X0039-001A
APOLLO SALES LTD
450 LATTICE BEAM RIDGE – 18 DEGREE
DESIGN CHECK CALCULATIONS

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Document Revision History

Revision	Description	Author	Revision Date	Checked
A	Initial Issue	anw	11/04/17	mmr

CALCULATION SHEET	Project :	Apollo Lattice beam 18 degree ridge			AWD ALAN WHITE DESIGN
	Element :	Brief			
	Job Number :	X0039	By : anw	Date: Feb 17	
	Document No :	001	Checked: mmr	Date: Feb 17	

Brief

To check design of ridge connector to ensure that it is at least equivalent in capacity to the standard beam

Design resistance

The design resistance of the apollo lattice beam is

Based on Eurocode 9

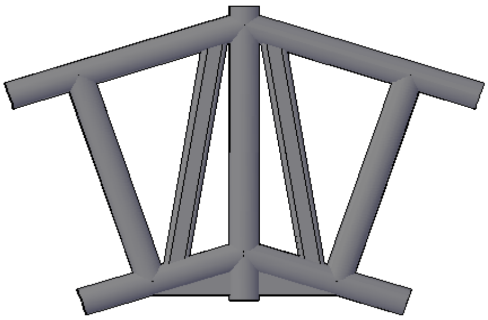
Max moment on the beam is

Long term allowable moment **16.2 kNm**

and Maximum Shear is

Long term Allowable shear **15.80 kN**

Geometry



The ridge angle is 18 degrees as shown

A gusset plate brace, 50mm deep, is required to the bottom boom.

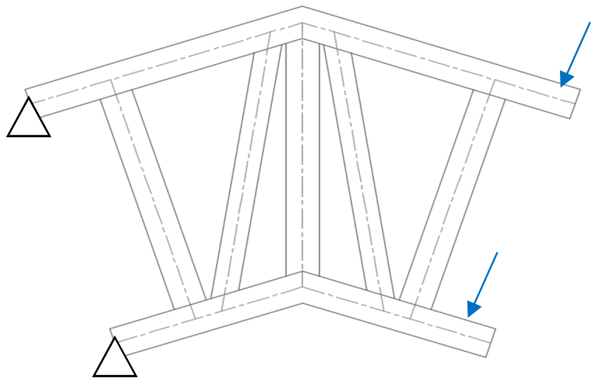
Loading

For the shear load case the applied forces are

V= 15.8/2

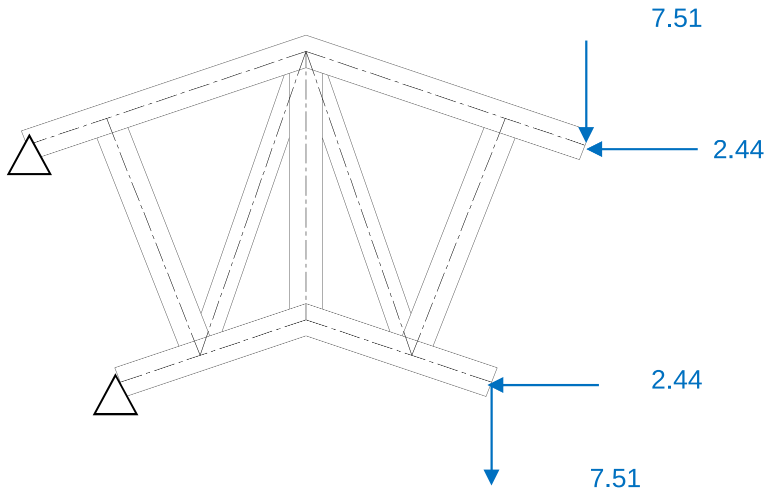
= **7.90 kN**

These are applied at the top and bottom booms as below



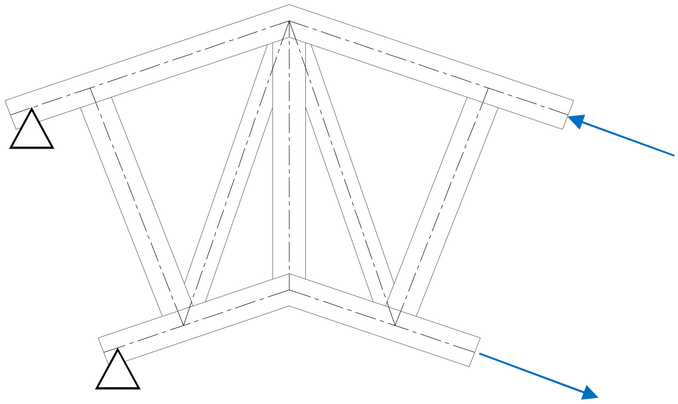
The model has the ridge piece supported as shown on the top and bottom booms by pins

