/1)*(xi > Lixz(2)).*(xi - Lixz(2)).^1 ...
        +(R3/1)*(xi > Lixz(3)).*(xi - Lixz(3)).^1 ...
        -(n*P/1)*(xi > (Li/2)).*(xi - (Li/2)).^1;

% Slope
S = -(fW(fD(1))/6)*(xi > 0).*(xi - 0).^3 + (fW(fD(1))/6)*(xi > 93).*(xi - 93).^3 ...
        -(fW(fD(2))/6)*(xi > 93).*(xi - 93).^3 + (fW(fD(2))/6)*(xi > 399).*(xi - 399).^3 ...
        -(fW(fD(1))/6)*(xi > 399).*(xi - 399).^3 ...
        +(R1/2)*(xi > Lixz(1)).*(xi - Lixz(1)).^2 ...
        +(R2/2)*(xi > Lixz(2)).*(xi - Lixz(2)).^2 ...
        +(R3/2)*(xi > Lixz(3)).*(xi - Lixz(3)).^2 ...
        -(n*P/2)*(xi > Lixz(2)).*(xi - Lixz(2)).^2 + bcS;

Iixz = I(fD(1))*(xi >= 0) - I(fD(1))*(xi >= 93) + ...
        I(fD(2))*(xi >= 93) - I(fD(2))*(xi >= 399) + ...
        I(fD(1))*(xi >= 399);
Aixz = A(fD(1))*(xi >= 0) - A(fD(1))*(xi >= 93) + ...
        A(fD(2))*(xi >= 93) - A(fD(2))*(xi >= 399) + ...
        A(fD(1))*(xi >= 399);
Sixz = S./(E*Iixz);

% Deflection
D = -(fW(fD(1))/24)*(xi > 0).*(xi - 0).^4 + (fW(fD(1))/24)*(xi > 93).*(xi - 93).^4 ...
        -(fW(fD(2))/24)*(xi > 93).*(xi - 93).^4 + (fW(fD(2))/24)*(xi > 399).*(xi - 399).^4 ...
        -(fW(fD(1))/24)*(xi > 399).*(xi - 399).^4 ...

```

```

+(R1/6)*(xi > Lixz(1)).*(xi - Lixz(1)).^(3)...
+(R2/6)*(xi > Lixz(2)).*(xi - Lixz(2)).^(3)...
+(R3/6)*(xi > Lixz(3)).*(xi - Lixz(3)).^(3)...
-(n*P/6)*(xi > Lixz(2)).*(xi - Lixz(2)).^(3) + bcS.*xi + bcD;

Dixz = D./(E*Iixz);

% Beam Diagrams
% Shear Force Diagram Figure
strSV01 = ('Main Length Shear Force Diagram XZ');
strSV02 = (['Shear Force [' strU02 ']]');
SVf = figure('Name',strSV01,'Resize','On','Visible','on');
hold on;
%axis([x min} {x max} {y min} {y max}]);
grid on;
hSF = area(xi,Vixz);
hlegSF = legend([hSF],{strSV02});
set(hlegSF,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01;
strYlab = strU02;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;

% Bending Moment Diagram Figure
strSM01 = ('Main Length Bending Moment Diagram XZ');
strSM02 = (['Bending Moment [' strU03 ']]');
SMf = figure('Name',strSM01,'Resize','On','Visible','on');
hold on;
%axis([x min} {x max} {y min} {y max}]);
grid on;
hSM = area(xi,Mixz);
hlegSM = legend([hSM],{strSM02});
set(hlegSM,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01;
strYlab = strU03;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;

% Slope Diagram Figure
strSS01 = ('Main Length Slope Diagram XZ');
strSS02 = (['Slope [' strU04 ']]');
SSf = figure('Name',strSS01,'Resize','On','Visible','on');
hold on;
%axis([x min} {x max} {y min} {y max}]);
grid on;

