# APOLLO SALES LTD
# 20 DEGREE X-BEAM RIDGE FRAME
# DESIGN CHECK CALCULATIONS

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V0181-01-001

**Brief**

The brief is to check the capacity of the Apollo 20 degree ridge frame unit when utilised with X-beams in a temporary roof

The beams are manufactured from tube extrusions in aluminium alloy 6082 T6.

The ridge frame is to be designed to have the same capacities as an X-beam

**Alloy**

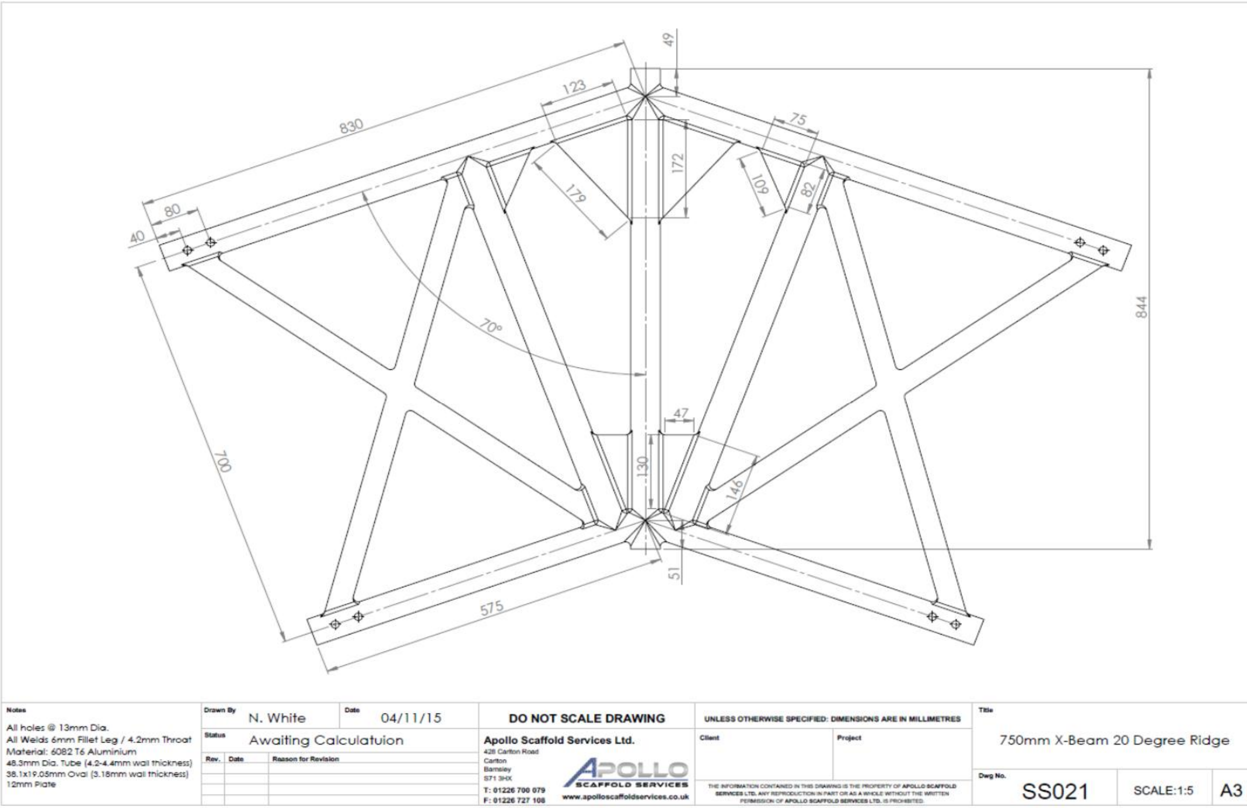
The alloy used is 6082 T6:

$f_o$= 250 N/mm$^2$

$f_u$= 290 N/mm$^2$

**Layout**

The geometry of the beam is shown in the drawing below:




**Design**

Eurocode 9: Design of Aluminium structures EN 1999-1-1

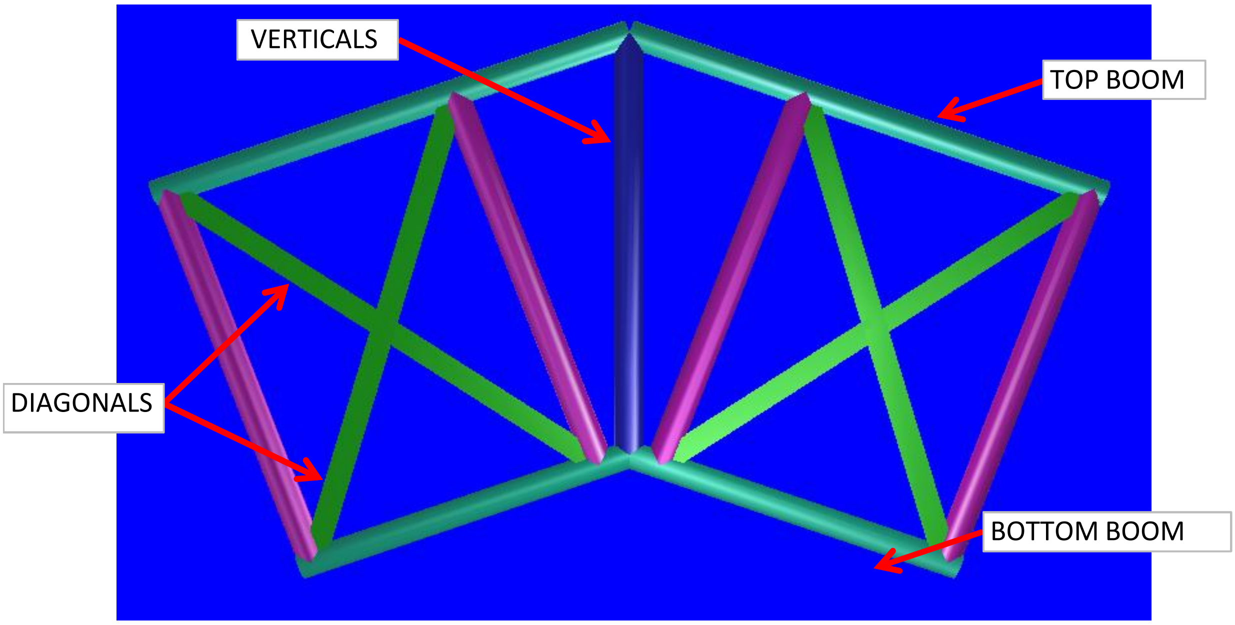
**X-beam Capacities**

From technical literature the capacities of an X-beam is

| | | |
|---|---|---|
| Allowable moment | 42.90 | kNm |
| Allowable shear | 45.40 | kN |

**STRAP Model**

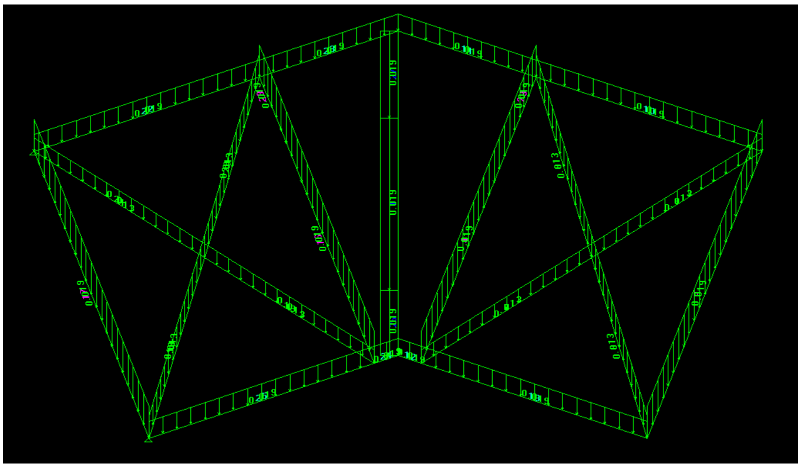
The structure was analysed in STRAP structural analysis program.