For STRAP model the forces are resolved to give vertical and horizontal loads as shown

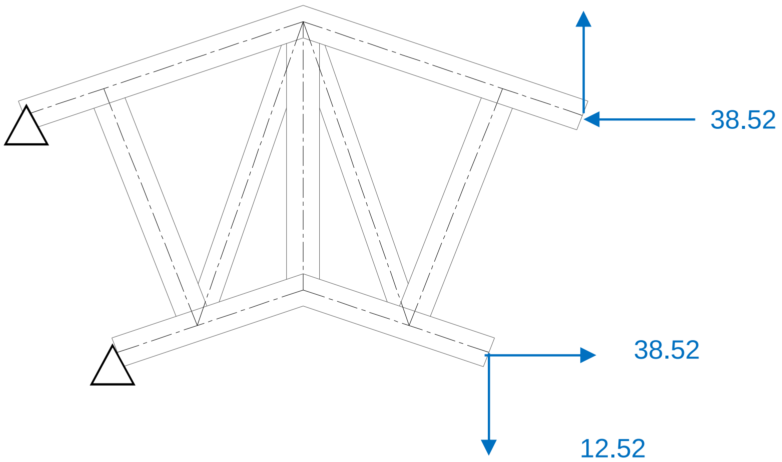


For the moment load case

P= 16.2/0.4
= **40.50 kN**



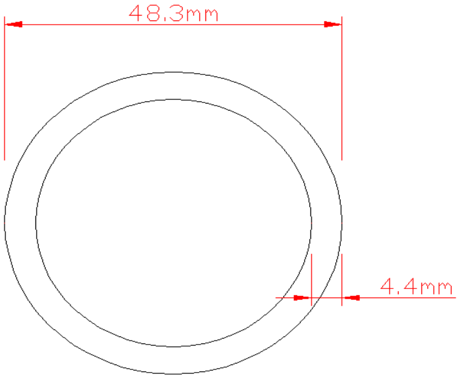
For STRAP model the forces are resolved to give vertical and horizontal loads as shown



Load direction

The direction of the forces are interchangeable and can produce either tension or compression in the members.

Main Boom Capacity
ø48.3mm x 4.4mm CHS 6082 T6



Section Properties

A=	607	mm^2
I=	147654	mm^4
W_{el}=	6114	mm^3
W_{pl}=	8254	mm^3
ry=	15.6	mm

for slenderness

β=	b/t	b=	48.30	mm
=	10.98	t =	4.40	mm
ε=	sqrt(250/f_o)	f_o=	250N/mm^2	
=	1.00			

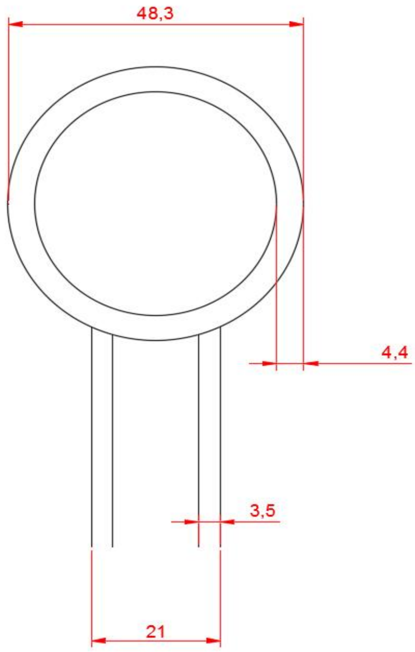
Class A, without welds, Internal parts

β_1=	11ε
=	11*1.0
=	11.00
>	10.98

Section is class 1

Main Boom HAZ

There is a HAZ at welded joint to the diagonal brace



t_{boom}= 4.40mm

$t_{diagonal}$= 3.5mm

$t_{average}$= 3.95mm

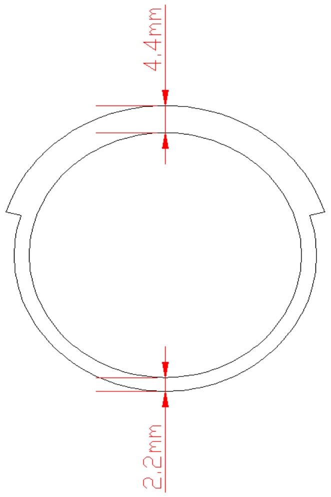
All welds are TIG.
As per EN 1999-1-1 6.1.6.3

b_{haz} = 30mm

Therefore HAZ extends 30mm from intersection of welded materials

HAZ Section Layout

Take section shown as non-HAZ.