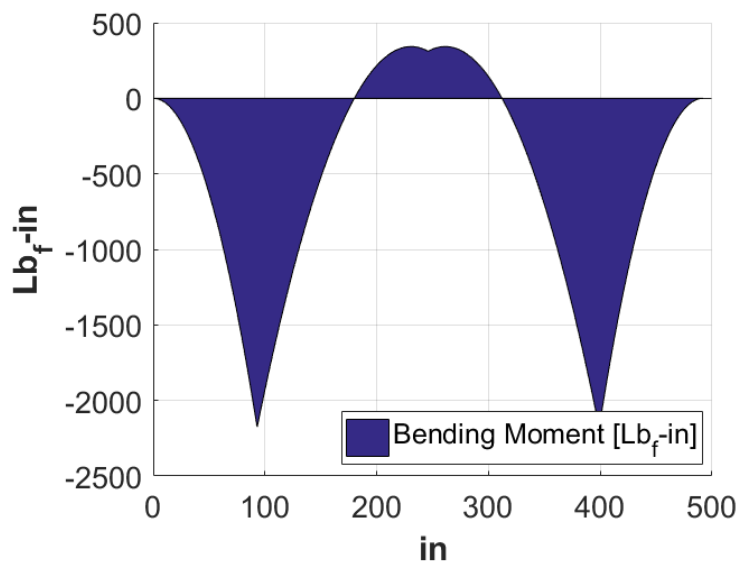
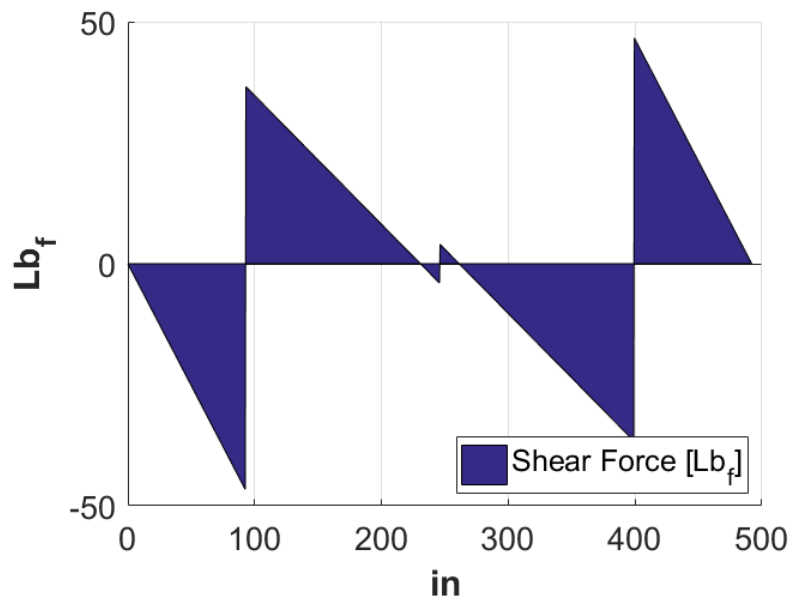
```

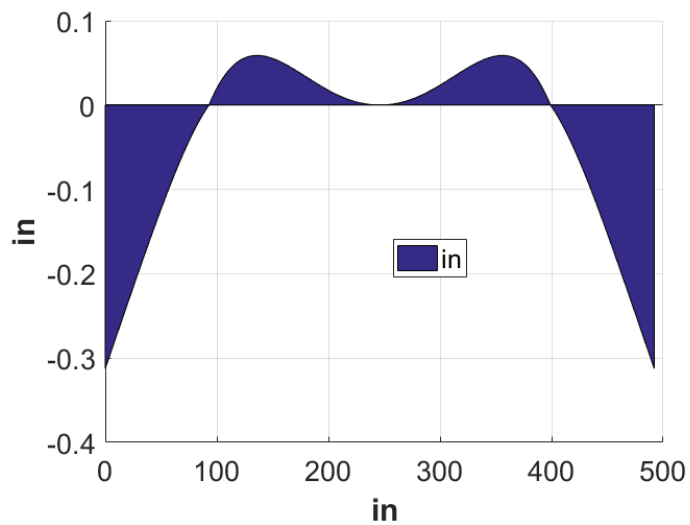
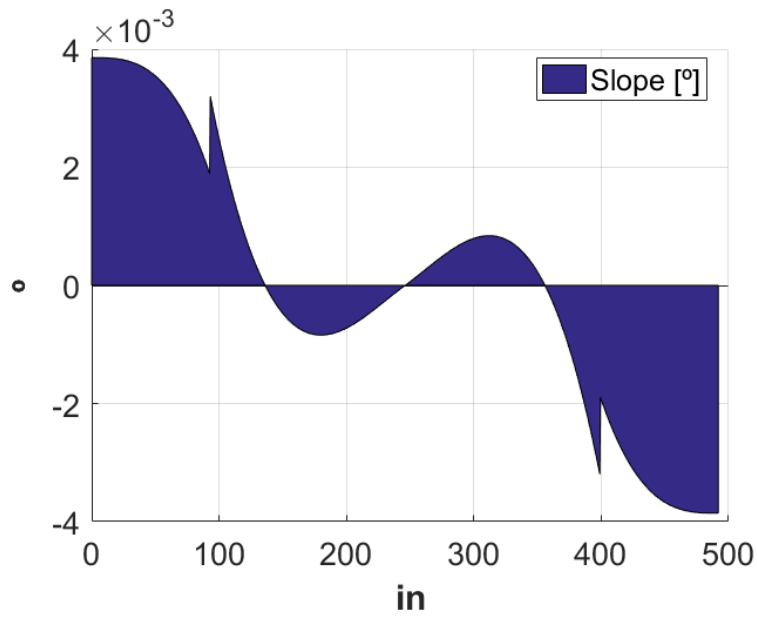
```

hSS = area(xi,Sixz);
hlegSS = legend([hSS],{strSS02});
set(hlegSS,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01;
strYlab = strU04;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;

