Far Detector Vacuum Lifting Fixture

Victor Guarino
Argonne National Laboratory

April 29, 2011
Revised March 8, 2012

The construction of the NOvA Far Detector blocks requires the use of a vacuum lifting fixture for moving modules and moving steel compression plates. The fixture has two sets of suction cups. The first are Anver Part # OC12-128 rated at 50 lbs per cup for lifting modules. Originally custom made silicone cups were used on the beam. However, due to problems with robustness and occasional difficulties obtaining vacuum seal it was decided to change these cups to the Anver cups.

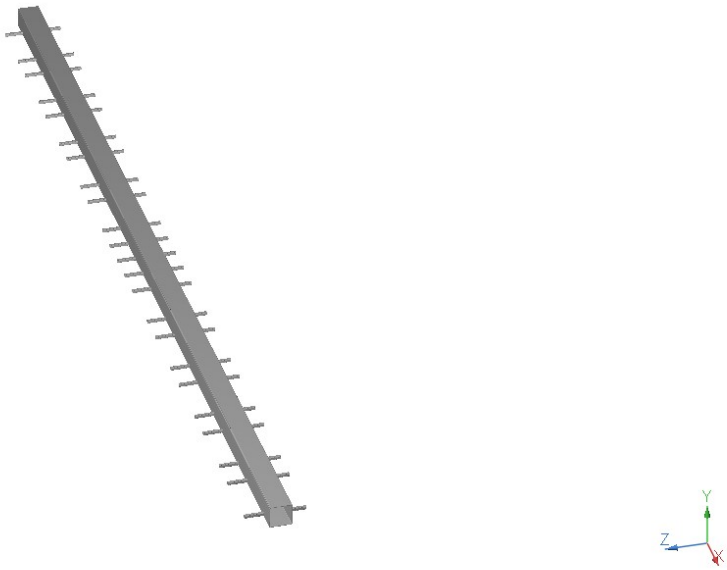
The second set of cups is blue Anver PS65R-NBR200 cups that are used for moving the steel compression plates.

The calculation of the suction cups was done per ASME BTH-1-2008 and the calculations are shown in the appendix

The steel beam was constructed according to ASME BTH-1-2008. Drawings of the beam can be found in Appendix. A simple beam element model of the lifting fixture beam and arms was created with the nominal load case of 3200 lbs. The FEA programs is a civil engineering package called RAM and pictures of the model are shown below. The 2" square tube arms are modeled in the offset position as shown in these figures. The maximum loads/stresses were extracted from this model and used in the calculations shown in the appendix. Civil engineering programs like RAM model members which are broken into individual elements and the output is for members. In this model the 14" square tube is modeled as a single member and the loads/stresses can be extracted at any point along its length. (Internal to the program of course the member is divided into elements) Output is typically provided as max/min values for the entire member or a distances from the end (i.e. 50% is a point halfway along the length from the first node) The main beam is member 26. The 2" arms are members 41-63 on one side and 64-86 on the other side.

All calculations are shown in the appendix.

The welds of the arms to the beam were also examined using the forces on the welds that were extracted from the FEA model. These calculations are shown in Appendix.



FEA Model

Appendix

Detailed Calculations

1.0 Calculation of the strength of the 14" Square Section

1.1 Define Geometry and Material Properties

Design Category B Lifting Device so Nd=3

$Nd := 3$

$d := 14in$ Depth of beam

$tw := .375in$ Thickness of wall

$b := d - 4 \cdot tw$ Inside dimention of the beam assuming a radius of tw per Fig C3-1

$b = 12.5 \cdot in$

$\frac{b}{tw} = 33.333$

$Ix := 577in^4$

$Ag := 18.7in^2$

$r := 5.55in$

$J := 900in^4$

$Z := 95.4in^3$

$S := 82.5in^3$

Material is ASTM A500 Grade B

$Fy := 46ksi$

$Fu := 58ksi$

$E := 29000ksi$

$$1.12 \cdot \sqrt{\frac{E}{Fy}} = 28.121$$

$$1.40 \cdot \sqrt{\frac{E}{Fy}} = 35.152$$ Section is non-compact

$$Mp := \min(Fy \cdot Z, 1.5 \cdot Fy \cdot S)$$

$$Mp = 365.7 \cdot ft \cdot kip$$

1.2 Evaluation of Flexure

$$Lr := \frac{2 \cdot r \cdot E \cdot \sqrt{J \cdot Ag}}{Fy \cdot S}$$

$$Lr = 917.0 \cdot ft$$

The lifting beam is 50.8ft long. The beam is loaded symmetrically about its centerline so Lb is half of this distance

$$Lb := \frac{50.8ft}{2}$$ $$Lb = 25.4 \cdot ft$$ Less than Lr

The maximum bending moment in the 14" tube was extracted from the FEA model to find the maximum bending stress in the section.

