Eric Garza, Luke Graber, Nelson Winbush
Golden Innovation
1301 Arapahoe Street
Golden, CO 80401

94/100

Dr. Robert Amaro
Mechanical Engineering Department
Brown Hall W350
1610 Illinois Street
Golden, Colorado 80401

If your design worked, I agree with this grade, given that I don't think it does & there is no proof of it I would give a ~~80-85~~ 90-95

Dear Dr. Amaro:

I am submitting the attached engineering package *Golden Innovation: Final Design Engineering Package, Canvas Wing* assigned Spring Semester 2015 to design an iconic wing structure to be installed in the flagship of the U.S. store.

I would like to acknowledge the MEGN 481 professor Dr. Amaro for his help in the preparation of the document our team is presenting to the client. Dr. Amaro proved to be invaluable with his experience in the design field. The resources provided by the Colorado School of Mines created better opportunities for our team to complete the best report possible for your company and interests.

I hope this report exceeds your expectations and my team wishes you the best with the operation of your viewing screens. If you have any further questions, please don't hesitate to contact me at 303-919-7659 or at ergarza@mymail.mines.edu.

Sincerely,

only 1 person ?

Eric Garza
Golden Innovation Liaison

Encl: *Golden Innovation: Final Design Engineering Package*

**PLEASE ACKNOWLEDGE RECEIPT OF DOCUMENTS LISTED BY SIGNING THE ATTACHED COPY AND RETURNING IT TO THE ABOVE SIGNED WITHIN ONE WEEK AFTER RECEIPT.**

**ACKNOWLEDGEMENT:**________________________________________

+

## Executive Summary:

### Introduction:

The report describes the Golden Innovation design solution proposed for the Canvas Wing. The report details alternative designs that were discussed in the early stages of designing the structure and the final agreed design. The agreed design was determined with a decision matrix and the requirements clarified by the project description provided from the customer. From this, a wing structure design, wing cable support design, and facility column support design has been created to address the different project requirements needed to automate the wing as requested by the client. The design was created to be aesthetically pleasing and customizable as per the client's liking. The structural design was created to be as light as possible to create a safe environment for the facility and visitors. The frame was modeled in Solidworks and a static analysis was performed to ensure the integrity of the structure during seismic conditions. Wing cable supports were sized and attachments selected via design criteria with appropriate safety factors. Cut sheets are attached in the engineering packet. Also, static analysis was performed on the existing columns to ensure that the selected automation system would be sufficiently supported. Any recommendations for the columns is included in the report as well as assumptions to their construction.

6 x2 array
public walking under -1

### General Construction:

ugh

Construction of the wing consists of a square tube aluminum frame appealing to the aesthetic design of a wings structure. The aluminum frame will be welded together on site. The wing frame was designed to emulate the shape of high tech stealth plane's wing while also incorporating elements to accentuate the projection screens. The frame is the support and structure for the two rear projection screens. Canvas is riveted to the frames on the sides to provide a surface where designs can be painted or printed as desired by the client. This allows for customization of the wings to a theme by the customer. The wings are supported from the center by two steel cables attached to the roof members using heavy duty beam clamps and a clevis attached to the frame by welding. The wing is to be animated using a winch and cable system attached to pre existing columns in the building. The winch system moves a set of steel rods that animate the structure from the rear. The wing is attached to the two steel rods with 4 bearings. The shaft bearings are bolted to the frame. The wing is to oscillate from the geometric center. The projection screens are not part of this scope and will be mounted by a subcontractor.

144" x102"

### Boundary and Initial Conditions:

wings "skeletal" in nature

Projector screens are to be mounted to the structure and weight 100 lbs. There will be two screens and they are self supporting, meaning that all forces being applied to the wing are point loads. The mounting design of the screens is to be determined in the future by the contractor installing them. The screens are to be projected from the back but separately from the wing. Decorative canvas is to be attached to the upper part of the structure. The canvas is not considered a structural material meaning it is for decoration only. Structural effects are

9'x 7' garage door

-1

neglected. Loading is to include lateral 3g seismic loads as specified by San Francisco building code. Building columns are pre existing and are created of a 4 in by 6 in by ½ in by 25 foot column. The columns are to be made of at least A-36 steel and are unsupported throughout the span. The wing can be made of any material but weight should be reduced as much as possible. The wing is to be articulated with two 1.5 inch diameter shafts that are 24 inches long. The shaft is to remain static. The structural slab that the columns are mounted on is considered sufficient for this application. The size limitations on the wings are that they can not be longer than 20 feet and narrower than 14 feet. The overall height of the structure must be less than 3 feet when laid flat on the ground. Twelve wings are to be constructed to fill a foyer that is 100 feet by 40 feet. The customer wishes that the wings be as long as possible to fill as much space. The wings are to be aesthetically pleasing in a wing type shape. The wings must articulate 13' vertically at their base. ~~fit through garage door~~

in this analysis

siesmic → where?

**Material Specifications:**

Structural Beam: 7075-T6 Aluminum
Wire Rope: Extra Improved Plow Steel
Welding: ER4043 Lincoln Electric Wire
Clevis Mount: 7075-T6 Aluminum
Swage Socket: Bar Quality Steel as specified by provider
Shaft Bearing: Cast Iron as specified by provider

**Findings:**

- Structural Aluminum to be made of 7075 - T6 3"x3" beam
- Wire rope to be made of Extra Improved Plow Steel, ⅜ " diameter
- Clevis Mounts to be made of 7075-T6 Aluminum
- All safety factors were determined to be SF > 3.5 for stress under loadings
- All deflections were sufficiently small (< L/360)

list eee individ

State all assumptions (e.g. welded connections are joined perfectly)

## Analysis:

-1

define. ☒ Tube, I-beam?

### Wing Analysis:

The Wing was constructed using 3"x3" 7075 - T6 Aluminum beam. The beam was loaded along the horizontal beams of the top frame of the structure. Each beam was loaded with a force of 100 lbf. In this we are making an assumption that the screens will be loaded to the structure along the beams as such since it was not stated in the project description. There were brackets in the assembly which were welded to the top frame of the assembly. These brackets then received a fixed geometry along the cylindrical faces, restricting the beam from moving in all but the translational and rotational Z direction. The two end joints were fixed similarly but were not free to translate in the Z direction. This restraint represents the shafts attached to the columns. Finally a gravitational load of g= 32.2ft/lb was applied to the center of the assembly to represent the effect of gravity on the structure.