HAZ Section Properties

A=	418	mm^2
I=	92785	mm^4
W_{el}=	3398	mm^3
W_{pl}=	4587	mm^3
ry=	14.7	mm

Main Boom Moment Capacity (6.2.5.1)

$M_{c,Rd} = \alpha W_{el} f_o / \gamma_{M1}$

α =	W_{pl}/W_{el}	(Table 6.4)
=	1.35	
W_{el} =	3.40	cm^3
f_o =	250	N/mm^2
γ_{M1} =	1.1	(6.1.3)

= 1.35*3.40*250/1100

$M_{c,Rd}$ = 1.04 kNm

Main Boom Shear Capacity (6.2.6)

$V_{Rd} = A_v f_o / \sqrt{3}\gamma_{M1}$

A_v=	0.6A	
A_v=	0.6*418	
A_v=	250.80	mm^2
γ_{M1}=	1.1	
f_o =	250	N/mm^2

= 250.80*250/(SQRT(3)*1100)

V_{Rd} = 32.91 kN

Main Boom Axial Comp Capacity @ 1000mm (effective length of beam between restraints)

$N_{b,Rd} = k \times A_{eff} f_o / \gamma_{M1}$ (6.3.1.1)

$N_{cr} = \pi^2 EI / k^2 L^2$ (Appendix I.3)

$E =$ 70,000 N/mm^2

$I =$ 147,654 mm^4

$k =$ 0.50 (Table I.2)

$L =$ 1,000 mm

$N_{cr} =$ ((PI()^2)*70000*147654)/((0.5^2)*(1000^2))

= 408,040.24 N

$\lambda = \sqrt{A_{eff} f_o / N_{cr}}$ (6.3.1.2)

= 0.51 $A =$ 418 mm^2

$X = 1/ \Phi+\sqrt{\Phi^2-\lambda^2}$

$\Phi = 0.5(1+\acute{\alpha}(\lambda-\lambda_o)+\lambda^2)$

$\acute{\alpha} =$ 0.20 Table 6.6

$\lambda_o =$ 0.10 Table 6.6

$\Phi =$ 0.67

$X =$ 0.90

$k = 1-(1-(A_1/A)10^{-\lambda}-(0.05+0.1(A_1/A))\lambda^{1.3(1-\lambda)}$

$A_1 = A-A_{HAZ}(1-\rho_{o,HAZ})$

= 607-(189*(1-0.5))

= 512.50 mm^2

$k =$ 0.96

$N_{b,Rd} = k \times A_{eff} f_o / \gamma_{M1}$

= 0.96*0.9*418*250/1100

= 82.08 kN

Main Boom Axial Tension Capacity (6.2.3)

General yielding

$N_{o,Rd} = A_g f_o / \gamma_{M1}$

$f_o =$ 250 N/mm^2

$A_g = \rho_{o,haz} * A$

= 418.00 mm^2

$\gamma_{M1} =$ 1.1

= 418*250/1100

= 95.00 kN

Local failure

$N_{u,Rd} = A_{net} f_u / \gamma_{M2}$

$f_u =$ 290 N/mm^2

$A_{net} = \rho_{u,haz} * A$

= 0.64*418/0.5

= 535.04 mm^2

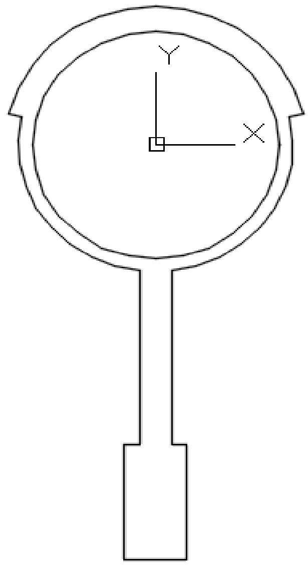
$\gamma_{M1} =$ 1.25

= 535*290/1250

= 124.12 kN

Main Boom HAZ

There is a HAZ at welded joint to the gusset



t_{boom}= 4.40mm

$t_{diagonal}$= 3.5mm

$t_{average}$= 3.95mm

All welds are TIG.
As per EN 1999-1-1 6.1.6.3

b_{haz} = 30mm

Therefore HAZ extends 30mm from intersection of welded materials

HAZ Section Properties

A=	775	mm^2
I_y=	1095414	mm^4
I_z=	95140	mm^4
$W_{el,y}$=	15225	mm^3
$W_{pl,y}$=	20553	mm^3
ry=	11.1	mm