% Deflection Diagram Figure
strD01 = ('Main Length Deflection Diagram XZ');
strD02 = (['Deflection [' strU01 ']]');
Df = figure('Name',strD01,'Resize','On','Visible','on');
hold on;
hD = area(xi,Dixz);
grid on;
hlegD = legend([hD],{strU01});
set(hlegD,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01; strYlab = strU01;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;

```





Major Length XY Plane

Beam Diagrams

```
Lixy = ([0 93 126 246 366 399 492]);

%{
spp1 = ([[1 1 1 1 1 1 1 0];...
    [-(1/6)*(Lixy(2) - Lixy(1))^3 0 0 0 0 0 -Lixy(2)];...
    [-(1/6)*(Lixy(3) - Lixy(1))^3 -(1/6)*(Lixy(3) - Lixy(2))^3 0 0 0 0 -
Lixy(3)];...
    [-(1/6)*(Lixy(4) - Lixy(1))^3 -(1/6)*(Lixy(4) - Lixy(2))^3 -(1/6)*(Lixy(4) -
Lixy(3))^3 0 0 0 0 -Lixy(4)];...
    [-(1/6)*(Lixy(4) - Lixy(1))^3 0 0 -Lixy(4)];...
    [-(1/6)*(Lixy(7) - Lixy(1))^3 -(1/6)*(Lixy(7) - Lixy(4))^3 0 -Lixy(7)];...
    ];
```

```

    [-(1/2)*(Lixy(7) - Lixy(1))^2) -((1/2)*(Lixy(7) - Lixy(4))^2) 0 -Lixy(7)];...
    [-(1/2)*(Lixy(4) - Lixy(1))^2) 0 0 -Lixy(4)]]];
spp2 = ([4*Tnety];...
    [-(0.5*Tnety/6)*(Lixy(2) - cT(1))^3]);...
    [-(0.5*Tnety/6)*(Lixy(3) - cT(1))^3)-((0.5*Tnety/6)*(Lixy(4) - cT(2))^3)];...
    []];...
    [-(0.5*Tnety/6)*(Lixy(4) - cT(1))^3)-((0.5*Tnety/6)*(Lixy(4) - cT(2))^3)-
    ((0.5*Tnety/6)*(Lixy(4) - cT(3))^3)-((0.5*Tnety/6)*(Lixy(4) - cT(4))^3)];...
    [-(0.5*Tnety/6)*(Lixy(7) - cT(1))^3)-((0.5*Tnety/6)*(Lixy(7) - cT(2))^3)-
    ((0.5*Tnety/6)*(Lixy(7) - cT(3))^3)-((0.5*Tnety/6)*(Lixy(7) - cT(4))^3)-
    ((0.5*Tnety/6)*(Lixy(7) - cT(5))^3)-((0.5*Tnety/6)*(Lixy(7) - cT(6))^3)-
    ((0.5*Tnety/6)*(Lixy(7) - cT(7))^3)-((0.5*Tnety/6)*(Lixy(7) - cT(8))^3)];...
    [-(0.5*Tnety/2)*(Lixy(7) - cT(1))^2)-((0.5*Tnety/2)*(Lixy(7) - cT(2))^2)-
    ((0.5*Tnety/2)*(Lixy(7) - cT(3))^2)-((0.5*Tnety/2)*(Lixy(7) - cT(4))^2)-
    ((0.5*Tnety/2)*(Lixy(7) - cT(5))^2)-((0.5*Tnety/2)*(Lixy(7) - cT(6))^2)-
    ((0.5*Tnety/2)*(Lixy(7) - cT(7))^2)-((0.5*Tnety/2)*(Lixy(7) - cT(8))^2)];...
    [-(0.5*Tnety/2)*(Lixy(4) - cT(1))^2)-((0.5*Tnety/2)*(Lixy(4) - cT(2))^2)-
    ((0.5*Tnety/2)*(Lixy(4) - cT(3))^2)-((0.5*Tnety/2)*(Lixy(4) - cT(4))^2)]];
spp3 = spp1\spp2;
%}
spp1 = ([1 1 1 1 0];...
    [(Lixy(4)-Lixy(1)) (Lixy(4)-Lixy(2)) (Lixy(4)-Lixy(3)) 0 0];...
    [(1/6)*(Lixy(2) - Lixy(1))^3 0 0 0 -Lixy(2)];...
    [(1/6)*(Lixy(3) - Lixy(1))^3 (1/6)*(Lixy(3) - Lixy(2))^3 0 0 -Lixy(3)];...
    [(1/6)*(Lixy(4) - Lixy(1))^3 (1/6)*(Lixy(4) - Lixy(2))^3 (1/6)*(Lixy(4) -
Lixy(3))^3 0 -Lixy(4)];...
    [(1/2)*(Lixy(4) - Lixy(1))^2 (1/2)*(Lixy(4) - Lixy(2))^2 (1/2)*(Lixy(4) -
Lixy(3))^2 0 -1]]];
spp2 = ([2*Tnety];...
    [0.5*Tnety*(Lixy(4)-cT(1))+0.5*Tnety*(Lixy(4)-cT(2))+0.5*Tnety*(Lixy(4)-
cT(3))+0.5*Tnety*(Lixy(4)-cT(4))];...
    [(Tnety/12)*(Lixy(2)-cT(1))^3];...
    [(Tnety/12)*(Lixy(3)-cT(1))^3 + (Tnety/12)*(Lixy(3)-cT(2))^3];...
    [(Tnety/12)*(Lixy(4)-cT(1))^3 + (Tnety/12)*(Lixy(4)-cT(2))^3 +
(Tnety/12)*(Lixy(4)-cT(3))^3 + (Tnety/12)*(Lixy(4)-cT(4))^3];...
    [(Tnety/4)*(Lixy(4)-cT(1))^2 + (Tnety/4)*(Lixy(4)-cT(2))^2 +
(Tnety/4)*(Lixy(4)-cT(3))^2 + (Tnety/4)*(Lixy(4)-cT(4))^2]]];
spp3 = spp1\spp2;
% Connection Reactions [lbfb]
R1 = spp3(1);    R2 = spp3(2);    R3 = spp3(3);    R4 = spp3(4);
R5 = spp3(3);    R6 = spp3(2);    R7 = spp3(1);    bcS = spp3(5);
bcd = 0;