$$Mmax := 32.88 kip \cdot ft$$

$$Fmax := \frac{Mmax}{S}$$ $$Fmax = 4782.55 \cdot psi$$

$$\frac{Fy}{Nd} = 15333.3 \cdot psi$$ Allowable stress

Maximum stress is below allowable stress

1.3 Evaluation of Compress

Since the beam is supported by slings the section of the beam between the support points are

under compression. The maximum compression load from the model is 0.86kips

$Ft := \frac{1.75kip}{Ag}$ $\qquad Ft = 93.6 \cdot psi$

$L := 72in$ distance between the pick points and length under compression

$K := 1$

$\frac{K \cdot L}{r} = 13$

$Cc := \sqrt{\frac{2 \cdot \pi^2 \cdot E}{Fy}}$ $\qquad Cc = 111.554$

$$Fa := \frac{\left[1 - \frac{\left(\frac{K \cdot L}{r}\right)^2}{2 \cdot Cc^2}\right] \cdot Fy}{Nd \cdot \left[1 + \frac{9 \cdot \left(\frac{K \cdot L}{r}\right)}{40 \cdot Cc} - \frac{3 \cdot \left(\frac{K \cdot L}{r}\right)^3}{40 \cdot Cc^3}\right]}$$

$Fa = 14843.0 \cdot psi$ Allowable stress in compression -- greater than actual

Analysis Results

Maximum forces at members

Condition : st2=Steel Plates 3200 lbs

	Axial	Shear V2	Shear V3	Torsion	M22	M33
	[Kip]	[Kip]	[Kip]	[Kip*ft]	[Kip*ft]	[Kip*ft]
MEMBER 26						
Max	0.00	3.00	0.00	0.00	0.00	0.00
Min	-1.75	-3.00	0.00	0.00	0.00	-32.88

Member stresses

Location of the fibers with maximum bending stresses

CONDITION : st2=Steel Plates 3200 lbs

Station	Axial [Kip/in2]	Shear V2 [Kip/in2]	Shear V3 [Kip/in2]	Bending 2-Pos [Kip/in2]	2-Neg [Kip/in2]	3-Pos [Kip/in2]	3-Neg [Kip/in2]
MEMBER 26							
0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20%	0.00	0.17	0.00	0.97	-0.97	0.00	0.00
40%	0.00	0.35	0.00	3.95	-3.95	0.00	0.00
60%	0.00	0.35	0.00	3.95	-3.95	0.00	0.00
80%	0.00	0.17	0.00	0.97	-0.97	0.00	0.00
100%	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2.0 Calculation of the strength of the 2" Square Section

2.1 Define Geometry and Material Properties

Design Category B Lifting Device so Nd=3

$Nd := 3$

$d := 2in$ Depth of beam

$tw := .25in$ Thickness of wall

$b := d - 4 \cdot tw$ $b = 1 \cdot in$

$\frac{b}{tw} = 4$

$Ix := .747in^4$

$Ag := 1.51in^2$

$r := .704in$

$J := 131in^4$

$Z := .964in^3$

$S := .747in^3$

Material is ASTM A500 Grade B

$Fy := 46ksi$

$Fu := 58ksi$

$E := 29000ksi$

$1.12 \cdot \sqrt{\frac{E}{Fy}} = 28.121$

$1.40 \cdot \sqrt{\frac{E}{Fy}} = 35.152$ Section is compact

$Mp := \min(Fy \cdot Z, 1.5 \cdot Fy \cdot S)$

$Mp = 3.695 \cdot ft \cdot kip$

2.2 Evaluation of Flexure

$Lp := \frac{.13 \cdot r \cdot E}{Mp} \cdot \sqrt{J \cdot Ag}$

$Lp = 70.149 \cdot ft$

$Lb := 16in$ Length of section -- less than Lp

The maximum bending moment in the 2 tube was extracted from the FEA model to find the maximum bending stress in the section.