Main Boom Moment Capacity (6.2.5.1)

$M_{c,Rd} = \alpha W_{el} f_o / \gamma_{M1}$

$\alpha = W_{pl}/W_{el}$ (Table 6.4)

$= 1.35$

$W_{el} = 15.22\ cm^3$

$f_o = 250\ N/mm^2$

$\gamma_{M1} = 1.1$ (6.1.3)

= 1.35*15.22*250/1100

$M_{c,Rd} = 4.67$ kNm

Main Boom Shear Capacity (6.2.6)

$V_{Rd} = A_v f_o / \sqrt{3}\gamma_{M1}$

$A_v = 0.6A$

$A_v = 0.6*774$

$A_v = 464.40\ mm^2$

$\gamma_{M1} = 1.1$

$f_o = 250\ N/mm^2$

= 464.4*250/(SQRT(3)*1100)

$V_{Rd} = 60.94$ kN

CALCULATION SHEET	Project :	Apollo Lattice beam 18 degree ridge			ALAN WHITE DESIGN
	Element :	Boom Capacities			
	Job Number :	X0039	By : anw	Date: Feb 17	
	Document No :	001	Checked: mmr	Date: Feb 17	

Main Boom Axial Comp Capacity @ 1000mm (effective length of beam between restraints)

$N_{b,Rd} = k \times A_{eff} f_o / \gamma_{M1}$ (6.3.1.1)

$N_{cr} = \pi^2 EI / k^2 L^2$ (Appendix I.3)

$E = 70{,}000\ N/mm^2$

$I = 1{,}095{,}414\ mm^4$

$k = 0.50$ (Table I.2)

$L = 1{,}000\ mm$

N_{cr} = ((PI()^2)*70000*195414)/((0.5^2)*(1000^2))

= 540,024.48 N

$\lambda = \sqrt{A_{eff} f_o / N_{cr}}$ (6.3.1.2)

= 0.60 $A = 775\ mm^2$

$X = 1/ \Phi + \sqrt{\Phi^2 - \lambda^2}$

$\Phi = 0.5(1+ά(\lambda-\lambda_o)+\lambda^2)$

ά = 0.20 Table 6.6

λ_o = 0.10 Table 6.6

Φ = 0.73

X = 0.87

$k = 1-(1-(A_1/A)10^{-\lambda}-(0.05+0.1(A_1/A))\lambda^{1.3(1-\lambda)}$

$A_1 = A - A_{HAZ}(1-p_{o,HAZ})$

= 607-(189*(1-0.5))

= 512.50 mm^2

k= 0.83

$N_{b,Rd} = k \times A_{eff} f_o / \gamma_{M1}$

= 0.87*0.83*775*250/1100

= 127.19 kN

Main Boom Axial Tension Capacity (6.2.3)

General yielding

$N_{o,Rd} = A_g f_o / \gamma_{M1}$

$f_o =$ 250 N/mm^2

$A_g = \rho_{o,haz} * A$

$=$ 775 mm^2

$\gamma_{M1} =$ 1.1

= 775*250/1100

= 176.14 kN

Local failure

$N_{u,Rd} = A_{net} f_u / \gamma_{M2}$

$f_u =$ 290 N/mm^2

$A_{net} = \rho_{u,haz} * A$

= 0.64*775/0.5

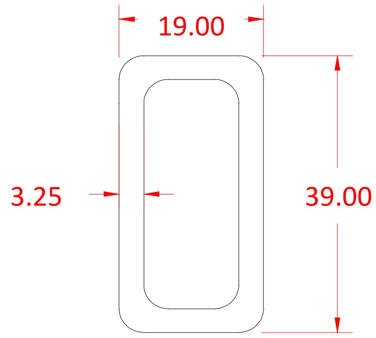
= 992.00 mm^2

$\gamma_{M1} =$ 1.25

= 992*290/1250

= 230.14 kN

RHS diagonal Layout
38 x 19 x 3.25mm oval 6082 T6



Section Properties

		A=	328	mm^2
		I_y=	16172	mm^4
		r_y=	7.0	mm

for slenderness	β=	b/t	b=	38-2*3.25	
			=	31.50	mm
	=	9.69	t =	3.25	mm

ε=	sqrt(250/f_o)	f_o=	250N/mm^2
=	1.00		

Class A, without welds, Internal parts	β_1=	11ε
	=	11*1.0
	=	11.00
	>	9.69

Section is class 1

Diagonal Axial Comp Capacity @ 527mm (effective length of beam)