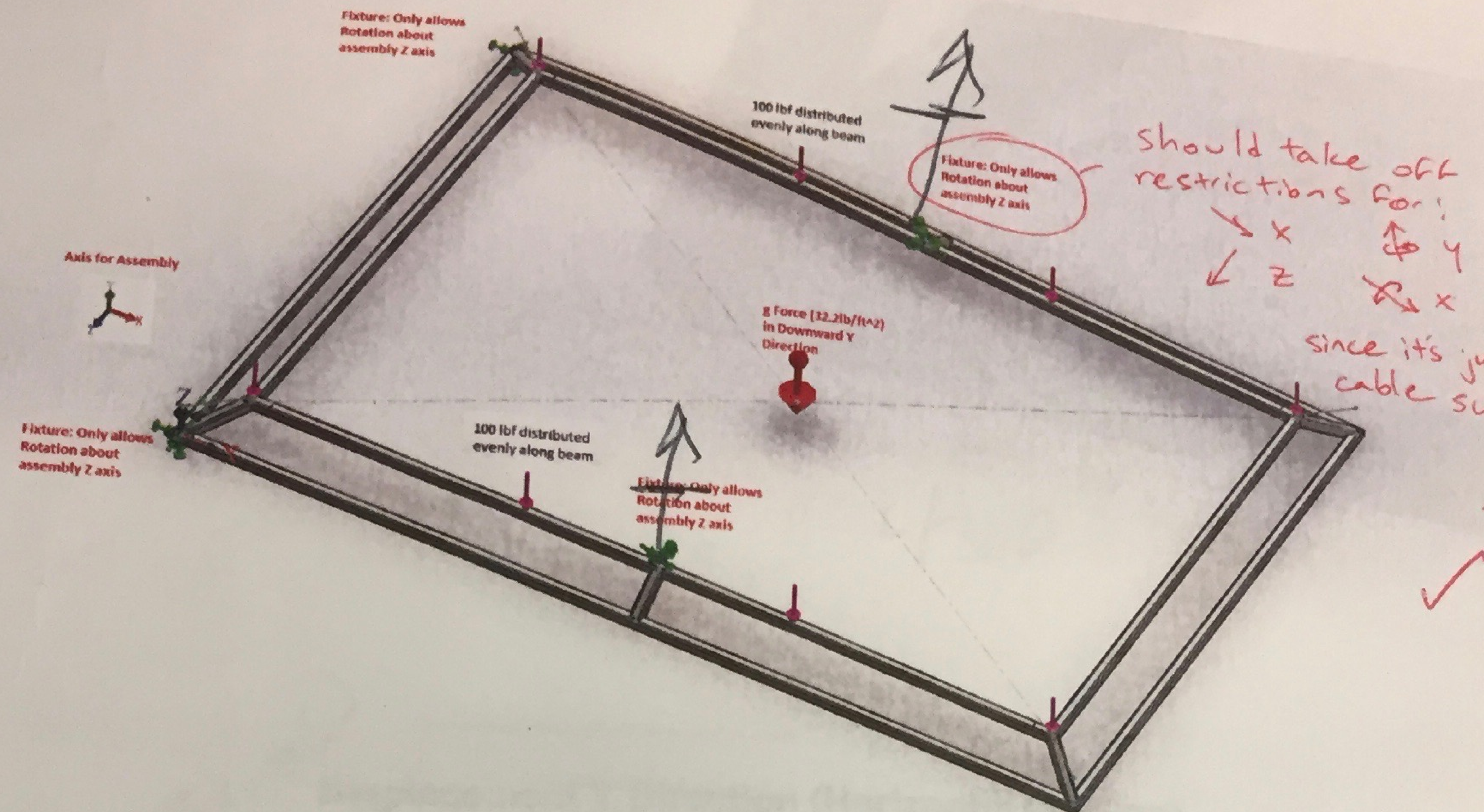
inc

wing sies $\sigma_{VM} =$ → FoS =

col sies

win sies $\delta_{max} =$ → FoS =

## Horizontal Loading FBD

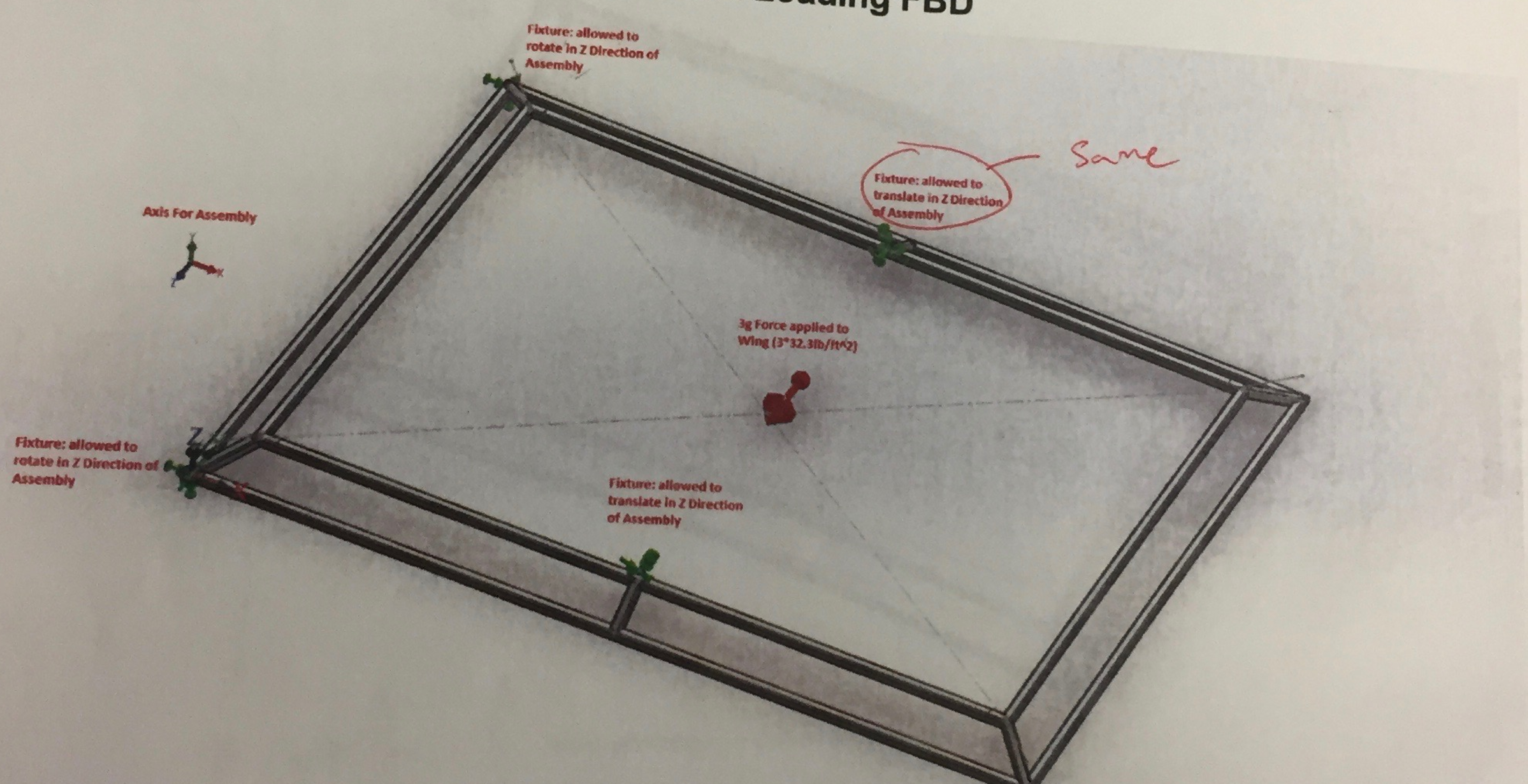



Should take off restrictions for:
X
Z
Y
X
since it's just cable support

-1

✓

## Seismic Loading FBD




Same

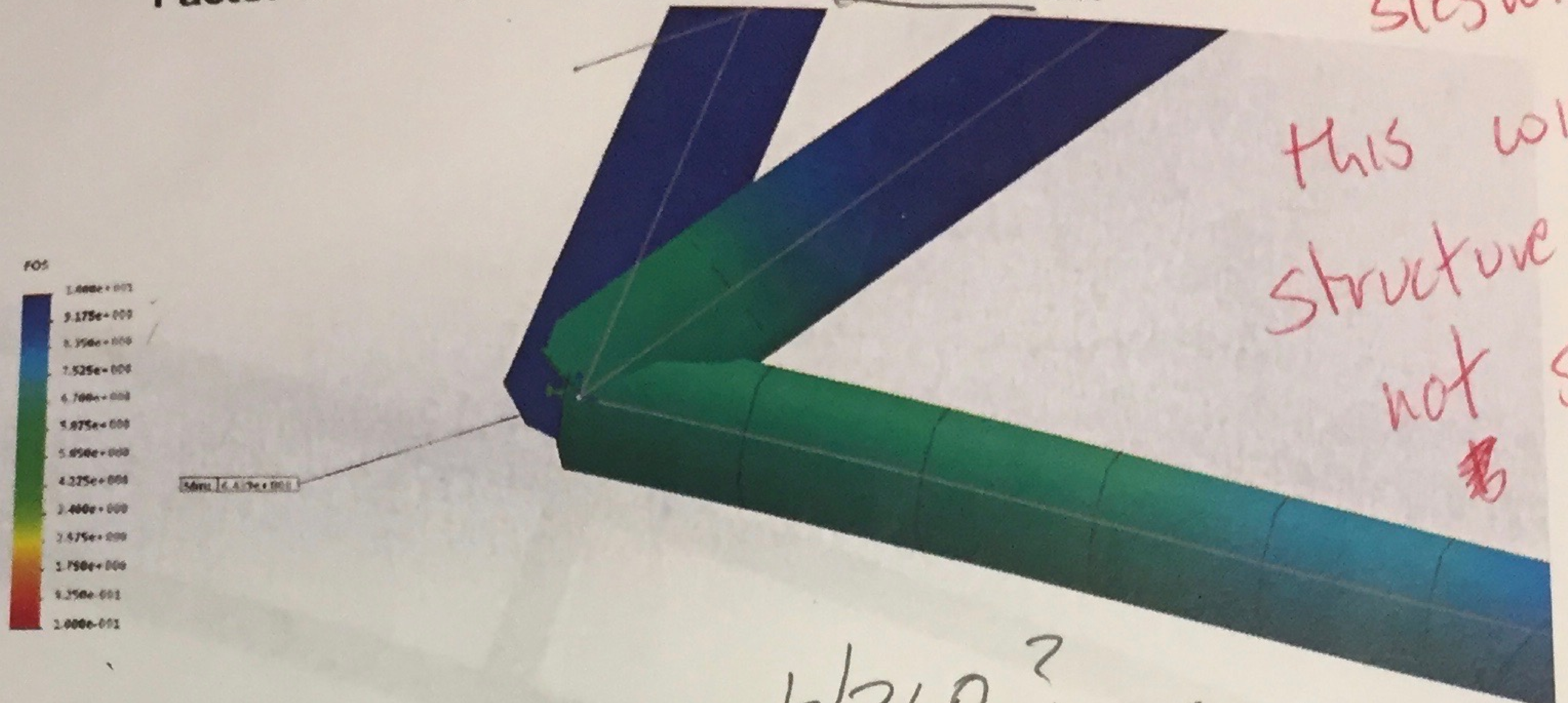
what about tests in the other orientations?