**Load Cases**

Load Case 1 — Self Weight

Self weight of all members is factored by 1.15 to account for connections



Load Case 2 — Beam shear downforce

The max end shear from an X-beam is applied locally to the ridge frame

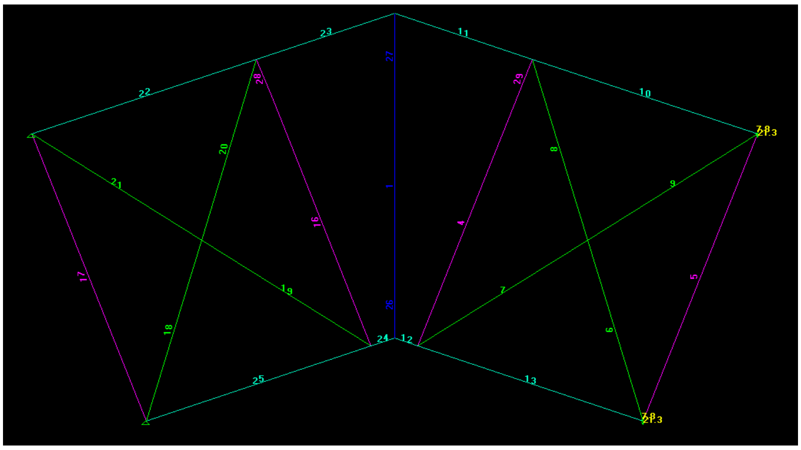
The X-beam max shear value of

Q= 45.40 kN

is applied to the ends and resolved to 20 degrees

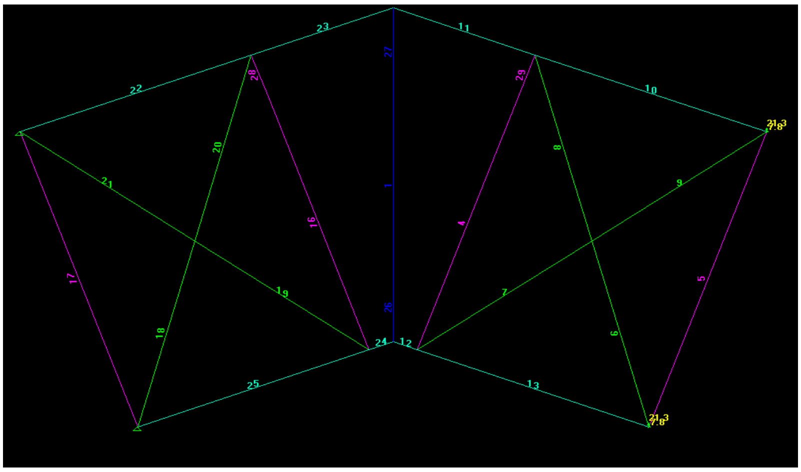
Vertical component $Q_v$= 0.5Q.cos 20
= 0.5*45.4*cos(20*PI()/180)
= 21.33 kN

Horizontal component $Q_h$= 0.5Q.sin20
= 0.5*45.4*sin(20*PI()/180)
= 7.76 kN



Load Case 3 — Beam shear uplift

The max end shear from an X-beam as above is applied locally to the ridge frame



Load Case 4 — Beam moment downforce

The push/pull loads from X-beam bending moment are applied to the ridge frame

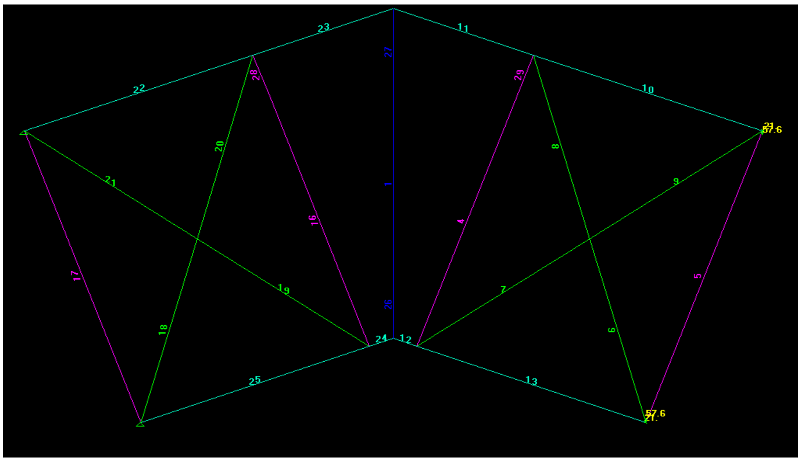
The X-beam max moment value of

M= 42.90 kN

is converted to a push pull load , applied to the ends and resolved to 20 degrees