$N_{b,Rd} = k \times A_{eff} f_o / \gamma_{M1}$ (6.3.1.1)

$k = \omega_x$

$\omega_x = \dfrac{\rho_{u,haz} f_u / \gamma_{M2}}{f_o / \gamma_{M1}}$

= (0.64*290/1.25)/(250/1.1)

= 0.65

k= 0.65

$N_{cr} = \pi^2 EI / k^2 L^2$ (Appendix I.3)

$E = 70{,}000\ N/mm^2$

$I_y = 16{,}172\ mm^4$

$k = 0.50$

$L = 515\ mm$

N_{cr} = ((PI()^2)*70000*29292)/((0.5^2)*(515^2))

= 291,464.44 N

$\lambda = \sqrt{A_{eff} f_u / N_{cr}}$ (6.3.1.2)

= 0.40 $A_{eff} = 164\ mm^2$

$X = 1/ \Phi+\sqrt{\Phi^2-\lambda^2}$

$\Phi = 0.5(1+\acute{\alpha}(\lambda-\lambda_o)+\lambda^2)$

$\acute{\alpha} = 0.20$ Table 6.6

$\lambda_o = 0.10$ Table 6.6

$\Phi = 0.61$

X = 0.82

$N_{b,Rd}$ = 0.82*1.0*164*290/1250

= 31.20 kN

Diagonal Axial Tension Capacity (6.2.3)

General yielding

$N_{o,Rd} = A_g f_o / \gamma_{M1}$

$f_o =$ 250 N/mm^2

$A_g = \rho_{o,haz} * A$

$=$ 0.50*328

$=$ 164.00 mm^2

$\gamma_{M1} =$ 1.1

$=$ 164*250/1100

$=$ 37.27 kN

Local failure

$N_{u,Rd} = A_{eff} f_u / \gamma_{M2}$

$f_u =$ 290 N/mm^2

$A_{eff} = \rho_{u,haz} * A$

$=$ 0.64*328

$=$ 209.92 mm^2

$\gamma_{M1} =$ 1.25

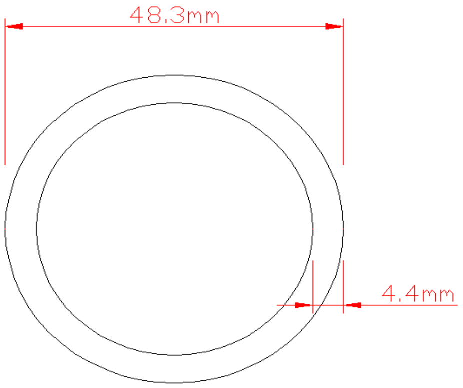
$=$ 209.92*290/1250

$=$ 48.70 kN

CALCULATION SHEET	Project :	Apollo MKII Lattice Beam			ALAN WHITE DESIGN
	Element :	Vertical CHS Member Capacity			
	Job Number :	W0126	By : mrb	Date: Sep 16	
	Document No :	001A	Checked: mmr	Date: Sep 16	

Vertical CHS Member Capacity

ø48.3mm x 4.4mm CHS 6082 T6



Section Properties

A=	607	mm^2
I=	147654	mm^4
W_{el}=	6114	mm^3
W_{pl}=	8254	mm^3
ry=	15.6	mm

for slenderness β= b/t b= 48.30 mm

= 10.98 t = 4.40 mm

ε= sqrt(250/f_o) f_o= 250N/mm^2

= 1.00

Class A, without welds, Internal parts β_1= 11ε

= 11*1.0

= 11.00

> 10.98

Section is class 1

CALCULATION SHEET	Project :	Apollo MKII Lattice Beam			AWD ALAN WHITE DESIGN
	Element :	Vertical CHS Member Capacity			
	Job Number :	W0126	By : mrb	Date: Sep 16	
	Document No :	001A	Checked: mmr	Date: Sep 16	