-2

☆ 4/360 for siesmic

this wing structure is not soffient,

## Factor of Safety Plot (3g Loading)- Von Mises:

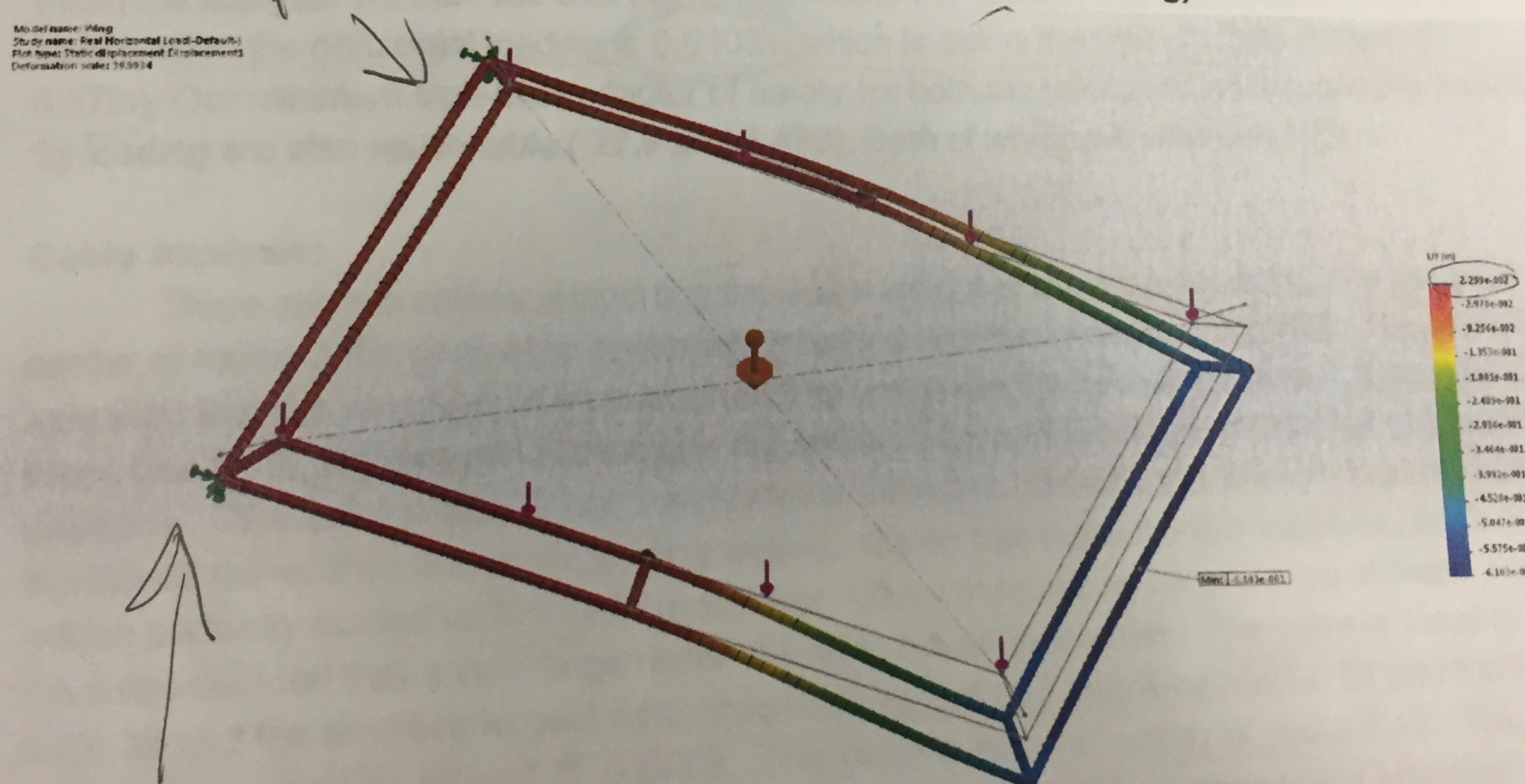



4/360? siesmic

Educational Version. For Instructional Use Only

Fixed

## Displacement Y Direction (Horizontal Loading)



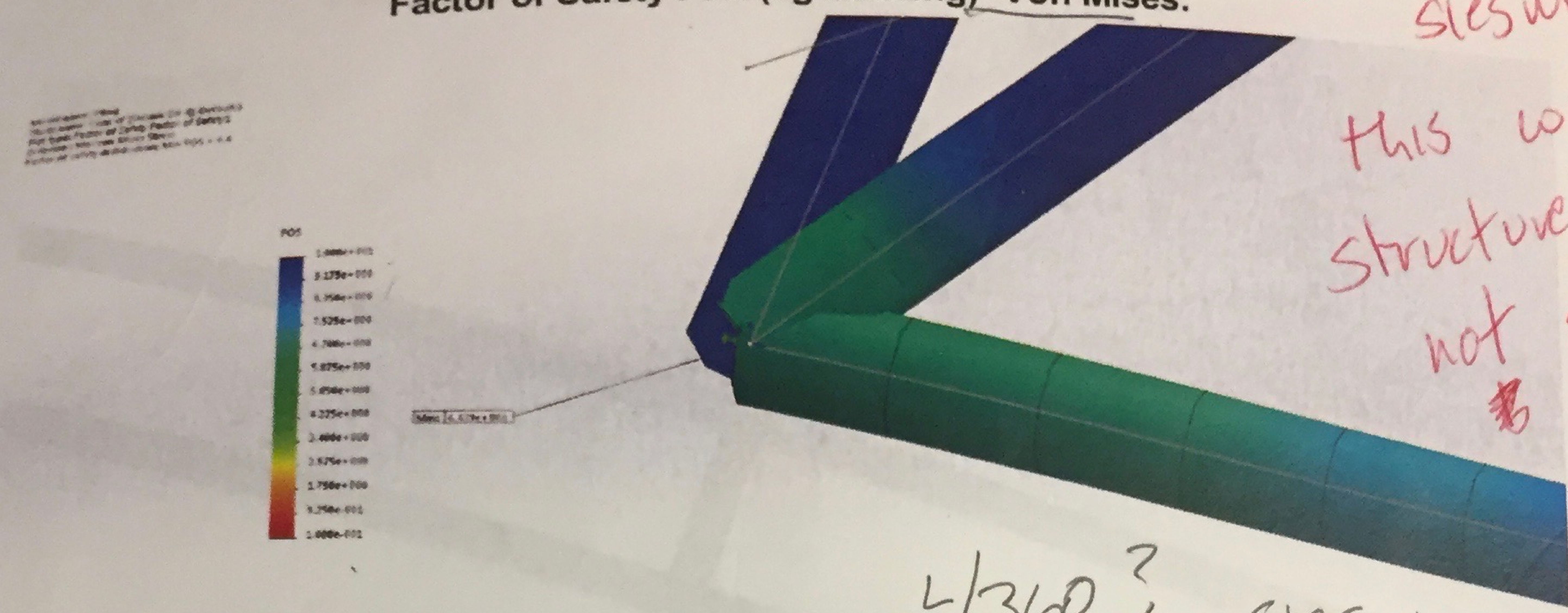

~~.002~~ .02

Fixed

Educational Version. For Instructional Use Only

L/360 for siesmic

### Factor of Safety Plot (3g Loading)- Von Mises:



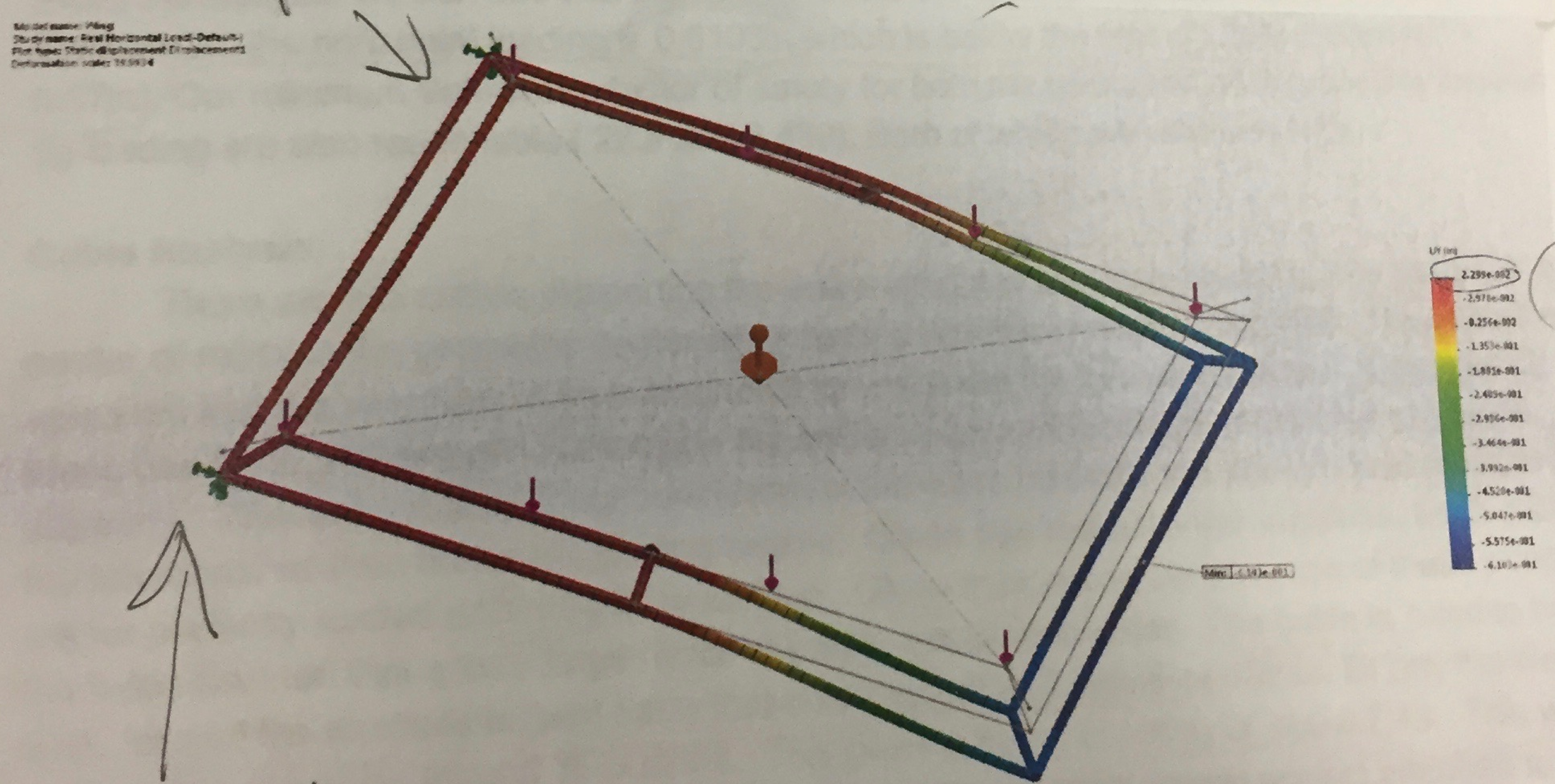
this wing structure is not soffient,

L/360? siesmic



Fixed

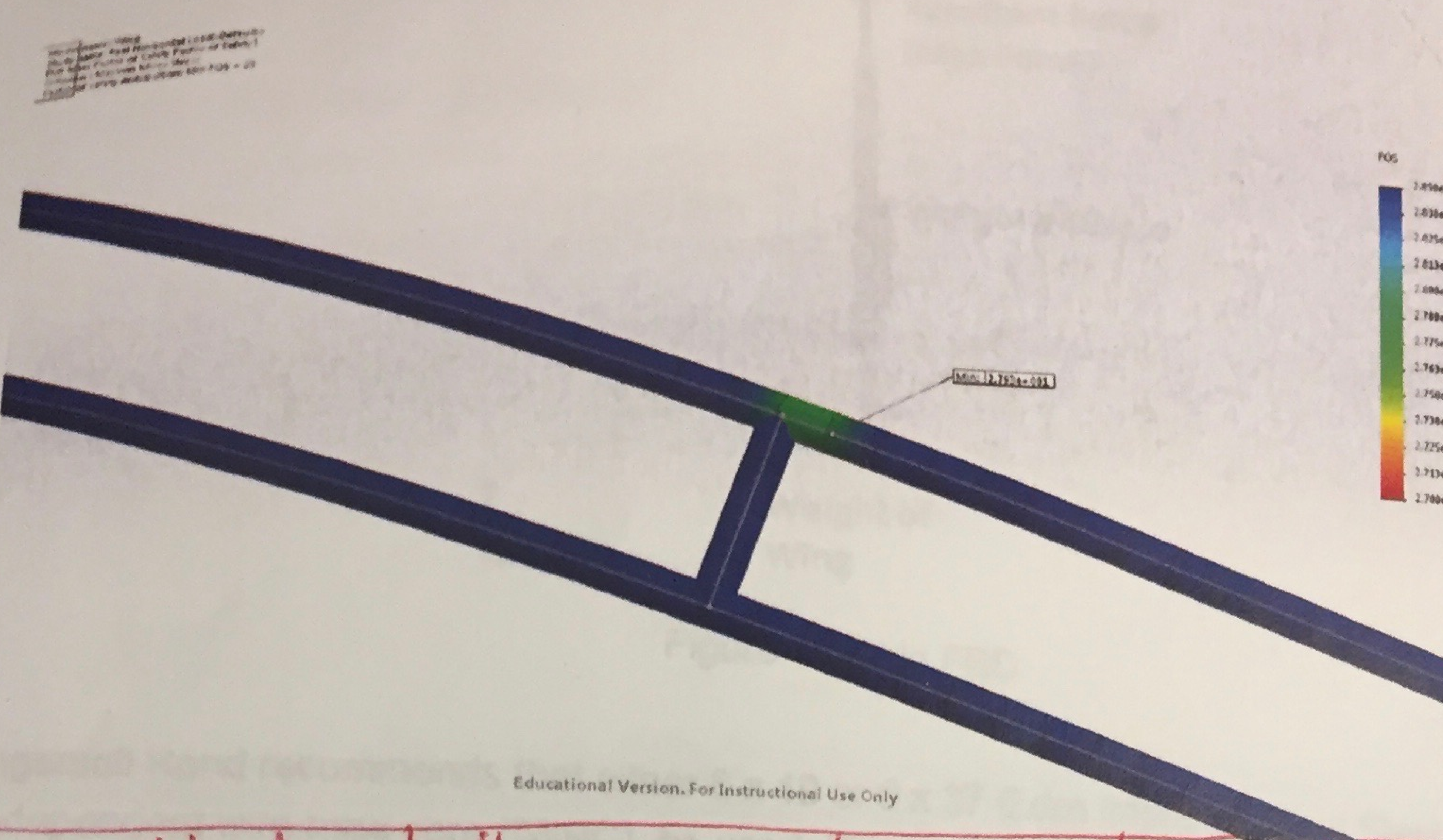
### Displacement Y Direction (Horizontal Loading)



~~.02~~ .02

Fixed

**Factor of Safety Plot (Horizontal Loading)- Von Mises:**




that tells me it won't meet seismic requi[re...] elsew[here...]

From the analysis we can see that the design meets the criteria. The deformation in the Y direction for the horizontal loading is 0.6103in which is below the limit of L/360 (240in/360 = 0.67in). Our minimum Von-Mises factor of safety for both the horizontal loading and the seismic 3g loading are also reasonable ( 27.9 and 6.439). Both of which are relatively high.

**Cable Analysis:**

There are two cables supporting the entire weight of the wing structure. The wing has a center of mass in the geometric center when loaded with the projection screens. The customer specified that the wing should be supported from cables in the geometric center. Considering these two facts, the analysis will include the entire weight of the structure from the two cable supports. The seismic load is not considered in this case because the seismic load is applied in the lateral rather than horizontal loading regime. Given that there are two supports, each cable will be perfectly loaded to 208.04 lbf in tension. Given the cost and importance of these supports the team decided that a very large factor of safety would be in order. The cable is rated to hold 3020 lbf and the absolute largest force that could be put on it would be 408.08 lbf and the weight of the cable would be around 15 pounds. This gives a factor of safety of about 7.13. This will be more than sufficient. The cable will be terminated using an open swage socket attached to a clevis mount welded to the overall structure. Because there was no way to purchase such a mount, the piece will be fabricated and mounted to the teams specifications to fit the selected swage socket. The roof end of the wire rope will be terminated with a swage hex threaded stud that will connect to the roof using epoxy all thread fasteners as specified by Hilti. A ⅜" threaded rod nut will connect these two entities to secure to the building.

where'd you get this number? I didn't see the mass mentioned yet. 204.04?

pul[l] f[...]

ok [...]

over lif[t]

We det wing weight = 208 ×2

which cable, specifically?

3/8" ϕ

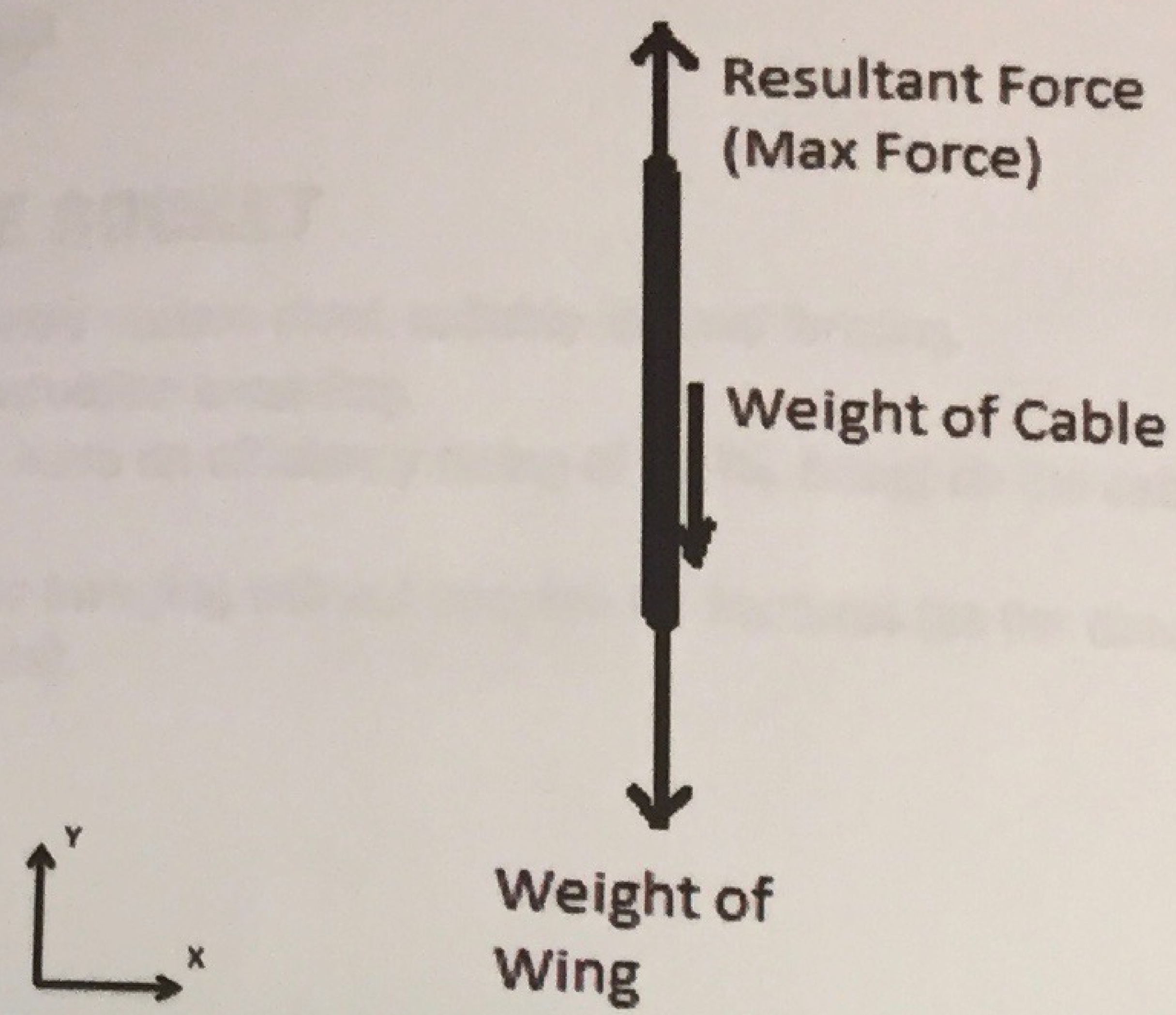



Figure - Cable FBD

Ingersoll Rand recommends that either 6 x 19 or 6 x 37 Extra Improved Plow Steel (EIPS), with independent wire rope core (IWRC), be used. This is a higher-strength rope than Improved Plow Steel (IPS), offering approximately a 15% increase in breaking strength. We recommend it, as it is readily available and offers better value overall.