% Shear
Vixy = (0.5*Tnety/1)*(xi > cT(1)).*(xi - cT(1)).^(0) ...
    +(0.5*Tnety/1)*(xi > cT(2)).*(xi - cT(2)).^(0) ...
    +(0.5*Tnety/1)*(xi > cT(3)).*(xi - cT(3)).^(0) ...
    +(0.5*Tnety/1)*(xi > cT(4)).*(xi - cT(4)).^(0) ...
    +(0.5*Tnety/1)*(xi > cT(5)).*(xi - cT(5)).^(0) ...
    +(0.5*Tnety/1)*(xi > cT(6)).*(xi - cT(6)).^(0) ...
    +(0.5*Tnety/1)*(xi > cT(7)).*(xi - cT(7)).^(0) ...

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```

+(0.5*Tnety/1)*(xi > cT(8)).*(xi - cT(8)).^(0) ...
-(R1/1)*(xi > Lixy(1)).*(xi - Lixy(1)).^(0) ...
-(R2/1)*(xi > Lixy(2)).*(xi - Lixy(2)).^(0) ...
-(R3/1)*(xi > Lixy(3)).*(xi - Lixy(3)).^(0) ...
-(R4/1)*(xi > Lixy(4)).*(xi - Lixy(4)).^(0) ...
-(R5/1)*(xi > Lixy(5)).*(xi - Lixy(5)).^(0) ...
-(R6/1)*(xi > Lixy(6)).*(xi - Lixy(6)).^(0) ...
-(R7/1)*(xi > Lixy(7)).*(xi - Lixy(7)).^(0);

% Moment
Mixy = (0.5*Tnety/1)*(xi > cT(1)).*(xi - cT(1)).^(1) ...
+(0.5*Tnety/1)*(xi > cT(2)).*(xi - cT(2)).^(1) ...
+(0.5*Tnety/1)*(xi > cT(3)).*(xi - cT(3)).^(1) ...
+(0.5*Tnety/1)*(xi > cT(4)).*(xi - cT(4)).^(1) ...
+(0.5*Tnety/1)*(xi > cT(5)).*(xi - cT(5)).^(1) ...
+(0.5*Tnety/1)*(xi > cT(6)).*(xi - cT(6)).^(1) ...
+(0.5*Tnety/1)*(xi > cT(7)).*(xi - cT(7)).^(1) ...
+(0.5*Tnety/1)*(xi > cT(8)).*(xi - cT(8)).^(1) ...
-(R1/1)*(xi > Lixy(1)).*(xi - Lixy(1)).^(1) ...
-(R2/1)*(xi > Lixy(2)).*(xi - Lixy(2)).^(1) ...
-(R3/1)*(xi > Lixy(3)).*(xi - Lixy(3)).^(1) ...
-(R4/1)*(xi > Lixy(4)).*(xi - Lixy(4)).^(1) ...
-(R5/1)*(xi > Lixy(5)).*(xi - Lixy(5)).^(1) ...
-(R6/1)*(xi > Lixy(6)).*(xi - Lixy(6)).^(1) ...
-(R7/1)*(xi > Lixy(7)).*(xi - Lixy(7)).^(1);