Vertical CHS Moment Capacity (6.2.5.1)

$M_{c,Rd} = \alpha W_{el} f_o / \gamma_{M1}$

$\alpha = W_{pl}/W_{el}$ (Table 6.4)

$=$ 0.00

$W_{el} =$ 8.25 cm^3

$f_o =$ 255 N/mm^2

$\gamma_{M1} =$ 1.1 (6.1.3)

= 1.35*6.11*255/1100

$M_{c,Rd} =$ 1.91 kNm

$M_{u,Rd} = W_{net} f_u / \gamma_{M2}$

$W_{net} = W_{el} * \rho_{u, haz}$

= 6.11*0.64

= 3.91 cm^3

$f_u =$ 295 N/mm^2

$\gamma_{M2} =$ 1.25 (6.1.3)

= 3.91*295/1250

$M_{u,Rd} =$ 0.92 kNm

$M_{Rd,x} =$ 0.92 kNm — lesser value of $M_{c,Rd}$ / $M_{u,Rd}$

Vertical CHS Shear Capacity (6.2.6)

$V_{Rd} = A_v f_o / \sqrt{3}\gamma_{M1}$

$A_v =$ 0.6A

$A_v =$ 0.6*0.64*607

$A_v =$ 233.09 mm^2

$\gamma_{M1} =$ 1.1

$f_o =$ 255 N/mm^2

= 233.09*255/(SQRT(3)*1100)

$V_{Rd} =$ 31.20 kN

CALCULATION SHEET	Project :	Apollo MKII Lattice Beam			AWD ALAN WHITE DESIGN
	Element :	Vertical CHS Member Capacity			
	Job Number :	W0126	By : mrb	Date: Sep 16	
	Document No :	001A	Checked: mmr	Date: Sep 16	

Vertical CHS Axial Comp Capacity @ 354mm (effective length of beam)

$N_{b,Rd} = k \, X \, A_{eff} f_o / \gamma_{M1}$ (6.3.1.1)

$k = \omega_x$

$\omega_x = \dfrac{\rho_{u,haz} f_u / \gamma_{M2}}{f_o / \gamma_{M1}}$

= (0.64*290/1.25)/(250/1.1)

= 0.65

k= 0.65

$N_{cr} = \pi^2 EI / k^2 L^2$ (Appendix I.3)

$E = 70{,}000\ N/mm^2$

$I = 6{,}114\ mm^4$

$k = 0.50$

$L = 354\ mm$

N_{cr} = ((PI()^2)*70000*147654)/((0.5^2)*(354^2))

= 3,256,090.52 N

$\lambda = \sqrt{A_{eff} f_o / N_{cr}}$ (6.3.1.2)

= 0.17 $A_{eff} = 388\ mm^2$

$X = 1/ \Phi+\sqrt{\Phi^2-\lambda^2}$

$\Phi = 0.5(1+ά(\lambda-\lambda_o)+\lambda^2)$

ά = 0.20 Table 6.6

λ_o = 0.10 Table 6.6

Φ = 0.52

X = 0.97

$N_{b,Rd}$ = 0.97*388*290/1250

= 87.32 kN

CALCULATION SHEET	Project :	Apollo MKII Lattice Beam			AWD ALAN WHITE DESIGN
	Element :	Vertical CHS Member Capacity			
	Job Number :	W0126	By : mrb	Date: Sep 16	
	Document No :	001A	Checked: mmr	Date: Sep 16	

Vertical CHS Axial Tension Capacity (6.2.3)