| Rope Size | | Breaking Strength | | Weight | | Rec'd safe working loads 3.5:1 | | 5:1 | |
|---|---|---|---|---|---|---|---|---|---|
| in. | mm | lbs | kg | lbs/ft | kg/m | lbs | kg | lbs | kg |
| 1/4 | 6 | 6800 | 3091 | 0.12 | .17 | 1943 | 883 | 1360 | 618 |
| 5/16 | 8 | 10540 | 4791 | 0.18 | .27 | 3011 | 1369 | 2108 | 958 |
| 3/8 | 9 | 15100 | 6864 | 0.26 | .39 | 4314 | 1961 | 3020 | 1373 |

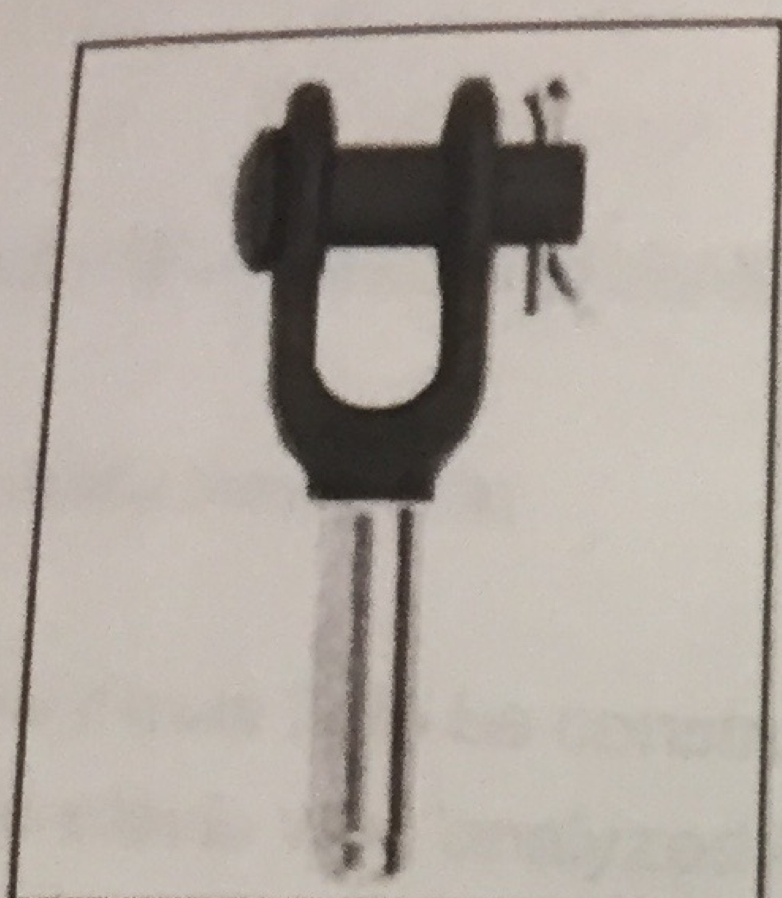
http://www.ingersollrandproducts.com/am-en/products/lifting/winches/winch-selection-support/wire-rope-selection

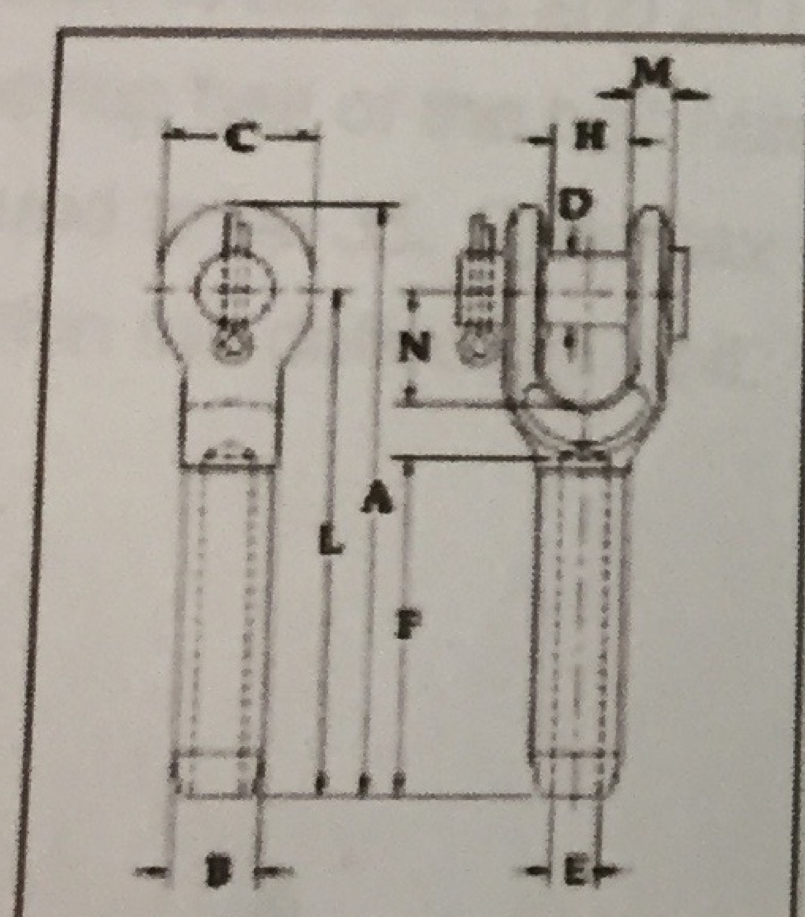
**The below Swage Lock is sufficient for our needs:**

the Crosby group inc.

## S-501 OPEN SWAGE SOCKET

- Forged from special bar quality carbon steel, suitable for cold forming.
- Hardness controlled by spheroidize annealing.
- Swage socket terminations have an efficiency rating of 100%, based on the catalog strength of wire rope.
- Stamp for identification after swaging without concern for fractures (as per directions in National Swaging Brochure).






these are nice, but need pull-out force

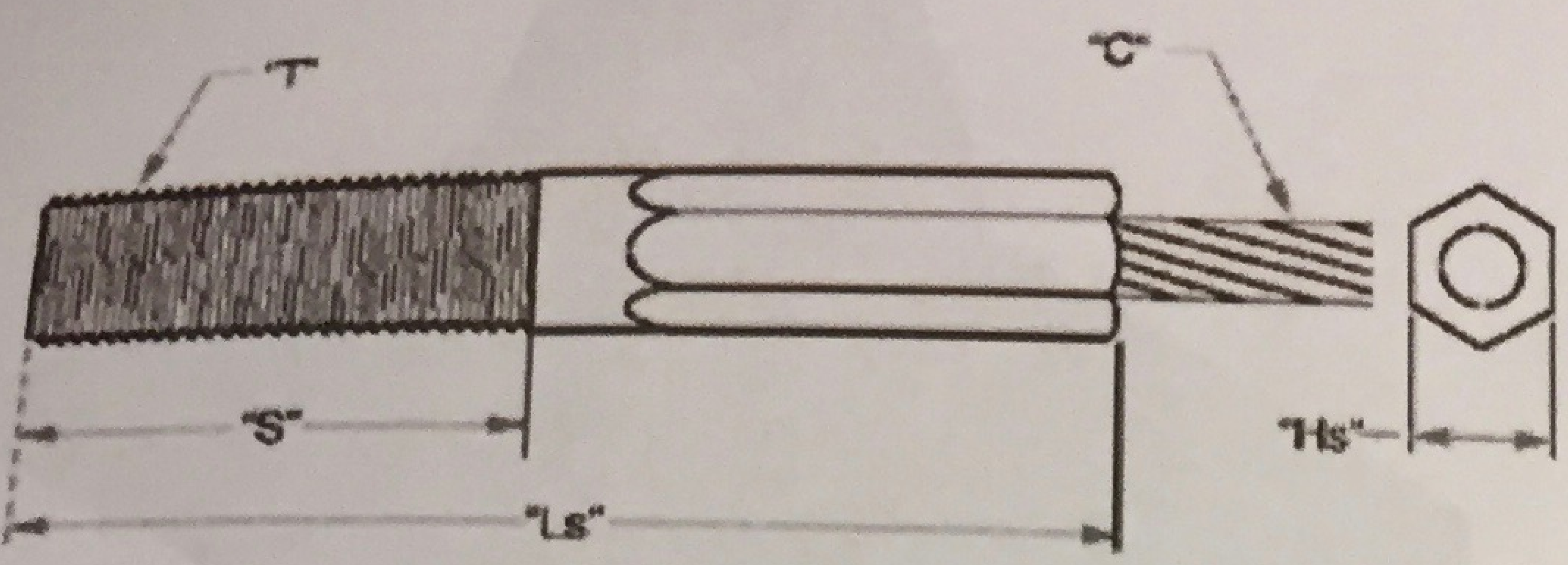
| S-501 OPEN SOCKET SPECIFICATIONS | | | | | | | | | | | | | | PRESS/DIE DATA BEFORE SWAGE DIMENSIONS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BEFORE SWAGE DIMENSIONS | | | | | | | | | | | | | | | |
| ROPE SIZE (INCHES)* | WEIGHT EACH (LBS.) | A | B | C | D | E | F | H | L | M | N | MAX. AFTER SWAGE DIM. (INCHES) | SOCKET DIE DESC. | 500 1000 1500 TON 5X7 | 1500 3000 TON 6X12 | 1500 TON 6X12 | 3000 TON 6X12 |
| 1/4 | .52 | 4.81 | .50 | 1.38 | .69 | .27 | 2.13 | .69 | 4.00 | .38 | 1.50 | .46 | 1/4 | 1192845 | — | — | — |
| 5/16 | 1.12 | 6.25 | .77 | 1.62 | .81 | .34 | 3.19 | .81 | 5.31 | .47 | 1.75 | .71 | 5/16–3/8 | 1192863 | — | — | — |
| 3/8 | 1.30 | 6.25 | .77 | 1.62 | .81 | .41 | 3.19 | .81 | 5.31 | .47 | 1.75 | .71 | 5/16–3/8 | 1192863 | — | — | — |

http://www.deltarigging.com/doc/Wire%20Rope/Rigging%20Hardware/Open%20Swage%20Sockets.pdf