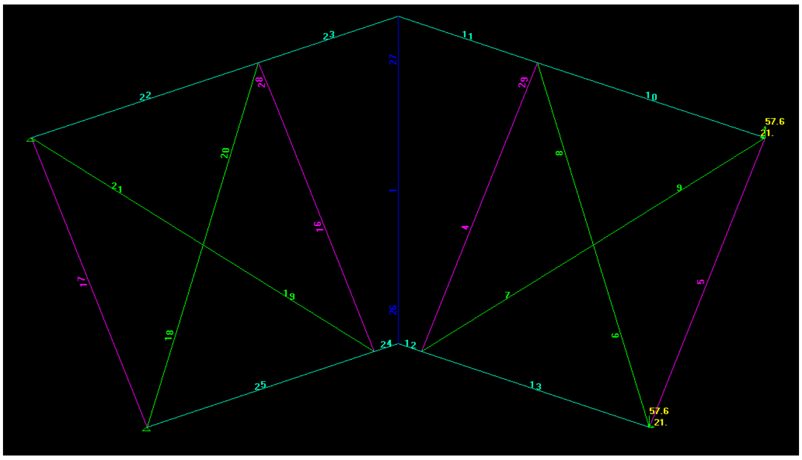
Vertical component $F_v$= M/0.7*sin 20
= 42.9/0.7*sin(20*PI()/180)
= 20.96 kN

Horizontal component $F_h$= M/0.7*cos20
= 42.9/0.7*cos(20*PI()/180)
= 57.59 kN




Load Case 5 — Beam moment uplift

The push/pull loads from X-beam bending moment as above are applied to the ridge frame



**Load Combinations**

| Combination Number | Combination Description | Load Cases |
|---|---|---|
| 1 | SLS Downforce | 1+2+4 |
| 2 | ULS Downforce | 1+2+4 |
| 3 | SLS Uplift | 1+3+5 |
| 4 | ULS Uplift | 1+3+5 |

Above Combinations were checked for the following design factors:

$\gamma_{D}$= 1.35

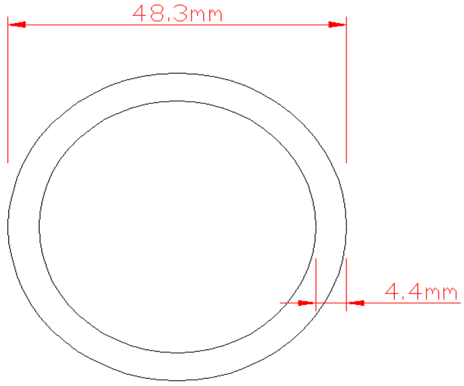
$\gamma_{Shear}$= 0.25

$\gamma_{Bending}$= 1.50

Due to the nature of the loading on a roof, the maximum shear will be found at the support with a very low shear force found in the ridge itself.

**CHS Boom Layout**

**Boom 48.3 x 4.4 CHS**




**Section Properties**

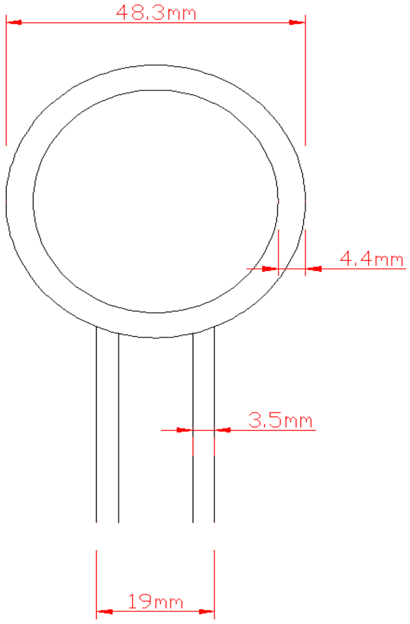
| | | | |
|---|---|---|---|
| $A=$ | 607 | $mm^2$ | |
| $I=$ | 147654 | $mm^4$ | |
| $W_{el}=$ | 6114 | $mm^3$ | |
| $W_{pl}=$ | 8254 | $mm^3$ | |
| $r_y=$ | 15.6 | mm | |

| | | | |
|---|---|---|---|
| for slenderness | $\beta=$ | b/t | b= 48.3 |
| | = | 10.98 | t = 4.4 |
| | $\varepsilon=$ | sqrt(250/$f_o$) | $f_o=$ 250N/$mm^2$ |
| | = | 1.00 | |
| Class A, without welds, Internal parts | $\beta_1=$ | 11ε | |
| | = | 11*1.0 | |
| | = | 11.00 | |
| | > | 10.98 | |

Section is class 1

**Boom 48.3 x 4.4 CHS HAZ**

There is a HAZ at welded joint to the diagonal brace




$t_{boom}$= 4.40mm

$t_{diagonal}$= 3.5mm

$t_{average}$= 3.95mm

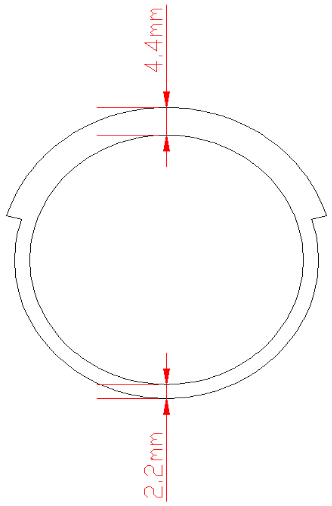
All welds are TIG.
As per EN 1999-1-1 6.1.6.3

$b_{haz}$ = 30mm

Therefore HAZ extends 30mm from intersection of welded materials

**HAZ Section Layout**

Take section shown as non-HAZ.