1. General yielding

$N_{o,Rd} = A_g f_o / \gamma_{M1}$

$f_o =$ 255N/mm^2

$A_g =$ 607mm^2

$\gamma_{M1} =$ 1.1

= 607*255/1100

= 140.71 kN

2. Local failure

$N_{u,Rd} = A_{net} f_u / \gamma_{M2}$

$f_u =$ 295 N/mm^2

$A_{net} = A^* \rho_{u,haz}$

= 607*0.64

= 388.5 mm^2

$\gamma_{M1} =$ 1.25

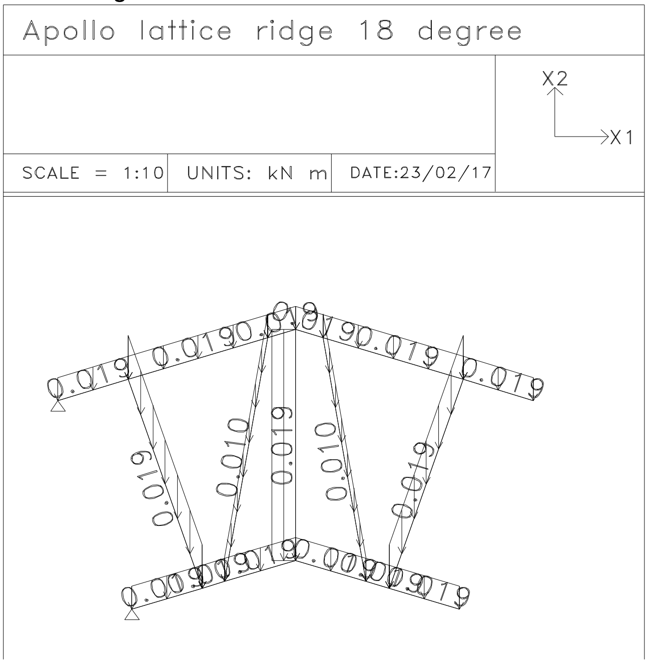
= 388.5*295/1250

= 91.69 kN

Lesser Value= 91.69 kN

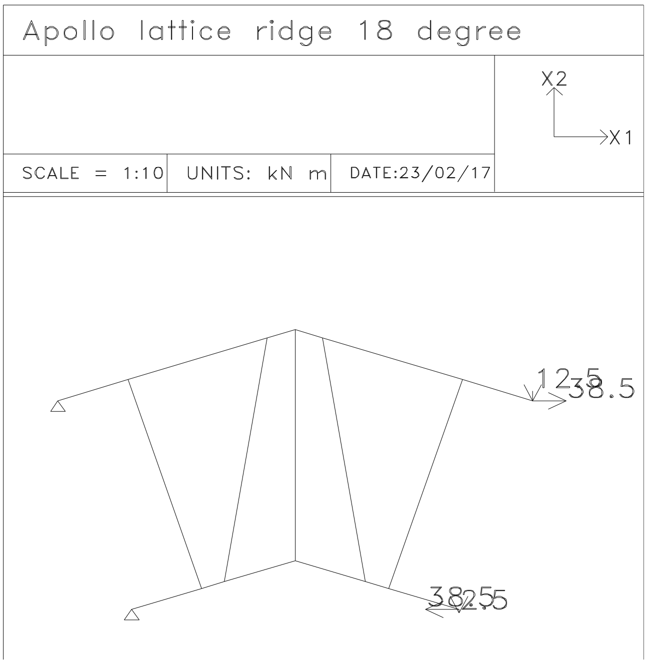
Load Case 1

Self Weight



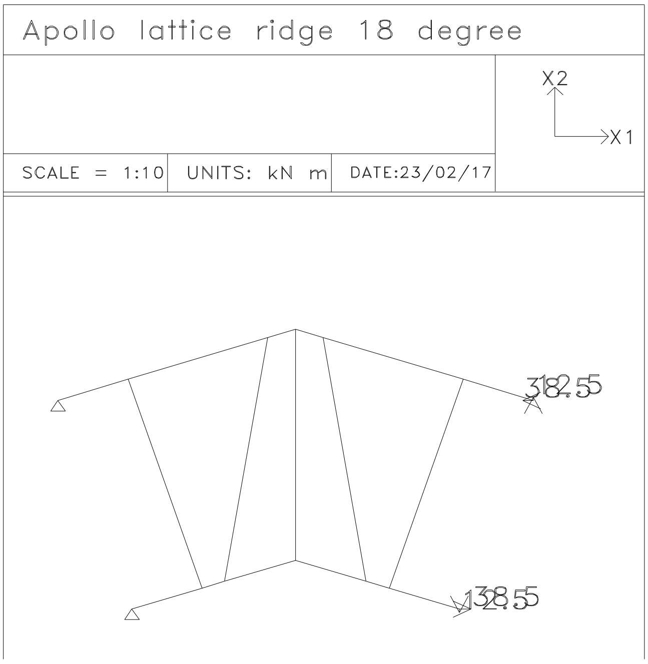
Load Case 2

Moment - down



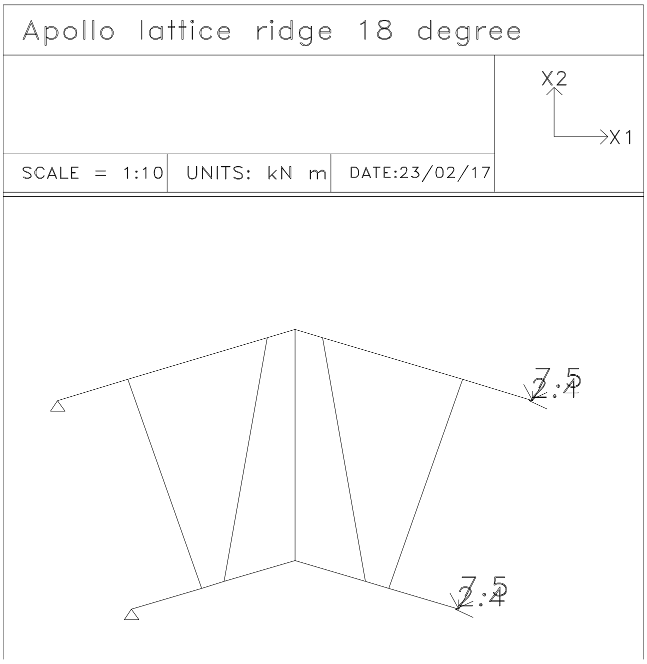
Load Case 3

Moment - up



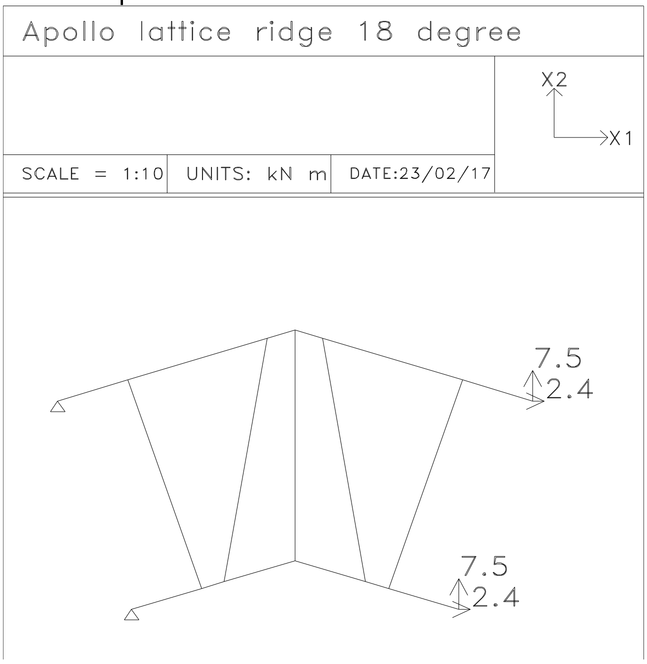
Load Case 4

Shear - down



Load Case 5

Shear - up



Combinations

Comb 1 -uls   1.35*Self +1.5* Moment down + 0.25* shear down

Comb 2 -uls   1.358Self + 1.5*Moment up + 0.25* shear up

0.25 factor taken for shear because max moment and max shear do not occur at same location in beam.

Element	Action	Formula	Capacity	Calculated	Factor