**The below Hex threaded studs are sufficient for our needs:**

### *Hex threaded studs*

**Custom wire rope assemblies with hex threaded studs swaged onto cable**

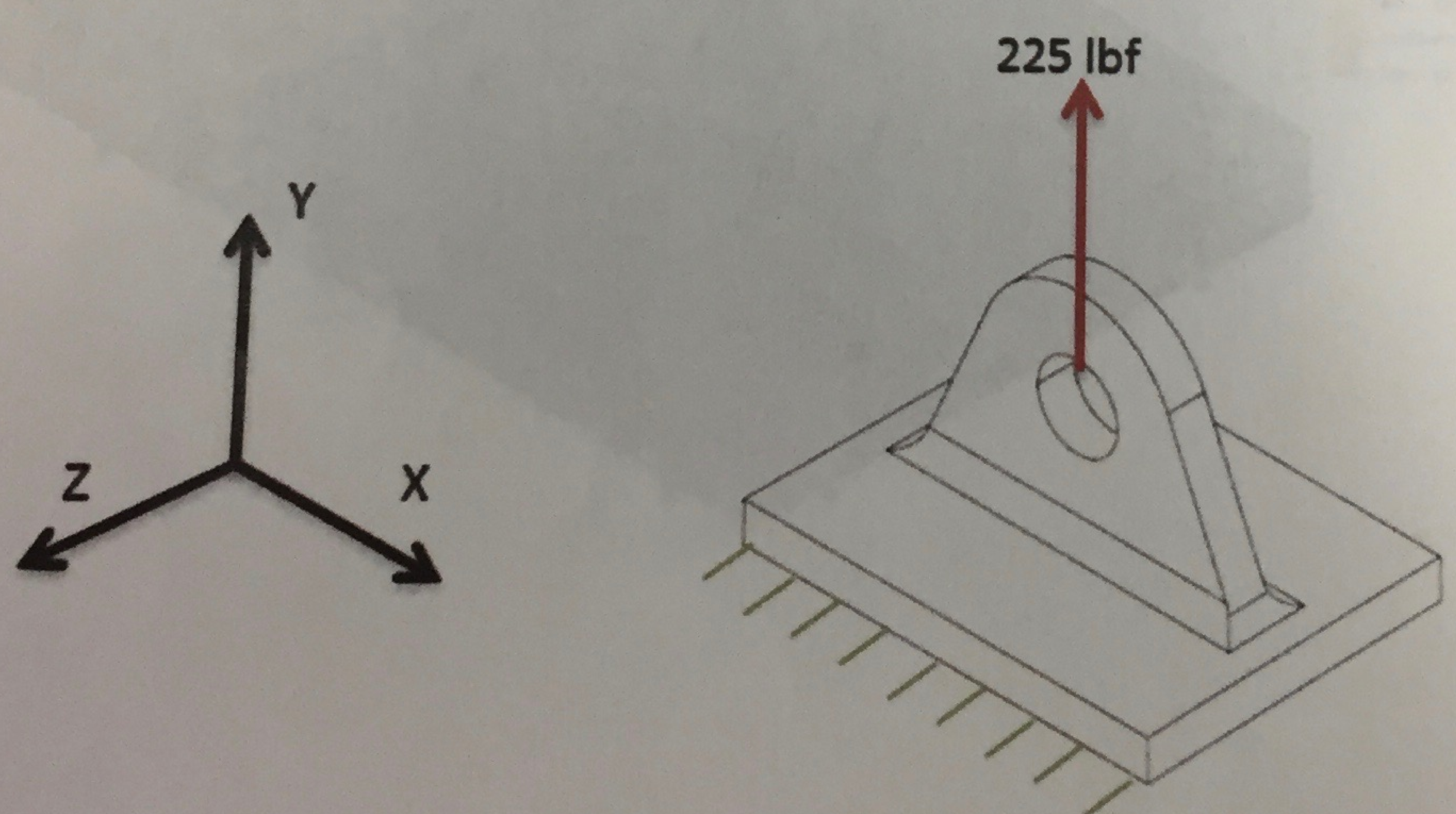



these are very nice

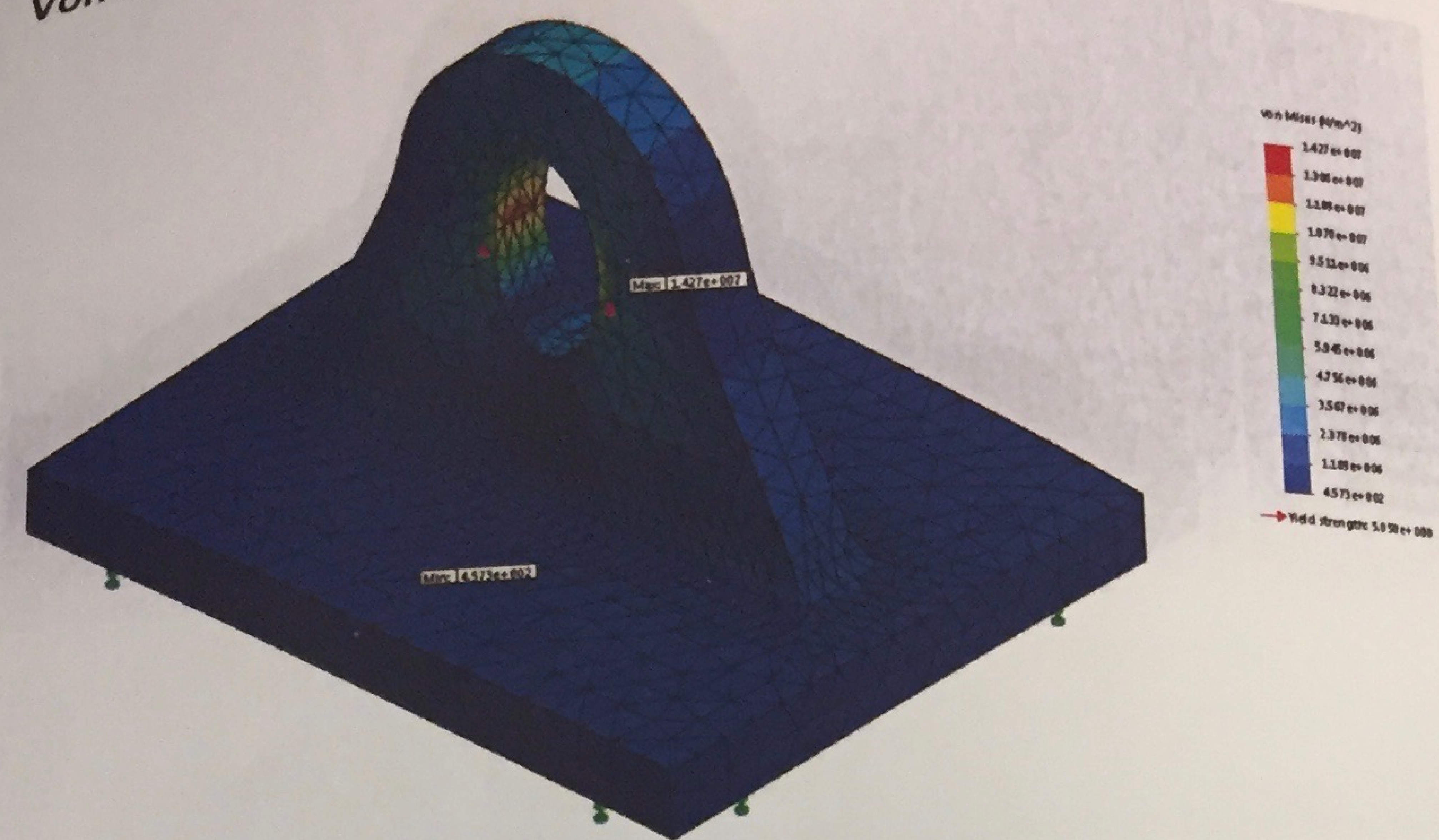
[http://thecableconnection.com/studs.html](http://thecableconnection.com/studs.html)

**Clevis Analysis:**

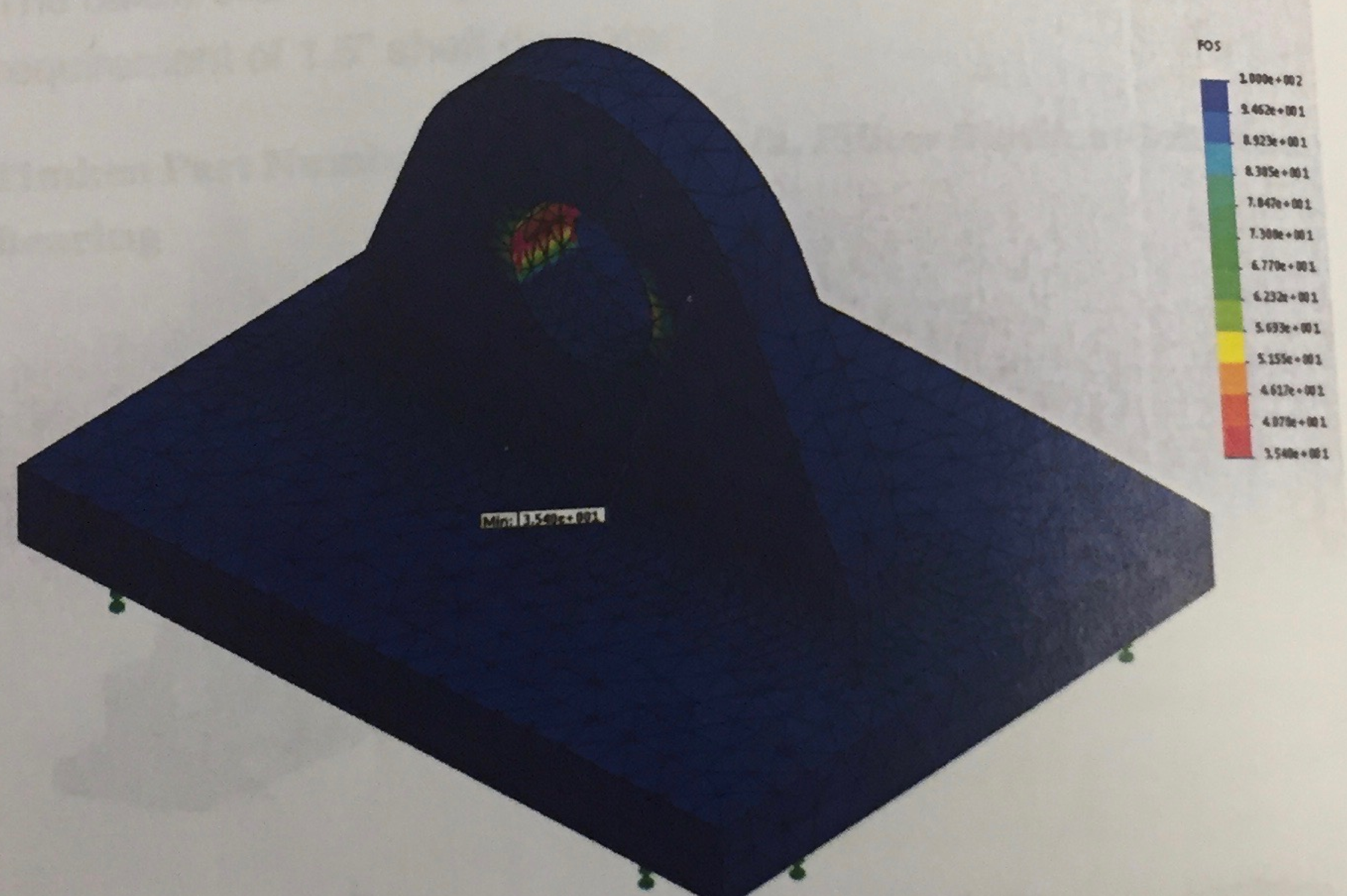
The clevis is to be constructed using 7075 T6 Aluminum Plate. The clevis was analyzed in SWS. The Base of the clevis was taken to be fixed and an upwards force of 225 lbf was applied over the top half of the bolt hole. The minimum factor of safety was found to be 35. The max deflection was found to be 0.0001" well within the deflection limit.