% Slope
S = (0.5*Tnety/2)*(xi > cT(1)).*(xi - cT(1)).^(2) ...
+(0.5*Tnety/2)*(xi > cT(2)).*(xi - cT(2)).^(2) ...
+(0.5*Tnety/2)*(xi > cT(3)).*(xi - cT(3)).^(2) ...
+(0.5*Tnety/2)*(xi > cT(4)).*(xi - cT(4)).^(2) ...
+(0.5*Tnety/2)*(xi > cT(5)).*(xi - cT(5)).^(2) ...
+(0.5*Tnety/2)*(xi > cT(6)).*(xi - cT(6)).^(2) ...
+(0.5*Tnety/2)*(xi > cT(7)).*(xi - cT(7)).^(2) ...
+(0.5*Tnety/2)*(xi > cT(8)).*(xi - cT(8)).^(2) ...
-(R1/2)*(xi > Lixy(1)).*(xi - Lixy(1)).^(2) ...
-(R2/2)*(xi > Lixy(2)).*(xi - Lixy(2)).^(2) ...
-(R3/2)*(xi > Lixy(3)).*(xi - Lixy(3)).^(2) ...
-(R4/2)*(xi > Lixy(4)).*(xi - Lixy(4)).^(2) ...
-(R5/2)*(xi > Lixy(5)).*(xi - Lixy(5)).^(2) ...
-(R6/2)*(xi > Lixy(6)).*(xi - Lixy(6)).^(2) ...
-(R7/2)*(xi > Lixy(7)).*(xi - Lixy(7)).^(2) + bcS;

Iixy = I(fD(1))*(xi >= 0) - I(fD(1))*(xi >= 93) + ...
I(fD(2))*(xi >= 93) - I(fD(2))*(xi >= 399) + ...
I(fD(1))*(xi >= 399);
Aixy = A(fD(1))*(xi >= 0) - A(fD(1))*(xi >= 93) + ...
A(fD(2))*(xi >= 93) - A(fD(2))*(xi >= 399) + ...
A(fD(1))*(xi >= 399);
Sixy = S./(E*Iixy);

% Deflection
D = +(0.5*Tnety/6)*(xi > cT(1)).*(xi - cT(1)).^(3) ...

```

```

+ (0.5*Tnety/6)*(xi > cT(2)).*(xi - cT(2)).^(3) ...
+ (0.5*Tnety/6)*(xi > cT(3)).*(xi - cT(3)).^(3) ...
+ (0.5*Tnety/6)*(xi > cT(4)).*(xi - cT(4)).^(3) ...
+ (0.5*Tnety/6)*(xi > cT(5)).*(xi - cT(5)).^(3) ...
+ (0.5*Tnety/6)*(xi > cT(6)).*(xi - cT(6)).^(3) ...
+ (0.5*Tnety/6)*(xi > cT(7)).*(xi - cT(7)).^(3) ...
+ (0.5*Tnety/6)*(xi > cT(8)).*(xi - cT(8)).^(3) ...
- (R1/6)*(xi > Lixy(1)).*(xi - Lixy(1)).^(3) ...
- (R2/6)*(xi > Lixy(2)).*(xi - Lixy(2)).^(3) ...
- (R3/6)*(xi > Lixy(3)).*(xi - Lixy(3)).^(3) ...
- (R4/6)*(xi > Lixy(4)).*(xi - Lixy(4)).^(3) ...
- (R5/6)*(xi > Lixy(5)).*(xi - Lixy(5)).^(3) ...
- (R6/6)*(xi > Lixy(6)).*(xi - Lixy(6)).^(3) ...
- (R7/6)*(xi > Lixy(7)).*(xi - Lixy(7)).^(3) + bcS.*xi + bcD;

Dixy = D./(E*Iixy);
%{
% Beam Diagrams
% Shear Force Diagram Figure
strSV01 = ('Main Length Shear Force Diagram XY');
strSV02 = (['Shear Force [' strU02 ']]');
SVf = figure('Name',strSV01,'Resize','On','Visible','on');
hold on;
%axis([x min} {x max} {y min} {y max}]);
grid on;
hSF = area(xi,Vixy);
hlegSF = legend([hSF],{strSV02});
set(hlegSF,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01;
strYlab = strU02;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;

% Bending Moment Diagram Figure
strSM01 = ('Main Length Bending Moment Diagram XY');
strSM02 = (['Bending Moment [' strU03 ']]');
SMf = figure('Name',strSM01,'Resize','On','Visible','on');
hold on;
%axis([x min} {x max} {y min} {y max}]);
grid on;
hSM = area(xi,Mixy);
hlegSM = legend([hSM],{strSM02});
set(hlegSM,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01;
strYlab = strU03;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);

```

```

%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;

% Slope Diagram Figure
strSS01 = ('Main Length Slope Diagram XY');
strSS02 = (['Slope [' strU04 ']]');
SSf = figure('Name',strSS01,'Resize','On','Visible','on');
hold on;
%axis([x min] [x max] [y min] [y max]));
grid on;
hSS = area(xi,Sixy);
hlegSS = legend([hSS],{strSS02});
set(hlegSS,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01;
strYlab = strU04;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;