Boom	Moment	$M_{c,Rd}$	1.04	0.11	0.11
	Shear	V_{Rd}	32.91	6.15	0.19
	Tension	$N_{o,Rd}$	95.00	64.05	0.67
	Compression	$N_{b,Rd}$	82.08	64.20	0.78
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$			0.70
Boom with gusset	Moment	$M_{c,Rd}$	4.67	0.54	0.12
	Shear	V_{Rd}	60.94	4.51	0.07
	Tension	$N_{o,Rd}$	176.14	64.03	0.36
	Compression	$N_{b,Rd}$	127.19	64.62	0.51
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$			0.38
Vertical	Moment	$M_{c,Rd}$	0.92	0.28	0.30
	Shear	V_{Rd}	31.20	1.10	0.04
	Tension	$N_{o,Rd}$	91.69	1.77	0.02
	Compression	$N_{b,Rd}$	87.32	29.28	0.34
	Combined	$(N_{ed}/N_{Rd})^{1.3} + [(M_{ed,x}/M_{rd,x})^{1.7}]^{0.6} < 1.0$			0.55
Diagonal	Tension	$N_{o,Rd}$	37.27	0.00	0.00
	Compression	$N_{b,Rd}$	31.20	9.69	0.31
				Factor	**0.78**

Summary

With the addition of a gusset plate brace to the bottom boom, the ridge piece has been found to be capable of providing the same load capacity as the alloy lattice beam.

The proposed layout is as shown below.