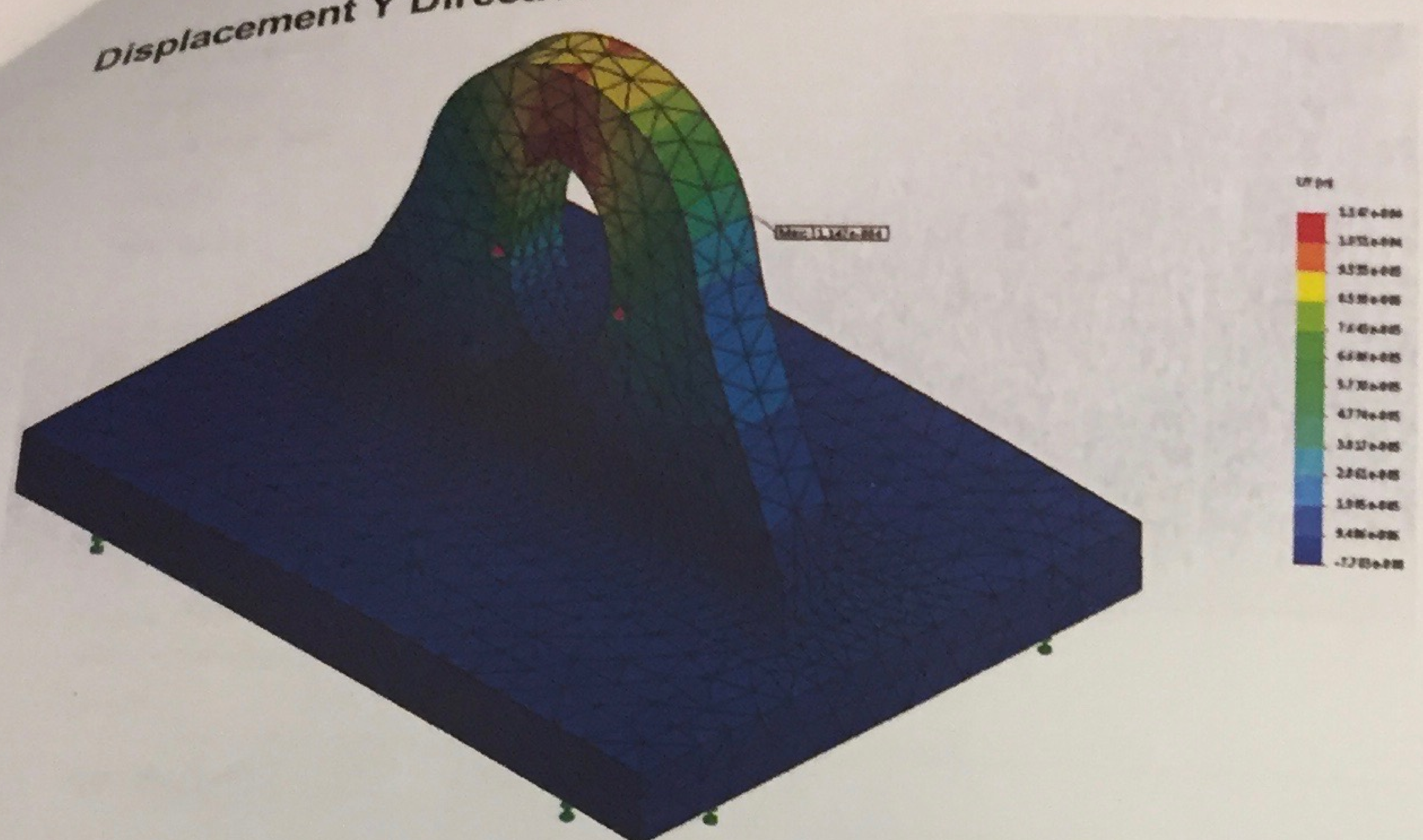
**Von Mises Stress Plot:**




**Factor of Safety Plot - Von Mises:**



**Displacement Y Direction:**

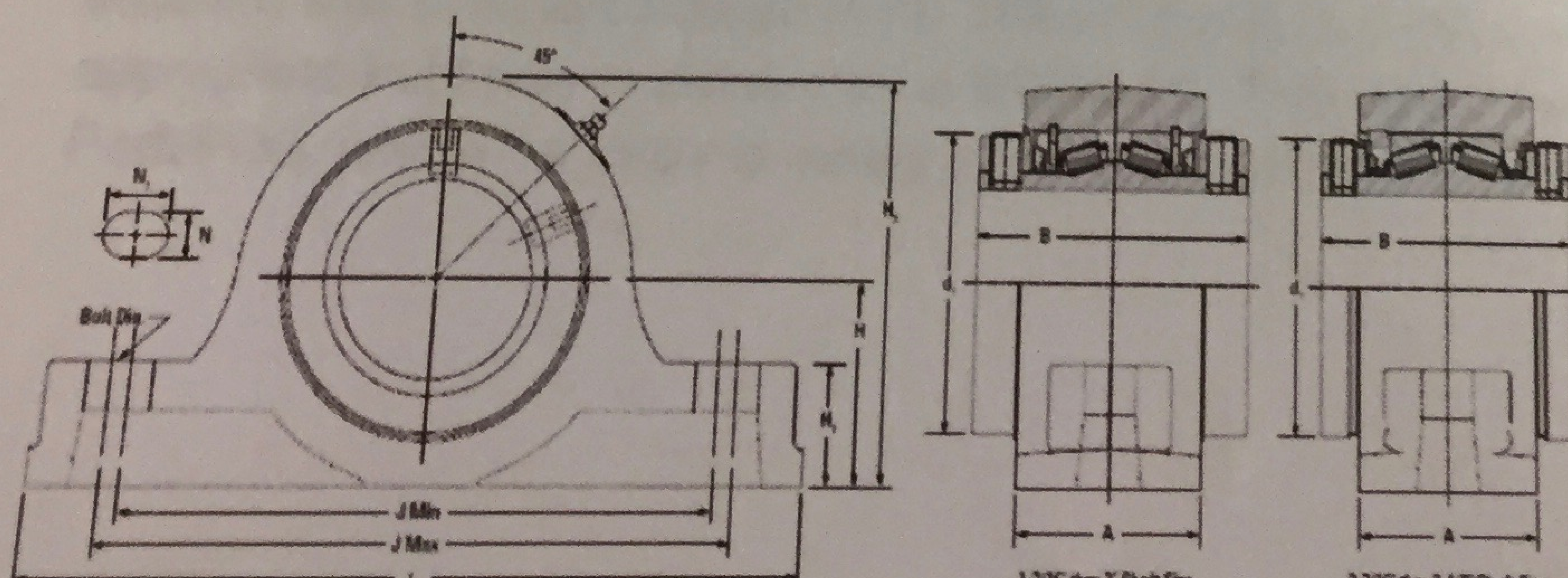


**Shaft Bearing:**

The below shaft bearing is sufficient for our needs with a requirement of 1.5" shaft diameter:

**Timken Part Number E-P2B-TRB-1 1/2, Pillow Block: 2-Bolt Base Bearing**

how is this used? confused



| | |
|---|---|
| Specifications | |
| Shaft Size | 1-1/2 in |
| Shaft Size Type | Imperial |
| Weight | 10 lb |
| UPC Code | 053893606637 |

| | |
|---|---|
| $C_{90}$ Dynamic Load Rating[1] | 7860 lb |
| $C_0$ Static Load Rating | 33000 lb |
| $F_{a\text{-}max}$ Maximum Permissible Thrust Load[2] | 2590 lb |
| $F_{r\text{-}max}$ Maximum Allowable Slip Fit Radial Load[3] | 6400 lb |
| Max. Speed[4] | 3320 rpm |

http://cad.timken.com/item/type-e-housed-unit-bearings/pillow-block-2-bolt-base-bearing/e-p2b-trb-1-1-2

**Column Analysis:**

The columns are made of A36 steel and are rectangular tubing 4 in x 6 in x ½ in. The columns were analyzed for buckling and then for 3g loads applied in the worst case loading scenario. Analysis for the worst case loading scenario was done concerning Max Von-Mises failure criterion, Max Deflection failure criterion.

Buckling Failure Criterion:

The Column was analyzed to find the critical force it could support, if acting as a two force member. The column was treated as fixed at both ends and the slenderness ratio was calculated. The column was determined to be in the long column regime and the appropriate equation was used to calculate Pcrit. The column is 25 ft tall, and is 6 in x 4 in x ½ in. The appropriate Pcrit was calculated to be 65,990 lbf. The applied loading must be less than Pcrit/FOS, where the factor of safety is determined by the building code.

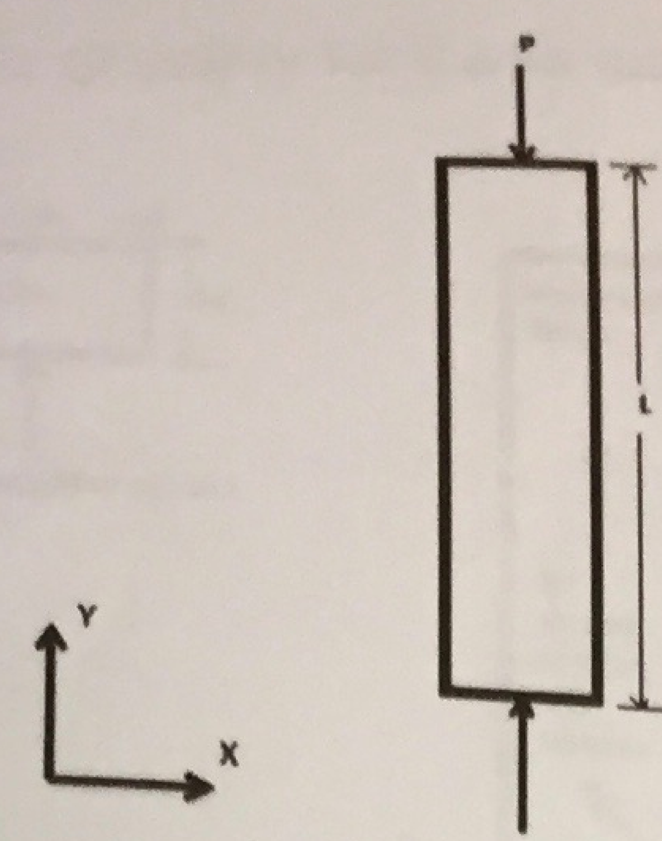



Figure - FBD depicting Beam deflection scenario.

**The Column is treated as a fixed-fixed for buckling analysis with an effective length equal to that of the column under the conservative value.**

$L := 25\ ft \qquad w_o := 4\ in \qquad l_o := 6\ in \qquad w_i := 3\ in \qquad l_i := 5\ in$

$$I := \frac{1}{12} l_o \cdot w_o^{\,3} - \frac{1}{12} l_i \cdot w_i^{\,3} = 20.75\ in^4 \qquad A := w_o \cdot l_o - w_i \cdot l_i = 9\ in^2$$

$$k := \sqrt{\frac{I}{A}} = 0.127\ ft \qquad Sr := \frac{L}{k} = 197.576$$

$E := 29 \cdot 10^6\ psi \qquad \sigma y := 36 \cdot 10^3\ psi$

$$Srd := \pi \cdot \sqrt{\frac{2 \cdot E}{\sigma y}} = 126.099$$

**Since Srd > Sr we are in the long regime:**

$$Pcr := \frac{\pi^2 \cdot E \cdot I}{L^2} = \left(6.599 \cdot 10^4\right)\ lbf$$

Figure - Calculations to determine Pcrit

Max Von-Mises Failure Criterion:

The Max Von-Mises Failure Criterion was determined in SWS using the worst case loading scenario. The worst case loading consisted of the weight of the winch loading vertically down on the column from a point 1ft from the top of the column. Three times the weight of the column was distributed evenly over the surface of the column laterally. Three times the weight of the wing was also distributed laterally at a point 11ft from the base of the column. The loading of the column and the wing were both applied in the direction of lowest Area moment of inertia I.

Using solidworks the minimum factor of safety for these loading conditions was found to be 3.521.