**Revised Section Properties**

$A=$ 418 $mm^2$

$I=$ 92785 $mm^4$

$W_{el}=$ 3398 $mm^3$

$W_{pl}=$ 4587 $mm^3$

$r_y=$ 14.7 mm

**Truss 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

$W_{el} =$ 3.40 $cm^3$

$f_o =$ 250 $N/mm^2$

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

= 1.35*3.40*250/1100

$M_{c,Rd} =$ 1.04 kNm

**Truss Boom Shear Capacity** (6.2.6)

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

$A_v=$ 0.6A

$A_v=$ 0.6*607

$A_v=$ 364.20 $mm^2$

$\gamma_{M1}=$ 1.1

$f_o =$ 250 $N/mm^2$

= 364.20*250/(SQRT(3)*1100)

$V_{Rd} =$ 47.79 kN

**Truss Top Boom Axial Comp Capacity @ 560mm (effective length of beam between restraints)**

$N_{b,Rd}$ = k x $A_{eff}$ $f_o$ /$\gamma_{M1}$ (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 = 560 mm

$N_{cr}$ = ((PI()^2)*70000*147654)/((0.5^2)*(560^2))
= 1,301,148.72 N

λ = √$A_{eff}$ $f_o$ / $N_{cr}$ (6.3.1.2)
= 0.34 $A_{eff}$ = 607 mm$^2$

X = 1/ Φ+√Φ$^2$-λ$^2$

Φ = 0.5(1+ά(λ-$\lambda_o$)+$\lambda^2$)
ά = 0.20 Table 6.6
$\lambda_o$= 0.10 Table 6.6
Φ = 0.58

X = 0.948

k= 1-(1-($A_1$/A)$10^{-\lambda}$-(0.005+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= 0.875

$N_{b,Rd}$ = k x $A_{eff}$ $f_o$ /$\gamma_{M1}$
$N_{b,Rd}$ = 0.875*0.948*607*250/1100
= 114.43 kN

**Truss Bottom Boom Axial Comp Capacity @ 1100mm**

$N_{b,Rd}$ = k x $A_{eff}$ $f_o$ /$\gamma_{M1}$ (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 = 1,100 mm

$N_{cr}$ = ((PI()^2)*70000*147654)/((0.5^2)*(1100^2))
= 337,223.34 N

λ = √$A_{eff}$ $f_o$ / $N_{cr}$ (6.3.1.2)
= 0.67 $A_{eff}$ = 607 mm$^2$

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

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

ά = 0.20 Table 6.6

$\lambda_o$= 0.10 Table 6.6

$\Phi$ = 0.78

X = 0.844

k= $1-(1-(A_1/A)10^{-\lambda}-(0.005+0.1(A_1/A))\lambda^{1.3(1-\lambda)}$

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

= 607-189*(1-0.5)

= 512.50 $mm^2$

k= 0.853

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

$N_{b,Rd}$ = 0.853*0.844*607*250/1100

= 99.32 kN

**Truss Boom Axial Tension Capacity** (6.2.3)

1. General yielding

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

$f_o$ = 250N/$mm^2$

$A_g$ = 607$mm^2$

$\gamma_{M1}$ = 1.1

= 607*250/1100

= 137.95 kN

2. Local failure

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

$f_u$ = 290N/$mm^2$

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

= 0.64*607$mm^2$

= 388.5$mm^2$

$\gamma_{M1}$ = 1.25

= 388.5*290/1250

= 90.13 kN

**Gusset plate**

A 80mm x 12.7mm thick gusset plate is added to strengthen the top and bottom boom
Assume section fully heat affected

A = 80*12.7
= 1,016.00 $mm^2$

$W_{el}$ = 12.7*80^2/6000
= 13.55 $cm^3$

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

$W_{net} = W_{el} * \rho_{u,\,haz}$
= 13.55*0.64
= 8.67 $cm^3$
$f_u$ = 290 $N/mm^2$
$\gamma_{M2}$ = 1.25 (6.1.3)