% Deflection Diagram Figure
strD01 = ('Main Length Deflection Diagram XY');
strD02 = (['Deflection [' strU01 ']]');
Df = figure('Name',strD01,'Resize','On','Visible','on');
hold on;
hD = area(xi,Dixy);
grid on;
hlegD = legend([hD],{strU01});
set(hlegD,'FontSize',pftxt,'Location','best','orientation','vertical');
set(gca,'FontName',psname,'FontSize',pstxt);
strXlab = strU01; strYlab = strU01;
xlabel(strXlab,'FontSize',patxt,'fontweight',pawt);
ylabel(strYlab,'FontSize',patxt,'fontweight',pawt);
%text({x position},{y position},str,'FontSize',pftxt,'FontName',psname);
hold off;
%}

```

Minor Length XY Plane

Column Loading

```

k = sqrt(I(fD(3))/A(fD(3))); % Radius of Gyration [in]

Sr = Lj/k; % Actual Slenderness Ratio
Srj = pi*sqrt(2*E/YS); % Slenderness Ratio for Johnson Region

Mjxy = zeros(1,length(xj));
Vjxy = zeros(1,length(xj));

```

```

% Critical Loading
if Sr <= Srj
    Pcr = A(fD(3))*(YS - E^(-1)*((YS*Sr)/(2*pi))^2); % Johnson Region
else
    Pcr = pi^2*E*A(fD(3))/Sr^2; % Euler Region
end

% Compression
sigC = max(abs([R1 R2 R3 R4 R5 R6 R7]))/A(fD(3));

% Factor of Safety
FScl = Pcr/max(abs([R1 R2 R3 R4 R5 R6 R7]));

```

Major Length Stresses

Top Surface

```

%{
Stresses coming from bending in XZ plane and transverse shear of bending in
XY plane
%}
for i = 1:length(xi)
    if abs(Vixy(i)) == max(abs(Vixy))
        ii = i;
    else
    end
    if abs(Mixz(i)) == max(abs(Mixz))
        jj = i;
    else
    end
end
% At length where max shear occurs
sgnx1 = Mixz(ii)*R/Iixz(ii);
txy1 = 2*Vixy(ii)/Aixz(ii);

ustr1 = ([[sgnx1 txy1 0];[txy1 0 0];[0 0 0]]);
sig_p1 = eig(ustr1); % Find the eigenvector to know stress in principle direction
p1a = max(sig_p1);
p3a = min(sig_p1);
p2a = sig_p1(2);

% At length where max bending occurs
sgnx2 = Mixz(jj)*R/Iixz(jj);
txy2 = 2*Vixy(jj)/Aixy(jj);

ustr2 = ([[sgnx2 txy2 0];[txy2 0 0];[0 0 0]]);
sig_p2 = eig(ustr2); % Find the eigenvector to know stress in principle direction
p1b = max(sig_p2);
p3b = min(sig_p2);
p2b = sig_p2(2);

```

```

% Side Surface
%{
Stresses coming from bending in XY plane and transverse shear of bending in
XZ plane
%}
for i = 1:length(xi)
    if abs(Vixz(i)) == max(abs(Vixz))
        ii = i;
    else
    end
    if abs(Mixy(i)) == max(abs(Mixy))
        jj = i;
    else
    end
end
% At length where max shear occurs
sgny3 = Mixy(ii)*R/Iixy(ii);
txz3 = 2*Vixz(ii)/Aixy(ii);

ustr3 = ([[0 0 txz3];[0 sgny3 0];[txz3 0 0]]);
sig_p3 = eig(ustr3); % Find the eigenvector to know stress in principle direction
p1c = max(sig_p3);
p3c = min(sig_p3);
p2c = sig_p3(2);

% At length where max bending occurs
sgny4 = Mixy(jj)*R/Iixy(jj);
txz4 = 2*Vixz(jj)/Aixy(jj);

ustr4 = ([[0 0 txz4];[0 sgny4 0];[txz4 0 0]]);
sig_p4 = eig(ustr4); % Find the eigenvector to know stress in principle direction
p1d = max(sig_p4);
p3d = min(sig_p4);
p2d = sig_p4(2);

% Neutral Axis
%{
Stresses coming from transverse shear of bending in XZ and XY planes
%}
for i = 1:length(xi)
    if abs(Vixz(i)) == max(abs(Vixz))
        ii = i;
    else
    end
    if abs(Vixy(i)) == max(abs(Vixy))
        jj = i;
    else
    end
end
end

```

```

% At length where max shear in XZ Plane occurs
txz5 = 2*Vixz(ii)/Aixz(ii);
txy5 = 2*Vixy(ii)/Aixz(ii);

ustr2 = ([0 txy5 txz5];[txy5 0 0];[txz5 0 0]);
sig_p2 = eig(ustr2); % Find the eigenvector to know stress in principle direction
p1b = max(sig_p2);
p3b = min(sig_p2);
p2b = sig_p2(2);