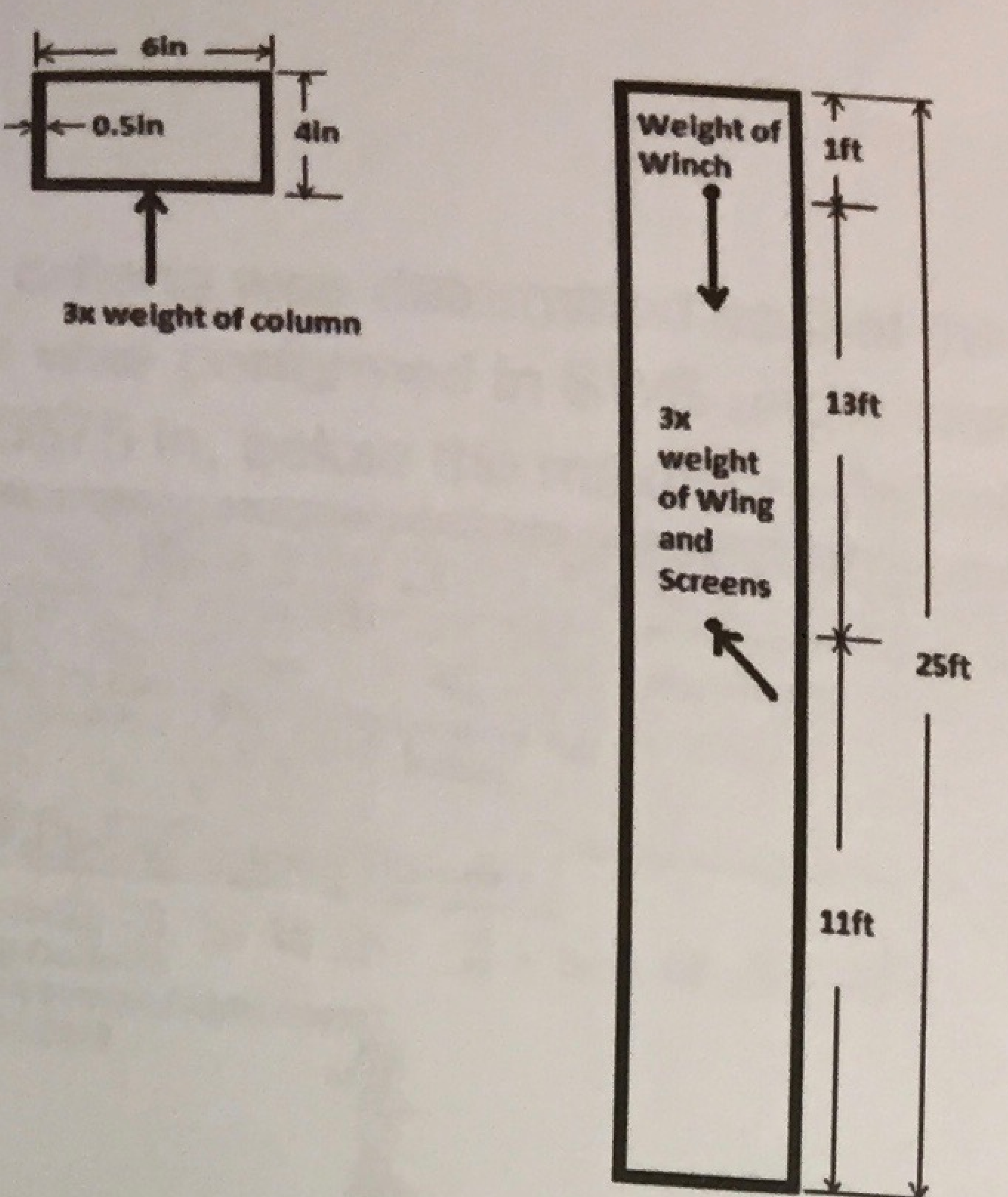



Figure - FBD showing worst case loading scenario

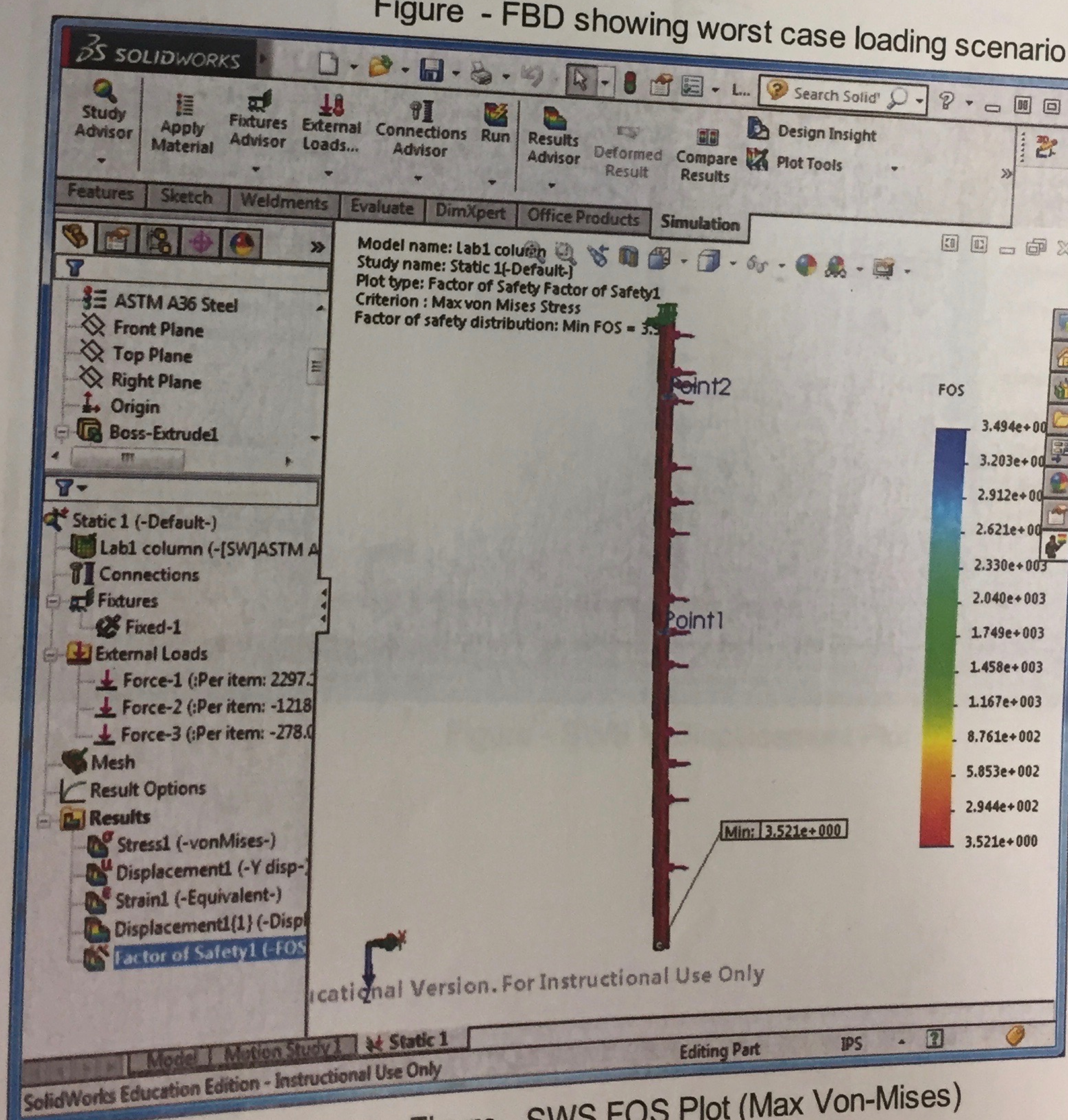



Figure - SWS FOS Plot (Max Von-Mises)

might be a chall

Maximum Deflection Criterion:

The maximum deflection criteria was determined so that the beam would deflect by less than L/360 where L is 25 ft. This was performed in SWS under worst case loading conditions. The maximum deflection was 0.5575 in, below the maximum deflection allowed: 0.833 in.

✓

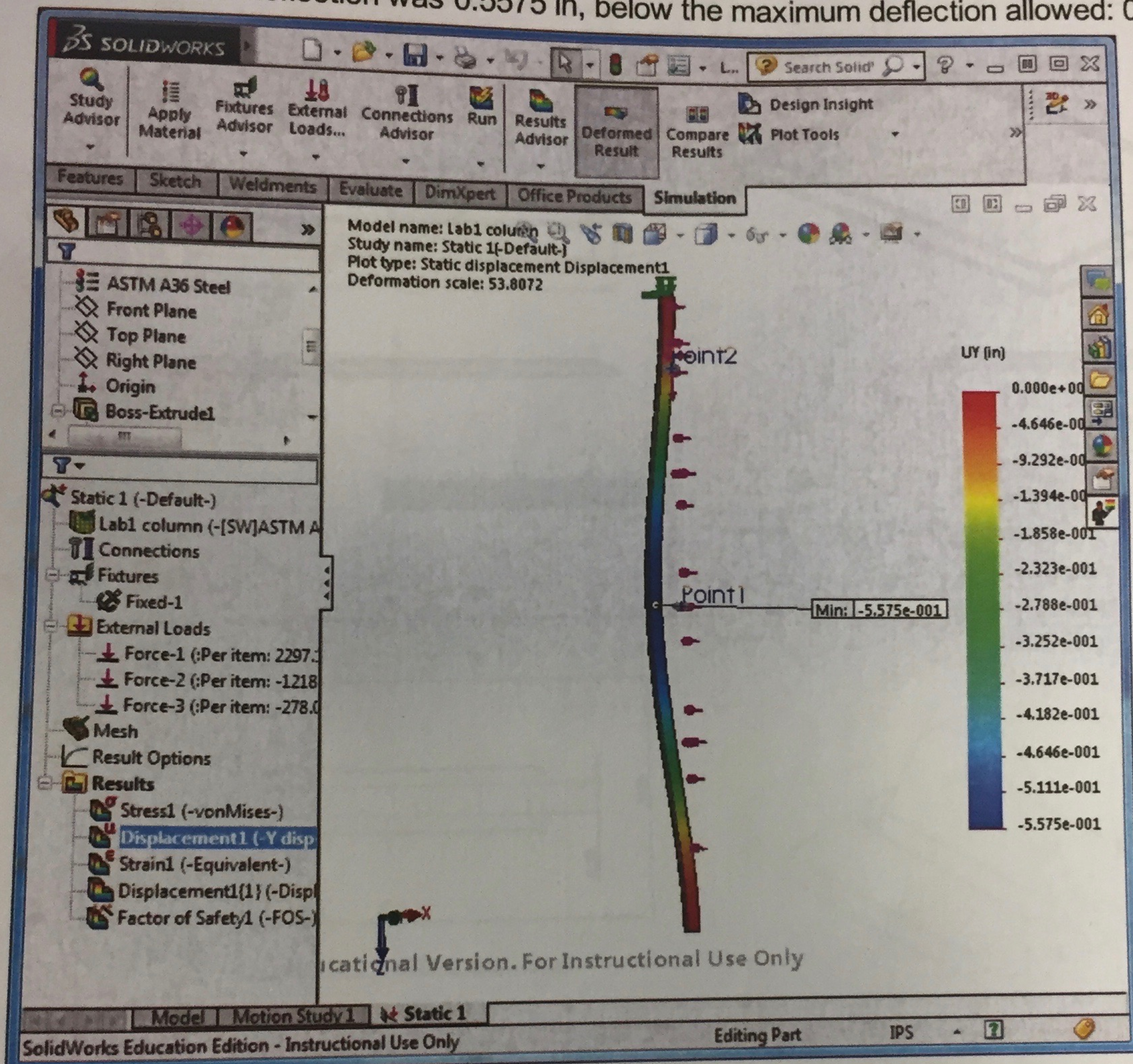
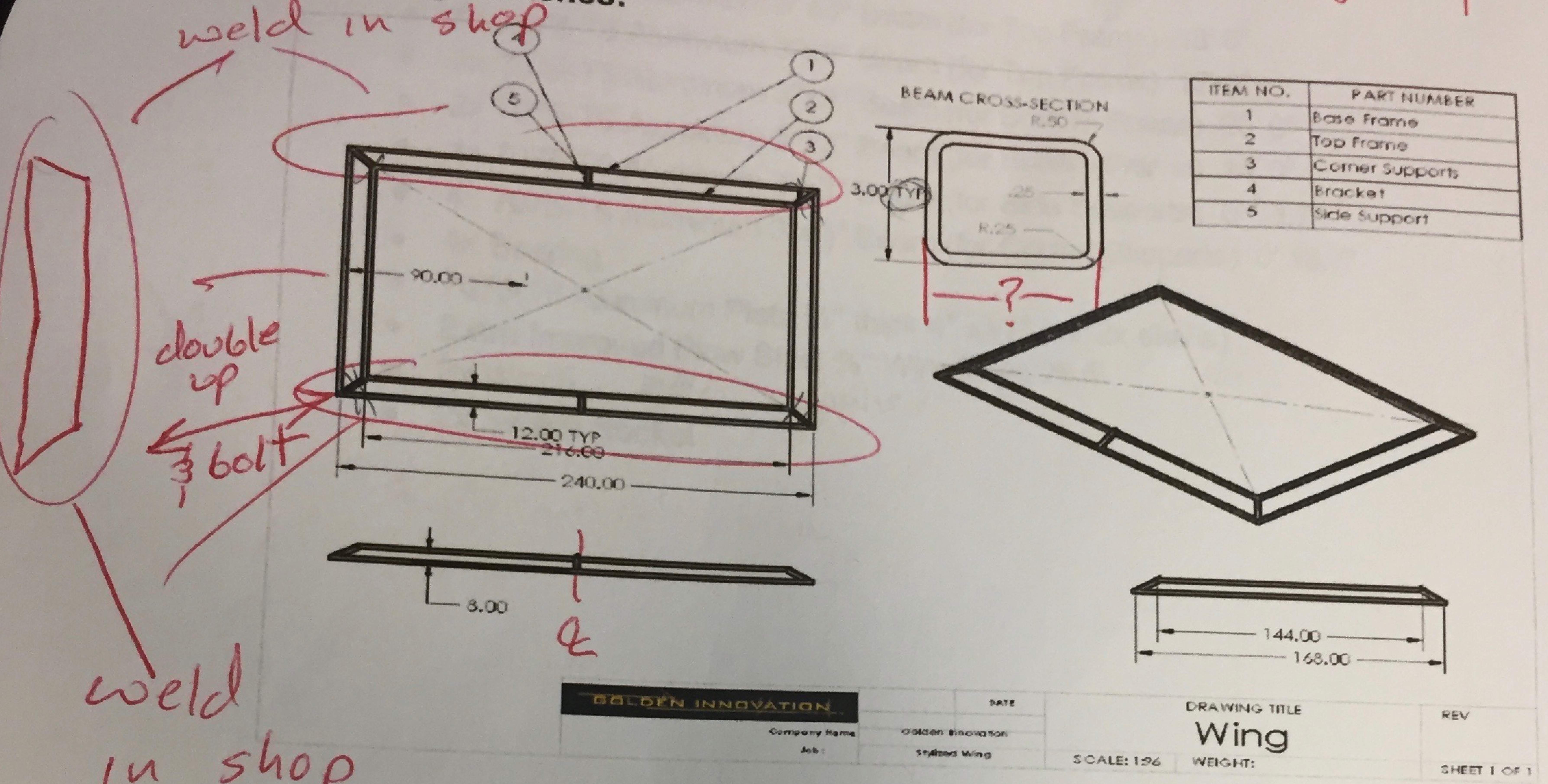