= 8.67*290/1250
$M_{u,Rd}$ = 2.01 kNm

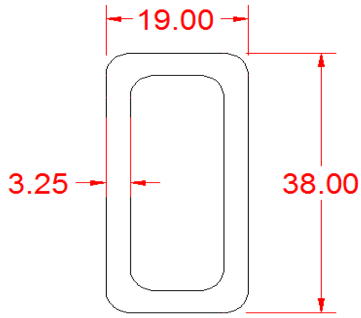
**Gusset Plate Shear Capacity** (6.2.6)

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

$A_v$= A
$A_v$= 1,016 $mm^2$
$\gamma_{M1}$= 1.1
$f_o$ = 250 $N/mm^2$

= 1016*250/(SQRT(3)*1100)
$V_{Rd}$ = 133.32 kN

**RHS-Oval Diagonal Member**
**Diagonal 38 x 19 x 3.25mm Oval**




| | | | | |
|---|---|---|---|---|
| **Section Properties** | A= | 328 | $mm^2$ | |
| | I= | 53341 | $mm^4$ | |
| | $W_{el}$= | 2807 | $mm^3$ | |
| | $W_{pl}$= | 3729 | $mm^3$ | |
| | $r_y$= | 7.0 | mm | |
| for slenderness | $\beta$= | b/t | | b= 38-2*3.25 |
| | | | | = 31.50 |
| | = | 9.69 | | t = 3.25 |
| | $\varepsilon$= | sqrt(250/$f_o$) | | $f_o$= 250N/$mm^2$ |
| | = | 1.00 | | |
| Class A, without welds, Internal parts | $\beta_1$= | 11$\varepsilon$ | | |
| | = | 11*1.0 | | |
| | = | 11.00 | | |
| | > | 9.69 | | |

**Section is class 1**

**Diagonal Axial Comp Capacity @ 400mm (effective length of beam)**

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

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

E = 70,000 N/$mm^2$
I = 53,341 $mm^4$
k = 0.50
L = 400 mm

$N_{cr}$ = ((PI()^2)*70000*53341)/((0.5^2)*(400^2))
= 921,295.49 N

$\lambda$ = $\sqrt{}A_{eff}$ $f_o$ / $N_{cr}$ (6.3.1.2)
= 0.30 $A_{eff}$ = 328 $mm^2$

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

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

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

$\lambda_o =$ 0.10 Table 6.6

$\Phi =$ 0.56

$X =$ 0.89

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

= 328-164*(1-0.5)