$Mmax := .08kip \cdot ft$

$Fmax := \frac{Mmax}{S}$ $Fmax = 1285.14 \cdot psi$

$$\frac{1.10Fy}{Nd} = 16866.7 \cdot psi$$ Allowable stress

Maximum stress is below allowable stress

Analysis Results

Maximum forces at members

Condition : st2=Steel Plates 3200 lbs

	AxialShear V2Shear V3Torsion	M22	M33
	[Kip] [Kip] [Kip][Kip*ft][Kip*ft][Kip*ft]		

MEMBER 85						
Max	0.00	-0.07	0.00	0.00	0.00	0.00
Min	0.00	-0.08	0.00	0.00	0.00	-0.08
MEMBER 41						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 42						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 43						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 44						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 45						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 46						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 47						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 48						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 49						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 50						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 51						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 52						

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 53						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 54						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 55						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 56						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 57						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 58						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 59						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 60						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 61						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 62						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 63						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 64						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 65						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 66						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 67						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 68						
Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08
MEMBER 69						

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 70

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 71

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 72

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 73

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 74

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 75

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 76

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 77

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 78

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 79

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 80

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 81

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 82

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 83

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 84

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

MEMBER 86

Max	0.00	0.08	0.00	0.00	0.00	0.00
Min	0.00	0.07	0.00	0.00	0.00	-0.08

3.0 calculation of weld between arms and main beam

Max Shear and bending moments at weld extracted from FEA

$Mu := 0.08kip \cdot ft$

$Mu = 960 \cdot lbf \cdot in$

$Vu := 80lbf$

Material ASTM A500 Grade 5 and weld material FE70

$Fy := 46ksi$

$FEXX := 70ksi$

$tw := 0.25in$ fillet weld size around 2" tube

$$Iweld := \left[\frac{.707 \cdot 0.25in\,(1.5in)^3}{12} + .707 \cdot 0.25in \cdot 1.5in \cdot (1in)^2 \right] \cdot 2$$

$Iweld = 0.63 \cdot in^4$ moment of inertia of weld ignoring weld on tube radius

$$\sigma s := \frac{Vu}{2 \cdot (1.5in \cdot .707 \cdot 0.25in)}$$

$\sigma s = 150.872 \cdot psi$ weld stress due to shear ignoring the weld in the radius and assuming the shear is only resisted by the two vertical welds

$$\sigma b := \frac{Mu \cdot 1in}{Iweld}$$

$\sigma b = 1524.6 \cdot psi$

$$\sigma weld := \sqrt{\sigma s^2 + \sigma b^2}$$

$\sigma weld = 1532.1 \cdot psi$

$0.6 \cdot FEXX = 42000 \cdot psi$

$SF := \frac{0.6FEXX}{\sigma weld}$ $SF = 27.414$ greater than 3

4.0 Analysis of weld between beam and swivel eye lug

$Fv := \frac{7kip}{2}$ $Fv = 3500 \cdot lbf$ vertical load per lifting eye

Lifting with the slings at a 60 degree angle so additional load in shear

$Fh := \frac{Fv}{\tan(60deg)}$ $Fh = 2020.7 \cdot lbf$ horizontal shear load

$tw := 0.375in$ fillet weld around disk

$Lweld := \pi \cdot 6in$ $Lweld = 18.85 \cdot in$ Length of weld

$$\sigma v := \frac{Fv}{0.707 \cdot tw \cdot Lweld}$$

$$\sigma v = 700.352 \cdot psi$$

$$\sigma h := \frac{Fh}{0.707 \cdot tw \cdot Lweld}$$

$$\sigma h = 404.348 \cdot psi$$

$$\sigma weld := \sqrt{\sigma v^2 + \sigma h^2}$$

$$\sigma weld = 808.697 \cdot psi$$

$SF := \frac{0.6FEXX}{\sigma weld}$ $SF = 51.935$ Safety factor greater than 3.

5.0 Calculations of Suction Cup Capacity

5.1 Define Inputs

Use Anver Cup Part # OC12-128 -- Rated Load by Anver is 50lbs for a vertical lift and 25 lbs in shear Previously custom made silicone cups had been used but due to occassional problems achieving vacuum seal and robustness of the cups it was decided to go with the Anver commercial cups. Section 5.2 shows the original silicone cup calculation and section 5.3 shows the calculation for the new cups.