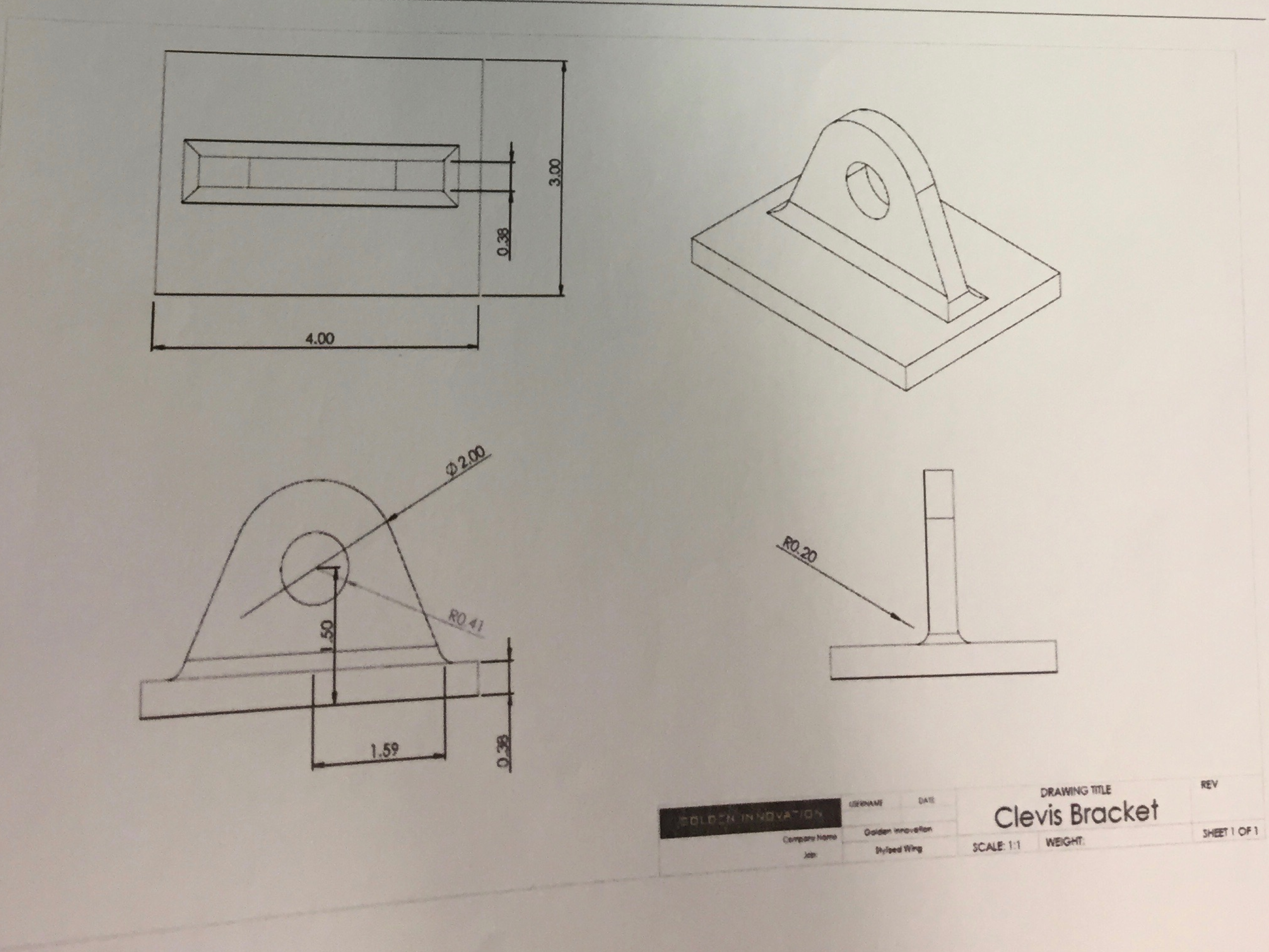

Figure - SWS Y-Displacement Plot

**Drawing Package:**

minimize field welding by

**Engineering Sketches:**



**Bill of Materials Per Wing:**

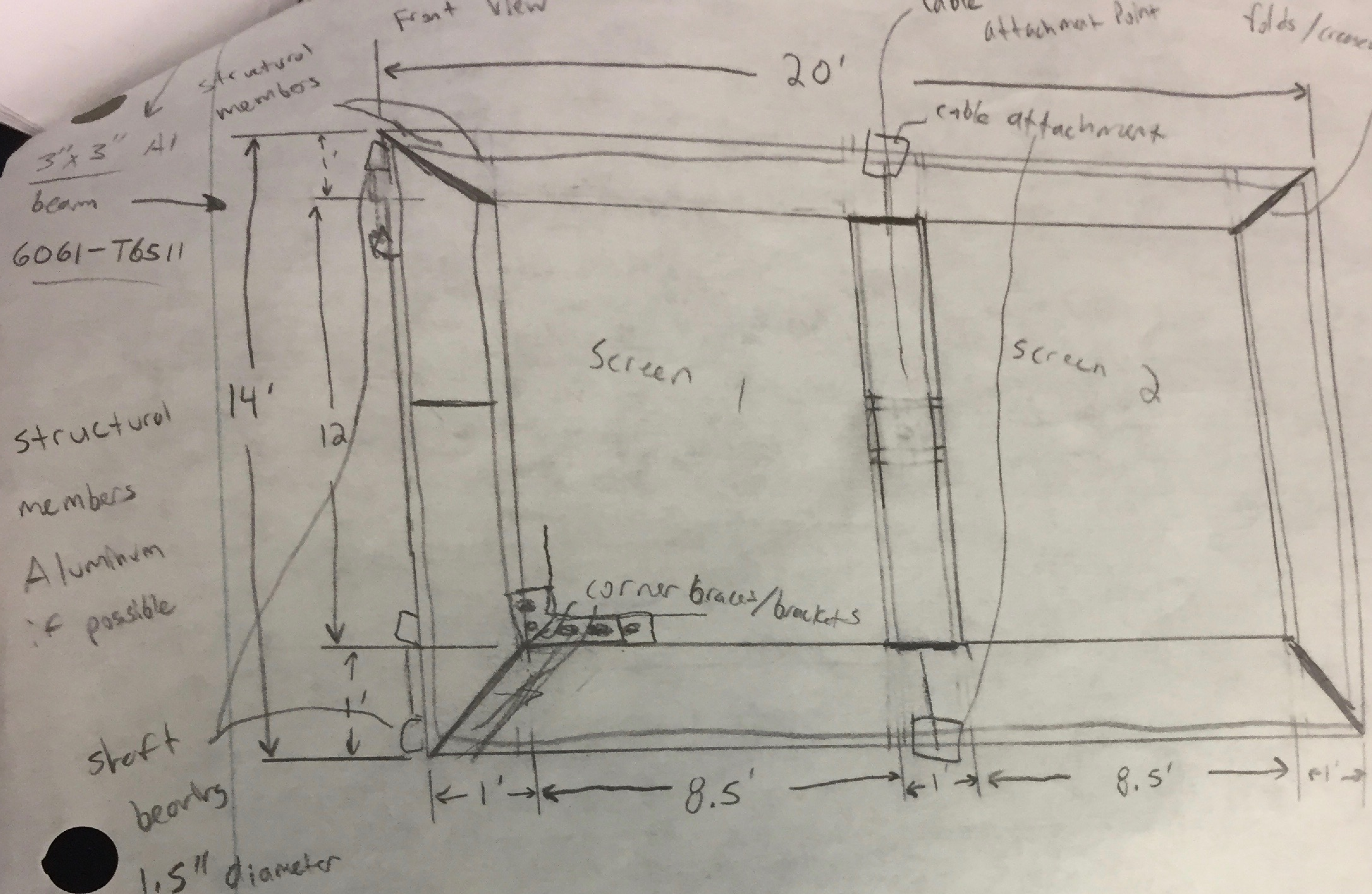
- 2x 7075-T6 Aluminum 3"x3" Beam (for Top Frame) 18' 0"
- 2x 7075-T6 Aluminum 3"x3" Beam (for Top Frame) 12' 0"
- 2x 7075-T6 Aluminum 3"x3" Beam (for Bottom Frame) 20' 0"
- 2x 7075-T6 Aluminum 3"x3" Beam (for Bottom Frame) 14' 0"
- 4x 7075-T6 Aluminum 3"x3" Beam (for Side Supports) 0' 13.7"
- 4x 7075-T6 Aluminum 3"x3" Beam (for Corner Supports) 0' 18.7"
- 4x Bearing
- 7075-T6 Aluminum Plate ⅜" thick 4" x17" (for 2x clevis)
- Extra Improved Plow Steel ⅜" Wire Rope 26.5'
- 2x Winch P/N supplier
- 2x Swage Socket

Should put in a table

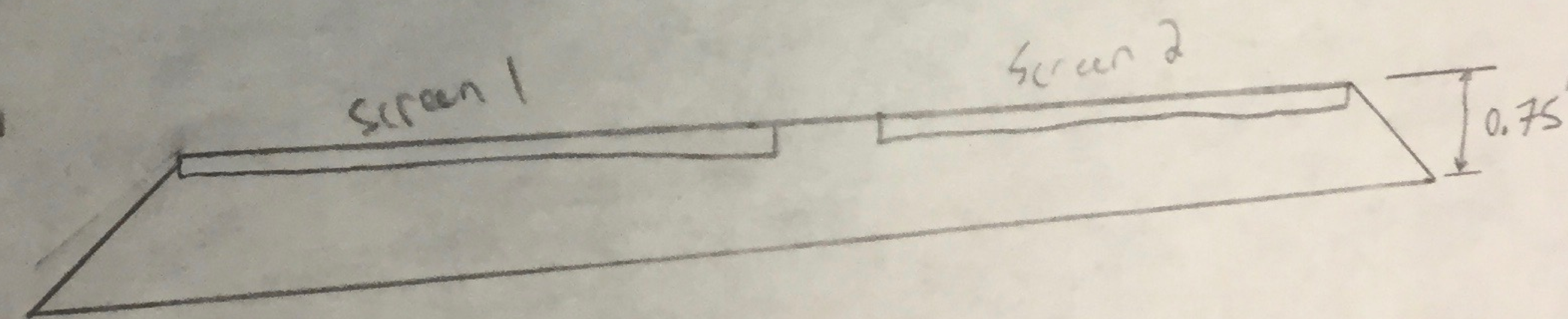
...ber, Trey Whitbush, Erik Garza | Conceptual Design

Machine Design - Wing Conceptual Design

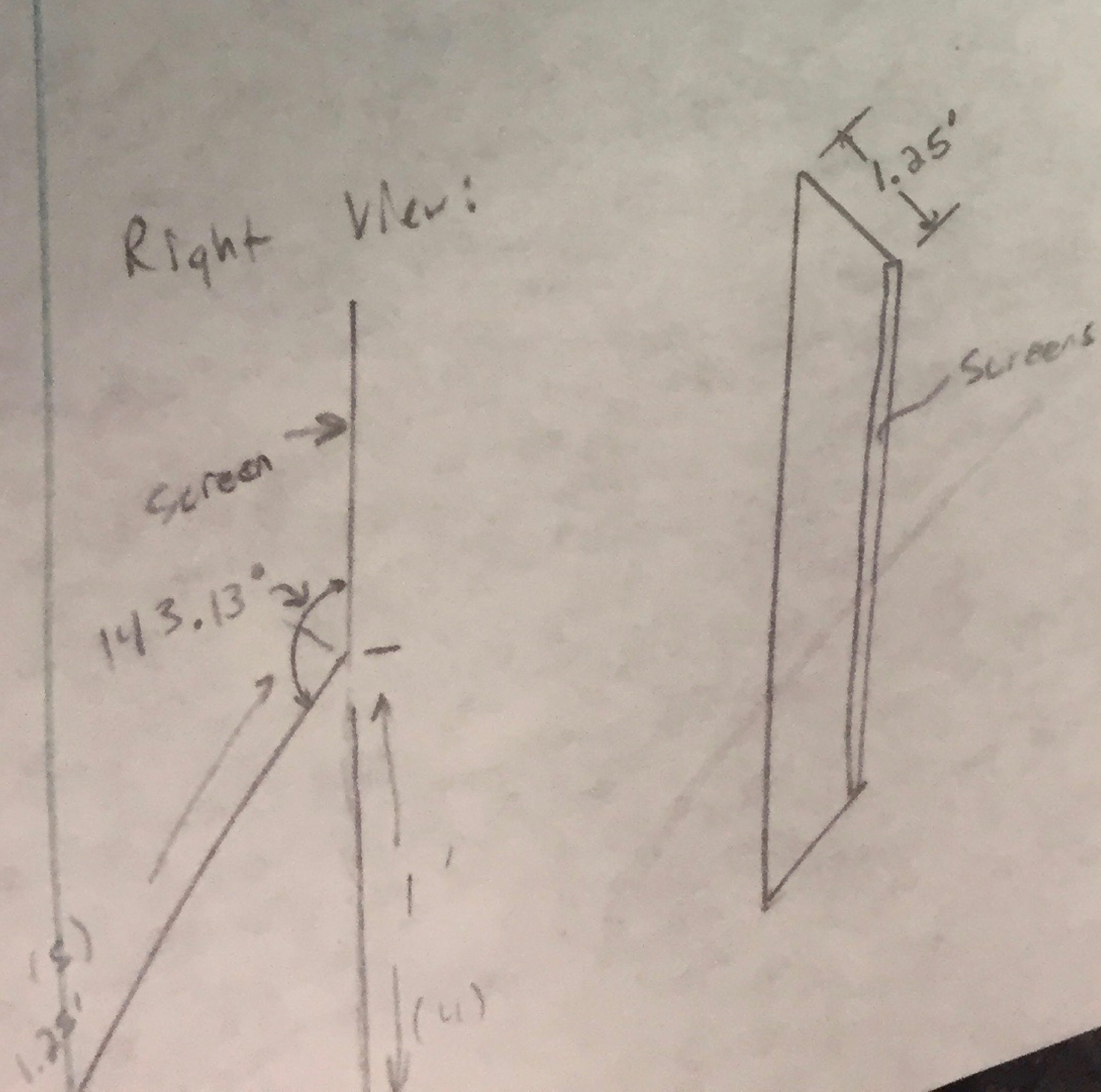
Front View




Top View




Right View:




Cover non-screen Areas w/ some type of Canvas (painted or w/ some kind of printed artwork)

or Sturdy cloth type material

or maybe colored-glass?

w/ lights?
electrical aspect might be a ...