= 246.00 $mm^2$

k= 0.833

$N_{b,Rd} =$ 0.833*0.89*328*250/1100

= 55.27 kN

**Diagonal Axial Tension Capacity** (6.2.3)

1. General yielding

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

$f_o =$ 250N/$mm^2$

$A_g =$ 328$mm^2$

$\gamma_{M1} =$ 1.1

= 328*250/1100

= 79.55 kN

2. Local failure

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

$f_u =$ 290N/$mm^2$

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

= 0.64*328$mm^2$

= 209.9$mm^2$

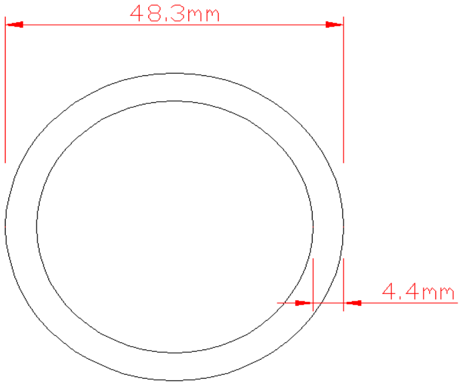
$\gamma_{M1} =$ 1.25

= 209.9*290/1250

= 48.70 kN

**Vertical 48.3 x 4.4mm CHS**

**Vertical CHS Layout**



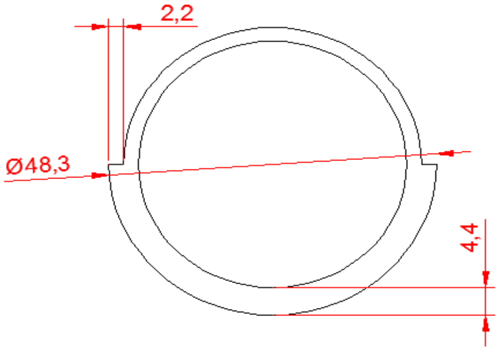

**Section Properties**

| | | | |
|---|---|---|---|
| | $A=$ | 607 | $mm^2$ |
| | $I=$ | 147654 | $mm^4$ |
| | $W_{el}=$ | 6114 | $mm^3$ |
| | $W_{pl}=$ | 8254 | $mm^3$ |
| | $r_y=$ | 15.6 | mm |
| for slenderness | $\beta=$ | b/t | b= 48.3 |
| | = | 10.98 | t = 4.4 |
| | $\varepsilon=$ | sqrt(250/$f_o$) | $f_o$= 250N/mm$^2$ |
| | = | 1.00 | |
| Class A, without welds, Internal parts | $\beta_1=$ | $11\varepsilon$ | |
| | = | 11*1.0 | |
| | = | 11.00 | |
| | > | 10.98 | |

| Section is class 1 |
|---|

**Vertical HAZ at Gusset Plate**

**Vertical CHS Layout**




**Section Properties**

A= 447 $mm^2$
I= 105237 $mm^4$
$W_{el}$= 4358 $mm^3$
$W_{pl}$= 5883 $mm^3$
$r_y$= 15.3 mm

**Vertical CHS Moment Capacity** (6.2.5.1)

$M_{c,Rd} = \alpha W_{el} f_o / \gamma_{M1}$ (Table 6.4)

$\alpha$ = 1.35
$W_{el}$ = 4.36 $cm^3$
$f_o$ = 250 $N/mm^2$
$\gamma_{M1}$ = 1.1 (6.1.3)

= 1.35*4.36*250/1100
$M_{c,Rd}$ = 1.34 kNm

**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*607
$A_v$= 364.20 $mm^2$
$\gamma_{M1}$= 1.1
$f_o$ = 250 $N/mm^2$

= 364.20*250/(SQRT(3)*1100)
$V_{Rd}$ = 47.79 kN

| CALCULATION SHEET | Project : | Apollo 20$^{o}$ Ridge Frame to Eurocode | | | AWD ALAN WHITE DESIGN |
|---|---|---|---|---|---|
| | Element : | Vertical capacity | | | |
| | Job Number : | V0181-01 | By : anw | Date:Nov 15 | |
| | Document No : | 001 | Checked:mmr | Date:Nov 15 | |

**Vertical CHS Axial Comp Capacity @ 500mm (effective length of beam)**

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

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

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

I = 105,237 $mm^4$

k = 0.50

L = 0.7*440 mm

= 308.00 mm

$N_{cr}$ = ((PI()^2)*70000*105237)/((0.5^2)*(308^2))

= 3,065,665.76 N

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

= 0.22 $A_{eff}$ = 607 $mm^2$

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

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

$\lambda_o$= 0.10 Table 6.6

$\Phi$ = 0.54

X = 0.94

$k= 1-(1-(A_1/A)10^{-\lambda}-(0.005+0.1(A_1/A))\lambda^{1.3(1-\lambda)}$

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

= 607-160*(1-0.5)

= 527.00 $mm^2$

k= 0.750

$N_{b,Rd}$ = 0.75*607*250/1100

= 103.47 kN

**Vertical CHS Axial Tension Capacity** (6.2.3)

1. General yielding $N_{o,Rd} = A_g f_o / \gamma_{M1}$

$f_o$ = 250N/$mm^2$

$A_g$ = 607$mm^2$

$\gamma_{M1}$ = 1.1

= 607*250/1100

= 137.95 kN

2. Local failure $N_{u,Rd} = A_{net} f_u / \gamma_{M2}$

$f_u$ = 290N/$mm^2$

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

= 607*0.64

= 388.5$mm^2$

$\gamma_{M1}$ = 1.25

= 388.5*290/1250

= 90.13 kN

| **Results** | Action | Formula | Ultimate | Calculated | Factor |
|---|---|---|---|---|---|

**Arrangement:** 20 Degree ridge
**Load orientation:** Downforce

**Top Boom Capacity**

| | Action | Formula | Ultimate | Calculated | Factor |
|---|---|---|---|---|---|
| | Moment | $M_{Rd,x}$ | 1.04 | 0.31 | 0.30 |
| | Shear | $V_{Rd}$ | 47.79 | 0.74 | 0.02 |
| | Tension | $N_{u,Rd}$ | 90.13 | 0.00 | 0.00 |
| | Compression | $N_{b,Rd}$ | 114.43 | 71.50 | 0.62 |
| | Combined | < 1.0 | 1.00 | 0.67 | 0.670 |