Module

$Wm := 1200lbf$ Weight of Module

5.2 Analysis of Original Slicone Suction Cups

$Dcup := 5.5in$ Vacuum diameter of Cup

$Ncups := 44$

$$Acup := \frac{\pi \cdot Dcup^2}{4}$$

$$Wcup := \frac{Wm}{Ncups}$$ $Wcup = 27.273 \cdot lbf$

$Pvacuum := 14psi$

$Fcups := Pvacuum \cdot Acup$

$Fcups = 332.616 \cdot lbf$

The calculation of the suction cups was done per ASME B30.20-2.2.2d. The ASME specification defines the Ultimate Pad Capacity (UPC) as:

UPC = A(Hg/2)

Where A = the effective area of the suction cup in square inches and Hg is the system vacuum expressed in inches of mercury.

The effective vacuum is expected to be 26” Hg. As per the ASME specification, the rated load should not be greater than 50% of the UPC when the load is normal to the suction cup surface.

$HG := 26in$ Vacuum in suction cups in inches of mercury

$UPC := Acup \cdot \left(\frac{HG}{2}\right) \frac{lbf}{in^3}$ $UPC = 308.858 \cdot lbf$

$Fallowed := 50\% \cdot UPC$

$Fallowed = 154.429 \cdot lbf$

The actual load per cup is: $Wcup = 27.273 \cdot lbf$

Additional safety factor above what is required by ASME B30 is:

$SF := \frac{Fallowed}{Wcup}$ $SF = 5.662$

Total lifting capacity:

$Flift := Ncups \cdot Fallowed$

$Flift = 6794.9 \cdot lbf$

5.3 Analysis of Anver Suction Cups

$Ncups := 44$

$Acup := .65in \cdot 11in$

$Wcup := \frac{Wm}{Ncups}$ $Wcup = 27.273 \cdot lbf$

$Pvacuum := 14psi$

$Fcups := Pvacuum \cdot Acup$

$Fcups = 100.1 \cdot lbf$

The calculation of the suction cups was done per ASME B30.20-2.2.2d. The ASME

specification defines the Ultimate Pad Capacity (UPC) as:

UPC = A(Hg/2)

Where A = the effective area of the suction cup in square inches and Hg is the system vacuum expressed in inches of mercury.

The effective vacuum is expected to be 26” Hg. As per the ASME specification, the rated load should not be greater than 50% of the UPC when the load is normal to the suction cup surface.

$HG := 26in$ Vacuum in suction cups in inches of mercury

$UPC := Acup \cdot \left(\frac{HG}{2}\right) \frac{lbf}{in^3}$ $UPC = 92.95 \cdot lbf$

$Fallowed := 50\% \cdot UPC$

$Fallowed = 46.475 \cdot lbf$

The actual load per cup is: $Wcup = 27.273 \cdot lbf$

Additional safety factor above what is required by ASME B30 is:

$SF := \frac{Fallowed}{Wcup}$ $SF = 1.704$

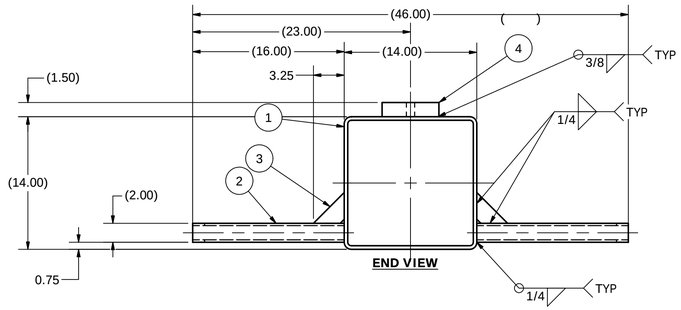
Total lifting capacity:

$Flift := Ncups \cdot Fallowed$

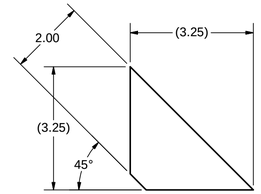
$Flift = 2044.9 \cdot lbf$

DWG NO

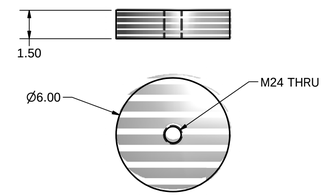
Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	SQ TUBE 14 x 14 x 3/8 WALL x 610.50 LG	ASTM A500-GR. B
2	44	SQ TUBE 2 x 2 x 1/4 WALL x 16.00 LG	ASTM A500-GR. B
3	44	PL 2 x 1/4 THK	AISC A 36
4	2	LIFTING HOIST DISK	AISC A 36