% At length where max shear in XY Plane occurs
txz6 = 2*Vixz(jj)/Aixz(jj);
txy6 = 2*Vixy(jj)/Aixy(jj);

ustr6 = ([0 txy6 txz6];[txy6 0 0];[txz6 0 0]);
sig_p6 = eig(ustr6); % Find the eigenvector to know stress in principle direction
p1f = max(sig_p6);
p3f = min(sig_p6);
p2f = sig_p6(2);

if p1a > p1b && p1a > p1c && p1a > p1d && p1a > p1b && p1a > p1f
    sig_pi = sig_p1;
    %disp('The maximum stress occurs on the top surface.');
```

```

elseif p1b > p1a && p1b > p1c && p1b > p1d && p1b > p1b && p1b > p1f
    sig_pi = sig_p2;
    %disp('The maximum stress occurs on the top surface.');
```

```

elseif p1c > p1a && p1c > p1b && p1c > p1d && p1c > p1b && p1c > p1f
    sig_pi = sig_p3;
    %disp('The maximum stress occurs on the side surface.');
```

```

elseif p1d > p1a && p1d > p1b && p1d > p1c && p1d > p1b && p1d > p1f
    sig_pi = sig_p4;
    %disp('The maximum stress occurs on the side surface.');
```

```

elseif p1b > p1a && p1b > p1b && p1b > p1c && p1b > p1d && p1b > p1f
    sig_pi = sig_p2;
    %disp('The maximum stress occurs along the neutral axis.');
```

```

elseif p1f > p1a && p1f > p1b && p1f > p1c && p1f > p1d && p1f > p1b
    sig_pi = sig_p6;
    %disp('The maximum stress occurs along the neutral axis.');
```

```

end

% Choose Greatest Principal Stress
p1i = max(sig_pi);
p3i = min(sig_pi);
p2i = sig_pi(2);

% Calculate Maximum Shear Stress
tml1 = (p1i-p3i)./2;

% Calculate Von Mises Stress
svmi = sqrt(p1i^2 + p2i^2 + p3i^2 - p1i*p2i - p2i*p3i - p1i*p3i);
```

```

% Determine Yielding
FSci = YS/svmi;           % Static Yielding Factor of Safety
YSshi = 0.500*YS;         % Shear Yielding
FScsi = YSshi/tmli;       % Shear Yielding Factor of Safety

```

Minor Length Stresses

Top Surface

```

%{
Stresses coming from bending in YZ plane and transverse shear of bending in
XY plane
%}
for i = 1:length(xj)
    if abs(Vjxy(i)) == max(abs(Vjxy))
        ii = i;
    else
    end
    if abs(Mjyz(i)) == max(abs(Mjyz))
        jj = i;
    else
    end
end
% At length where max shear occurs
sgnx1 = Mjyz(ii)*R/I(fD(3));
txyl = 2*Vjxy(ii)/A(fD(3));

ustr1 = ([0 txyl 0];[txyl sgnx1+sigC 0];[0 0 0]);
sig_p1 = eig(ustr1); % Find the eigenvector to know stress in principle direction
p1a = max(sig_p1);
p3a = min(sig_p1);
p2a = sig_p1(2);

% At length where max bending occurs
sgnx2 = Mjyz(jj)*R/I(fD(3));
txy2 = 2*Vjxy(jj)/I(fD(3));

ustr2 = ([0 txy2 0];[txy2 sgnx2+sigC 0];[0 0 0]);
sig_p2 = eig(ustr2); % Find the eigenvector to know stress in principle direction
p1b = max(sig_p2);
p3b = min(sig_p2);
p2b = sig_p2(2);

% Side Surface
%{
Stresses coming from bending in XY plane and transverse shear of bending in
YZ plane
%}
for i = 1:length(xj)
    if abs(Vjyz(i)) == max(abs(Vjyz))

```

```

        ii = i;
    else
    end
    if abs(Mjxy(i)) == max(abs(Mjxy))
        jj = i;
    else
    end
end
% At length where max shear occurs
sgny3 = Mjxy(ii)*R/I(fD(3));
tyz3 = 2*Vjyz(ii)/A(fD(3));

ustr3 = ([[0 0 tyz3];[0 sgny3+sigC 0];[tyz3 0 0]]);
sig_p3 = eig(ustr3); % Find the eigenvector to know stress in principle direction
plc = max(sig_p3);
p3c = min(sig_p3);
p2c = sig_p3(2);

% At length where max bending occurs
sgny4 = Mjxy(jj)*R/I(fD(3));
tyz4 = 2*Vjyz(jj)/A(fD(3));

ustr4 = ([[0 0 tyz4];[0 sgny4+sigC 0];[tyz4 0 0]]);
sig_p4 = eig(ustr4); % Find the eigenvector to know stress in principle direction
pld = max(sig_p4);
p3d = min(sig_p4);
p2d = sig_p4(2);