**Bottom Boom Capacity**

| | Action | Formula | Ultimate | Calculated | Factor |
|---|---|---|---|---|---|
| | Moment | $M_{Rd,x}$ | 3.05 | 0.63 | 0.21 |
| | Shear | $V_{Rd}$ | 181.10 | 13.57 | 0.07 |
| | Tension | $N_{u,Rd}$ | 90.13 | 78.30 | 0.87 |
| | Compression | $N_{b,Rd}$ | 99.32 | 0.00 | 0.00 |
| | Combined | < 1.0 | 1.00 | 0.90 | 0.90 |

**Diagonal Capacity**

| | Action | Formula | Ultimate | Calculated | Factor |
|---|---|---|---|---|---|
| | Tension | $N_{u,Rd}$ | 48.70 | 19.15 | 0.39 |
| | Compression | $N_{b,Rd}$ | 55.27 | 5.40 | 0.10 |

**Vertical Capacity**

| | Action | Formula | Ultimate | Calculated | Factor |
|---|---|---|---|---|---|
| | Moment | $M_{Rd,x}$ | 1.34 | 0.21 | 0.16 |
| | Shear | $V_{Rd}$ | 47.79 | 0.57 | 0.01 |
| | Tension | $N_{u,Rd}$ | 90.13 | 59.84 | 0.66 |
| | Compression | $N_{b,Rd}$ | 103.47 | 2.05 | 0.02 |
| | Combined | < 1.0 | 1.00 | 0.05 | 0.05 |

| CALCULATION SHEET | Project : | Apollo 20° Ridge Frame to Eurocode | | | ALAN WHITE DESIGN |
|---|---|---|---|---|---|
| | Element : | Results-20 Degree ridge Uplift | | | |
| | Job Number : | V0181-01 | By : anw | Date:Nov 15 | |
| | Document No : | 001 | Checked:mmr | Date:Nov 15 | |

| Results | Action | Formula | Ultimate | Calculated | Factor |
|---|---|---|---|---|---|

**Arrangement:** 20 Degree ridge
**Load orientation:** Uplift

**Top Boom Capacity**

| | Action | Formula | Ultimate | Calculated | Factor |
|---|---|---|---|---|---|
| | Moment | $M_{Rd,x}$ | 1.04 | 0.23 | 0.22 |
| | Shear | $V_{Rd}$ | 47.79 | 0.48 | 0.01 |
| | Tension | $N_{u,Rd}$ | 90.13 | 71.70 | 0.80 |
| | Compression | $N_{b,Rd}$ | 114.43 | 0.00 | 0.00 |
| | Combined | < 1.0 | 1.00 | 0.82 | 0.82 |

**Bottom Boom Capacity**

| | Action | Formula | Ultimate | Calculated | Factor |
|---|---|---|---|---|---|
| | Moment | $M_{Rd,x}$ | 3.05 | 0.23 | 0.08 |
| | Shear | $V_{Rd}$ | 181.10 | 0.48 | 0.00 |
| | Tension | $N_{u,Rd}$ | 90.13 | 0.00 | 0.00 |
| | Compression | $N_{b,Rd}$ | 99.32 | 78.67 | 0.79 |
| | Combined | < 1.0 | 1.00 | 0.75 | 0.75 |

**Diagonal Capacity**

| | Action | Formula | Ultimate | Calculated | Factor |
|---|---|---|---|---|---|
| | Tension | $N_{u,Rd}$ | 48.70 | 5.70 | 0.12 |
| | Compression | $N_{b,Rd}$ | 55.27 | 19.20 | 0.35 |

**Vertical Capacity**

| | Action | Formula | Ultimate | Calculated | Factor |
|---|---|---|---|---|---|
| | Moment | $M_{Rd,x}$ | 1.34 | 0.21 | 0.16 |
| | Shear | $V_{Rd}$ | 47.79 | 0.57 | 0.01 |
| | Tension | $N_{u,Rd}$ | 90.13 | 2.15 | 0.02 |
| | Compression | $N_{b,Rd}$ | 103.47 | 59.82 | 0.58 |
| | Combined | < 1.0 | 1.00 | 0.53 | 0.533 |

**Summary**

All structural members have passed design checks for specified loading

The ridge member has been checked and found to be stronger than the x-beams to which it will be connected.

The ridge can be used as part of an x-beam roof which is properly laced and braced without additional calculation.

Stiffener plates must be utilised as shown  in drawing below