END VIEW

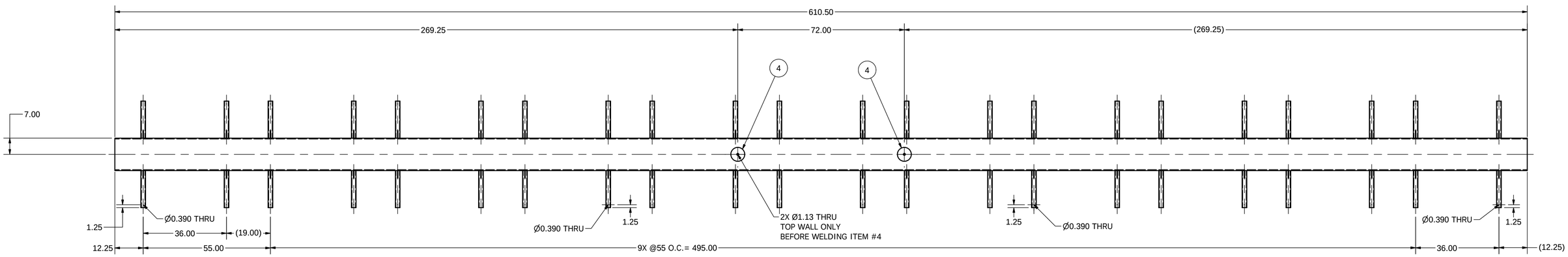


ITEM 3 DETAIL

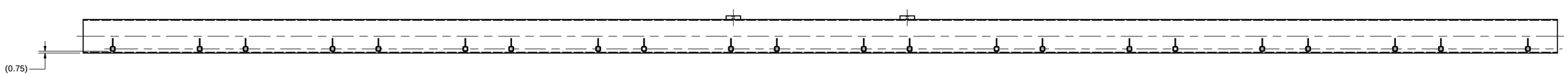


ITEM 4 DETAIL

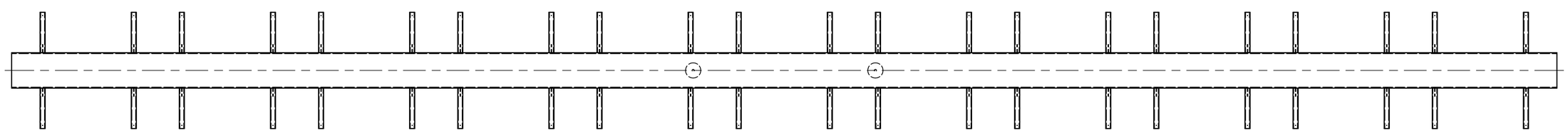
NOTE:
1. ALL STEEL SHALL BE A 36 WITH CERTIFICATION.
2. ALL WELDS AS PER AWS D.1.1.



TOP VIEW



SIDE VIEW



BOTTOM VIEW

1	G16362	1
ITEM NO	NEXT ASSEMBLY	REQD

Argonne NATIONAL LABORATORY — THIS DRAWING IS THE PROPERTY OF NE DIVISION

SYM	CHANGE	BY	CHKD	DATE	APVD	DATE

UNLESS OTHERWISE NOTED
ALL DIMENSIONS ARE INCHES
DECIMAL TOLERANCE
.X ± .1
.XX ± .02
.XXX ± .005
ANGULAR TOL ± 1/2
FRACTIONAL TOL ± 1/64
REMOVE ALL BURRS AND SHARP EDGES
SURFACES TO BE IN ACCORDANCE WITH LATEST ANSI B46.1
DIMENSIONS & TOLERANCES IN ACCORDANCE WITH LATEST ASME Y14.5M

CADD NUMBER G16363

DRAWN BY	DATE	GP LEADER	DATE
acorcuera	5/21/2010		
CHECKED J. MORGAN		PROJECT MGR	
RESPONSIBLE ENGINEER J. MORGAN		APVD/RELEASED	

MATERIAL: SEE PARTS LIST

DOCUMENT TITLE — PROJECT NO:

NOVA
GLUE MACHINE
ASSEMBLY WELDMENT

PROJECT TITLE:

SCALE	SHEET	DRAWING NUMBER	REV
----	1 OF 1	NOVA-01-01	00

INV2010