% Neutral Axis
%{
Stresses coming from transverse shear of bending in XZ and XY planes
%}
for i = 1:length(xj)
    if abs(Vjyz(i)) == max(abs(Vjyz))
        ii = i;
    else
    end
    if abs(Vjxy(i)) == max(abs(Vjxy))
        jj = i;
    else
    end
end
% At length where max shear in XZ Plane occurs
tyz5 = 2*Vjyz(ii)/A(fD(3));
txy5 = 2*Vjxy(ii)/A(fD(3));

ustr5 = ([[0 txy5 tyz5];[txy5 sigC 0];[tyz5 0 0]]);
sig_p5 = eig(ustr5); % Find the eigenvector to know stress in principle direction
ple = max(sig_p5);
p3e = min(sig_p5);

```

```

p2e = sig_p5(2);

% At length where max shear in XY Plane occurs
tyz6 = 2*Vjyz(jj)/A(fD(3));
txy6 = 2*Vjxy(jj)/A(fD(3));

ustr6 = ([[0 txy6 tyz6];[txy6 sigC 0];[tyz6 0 0]]);
sig_p6 = eig(ustr6); % Find the eigenvector to know stress in principle direction
plf = max(sig_p6);
p3f = min(sig_p6);
p2f = sig_p6(2);

%if pla > plb && pla > plc && pla > pld && pla > plb && pla > plf
if pla >= max([plb plc pld ple plf])
    sig_pj = sig_p1;
    %disp('The maximum stress occurs on the top surface.');
```

```

%elseif plb > pla && plb > plc && plb > pld && plb > plb && plb > plf
elseif plb >= max([pla plc pld ple plf])
    sig_pj = sig_p2;
    %disp('The maximum stress occurs on the top surface.');
```

```

%elseif plc > pla && plc > plb && plc > pld && plc > plb && plc > plf
elseif plc >= max([pla plb pld ple plf])
    sig_pj = sig_p3;
    %disp('The maximum stress occurs on the side surface.');
```

```

%elseif pld > pla && pld > plb && pld > plc && pld > plb && pld > plf
elseif pld >= max([pla plc plb ple plf])
    sig_pj = sig_p4;
    %disp('The maximum stress occurs on the side surface.');
```

```

%elseif ple > pla && ple > plb && ple > plc && ple > pld && ple > plf
elseif ple >= max([pla plb plc pld plf])
    sig_pj = sig_p2;
    %disp('The maximum stress occurs along the neutral axis.');
```

```

%elseif plf > pla && plf > plb && plf > plc && plf > pld && plf > plb
elseif plf >= max([pla plb plc pld ple])
    sig_pj = sig_p6;
    %disp('The maximum stress occurs along the neutral axis.');
```

```

end

% Choose Greatest Principal Stress
plj = max(sig_pj);
p3j = min(sig_pj);
p2j = sig_pj(2);

% Calculate Maximum Shear Stress
tmlj = (plj-p3j)./2;

% Calculate Von Mises Stress
svmj = sqrt(plj^2 + p2j^2 + p3j^2 - plj*p2j - p2j*p3j - plj*p3j);

% Determine Yielding
FScj = YS/svmj; % Static Yielding Factor of Safety

```

```
YSshj = 0.500*YS;      % Shear Yielding
FScsj = YSshj/tm1j;    % Shear Yielding Factor of Safety
```

Reporting

```
def = max(abs(Dixz));

j = 1;

for i = 1:length(xi)
    if abs(Dixz(i)) == max(abs(Dixz))
        ii(j) = i;
        j = j + 1;
    else
        end
end
if xi(ii) > xi(1) && xi(ii) < xi(length(xi))
    defp = xi(ii);
    str01 = (['The maximum deflection is ' num2str(def,'%2.4f') ' [in], located ' ...
        num2str(defp(1),'%3.1f') ' [in] from end.']);
elseif xi(ii) == xi(1)
    str01 = (['The maximum deflection is ' num2str(def,'%2.4f') ' [in], located at
end.']);
elseif xi(ii) == xi(length(xi))
    str01 = (['The maximum deflection is ' num2str(def,'%2.4f') ' [in], located at
end.']);
else
end
disp(str01);

rfsj = min([FScj FScsj]);
str02 = (['The minimum factor of safety in the cross-members is '
num2str(rfsj,'%2.2f') '.']);
disp(str02);

rfsi = min([FSci FScsi]);
str03 = (['The minimum factor of safety in the major length is ' num2str(rfsi,'%2.2f')
'.']);
disp(str03);
```

The maximum deflection is 0.3125 [in], located at end.

The minimum factor of safety in the cross-members is 20.84.

The minimum factor of safety in the major length is 4.54.

Concrete Pier Design

```
d = 2.8; %ft
L = 4.4; %ft
```

```

w = 300; %lbs
M = 4000; %lb*ft
F = 50*L*d; %lbs (soil force)
p = 150; %lb/ft^3 (density of concrete)
W = pi*(d/2)^2*L*p; %lbs (weight of concrete)
SumMom = W*(d/2) + F*(L/2) + w*(d/2) - M;
if SumMom >= 0
D = d*12
H = L*12
else
Disp('The design will fail. Try different values');
end
D =
33.6000
H =
52.8000

```

The diameter of the pier should be 34 inches and the height of the pier should be 53 inches.