APOLLO SCAFFOLDING SERVICES LTD
SPIGOT CONNECTION TO EUROCODES
DESIGN CHECK CALCULATIONS

Alan N White B.Sc., M.Eng., C.Eng., M.I.C.E., M.I.H.T.

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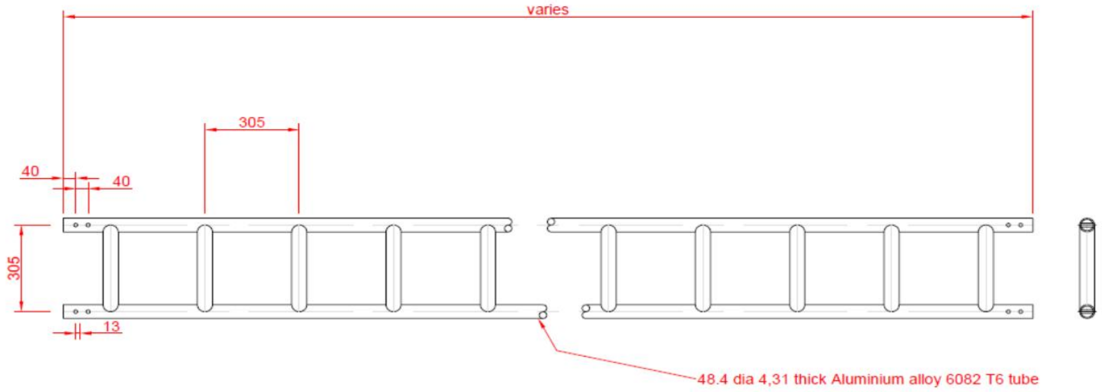
Somerset House
11 Somerset Place
GLASGOW G3 7JT
Tel:0141 354 6579
Fax:0141 354 6549

S0140/001

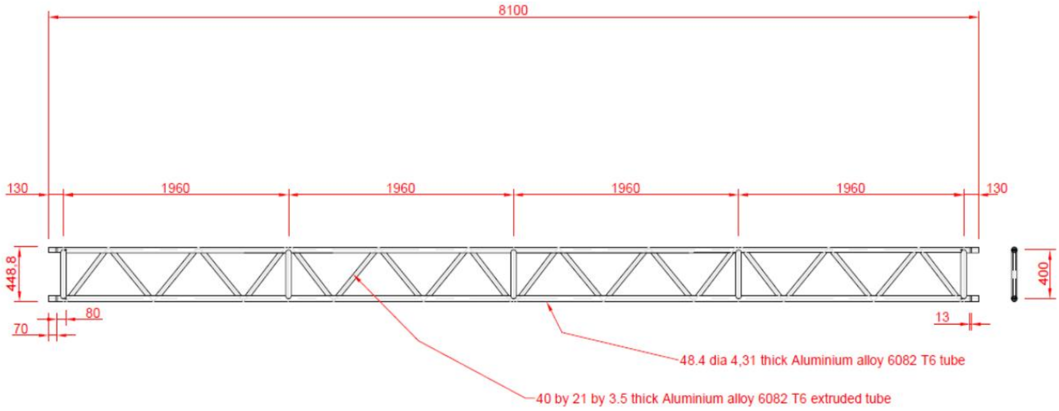
Brief

To check the capacity of the spigot for connecting booms of Apollo aluminium truss beams.

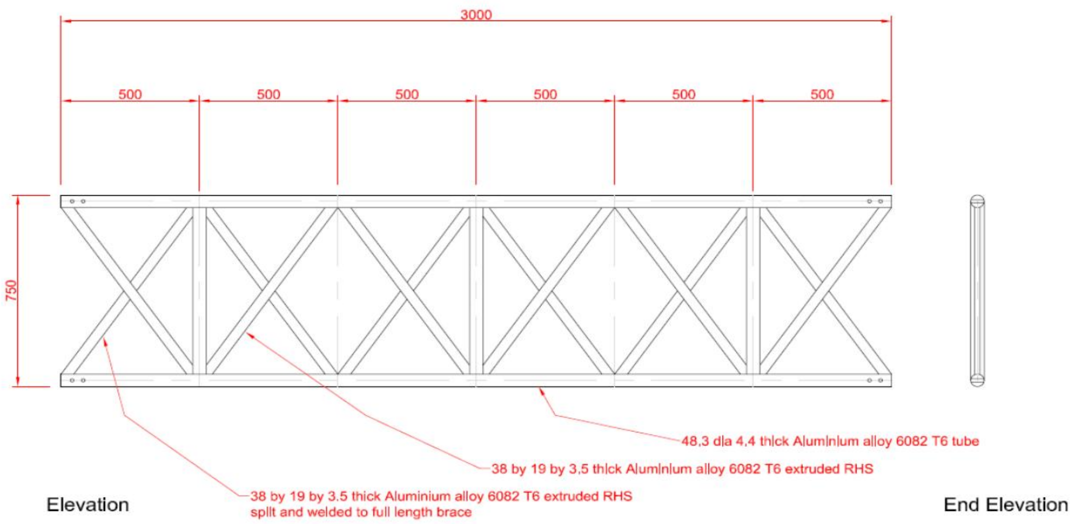
Three beams will be examined as below:



300mm ladder beam



450 lattice beam



750 X-beam

Design

Design of Steel Structures	EN 1993-1-1
Design of Aluminium Structures	EN-1999-1-1

The following AWD documents are referenced:

Apollo alloy lattice beam calc	S0072-001
Apollo alloy ladder beam calc	R0141-001
Apollo alloy X-beam calc	R0076-001

Design assumptions

Steelwork yield strength for CHS members is 355N/mm^2

Aluminium yield strength for Solid bar is 255N/mm^2

All bolts M12 Grade 8.8
Note the steel design factor of safety is 1.5 for live loads

Analysis

From the calculations for the ladder beam R0141-001

The capacities of the boom are:

Moment	0.92	kNm
Shear	48.74	kNm
Tension	91.69	kN
Compression	88.72	kN

From the calulations for the lattice beam S0072-001:

Moment	0.92	kNm
Shear	48.74	kNm
Tension	91.69	kN
Compression	80.47	kN

From the calculations for the X-beam R0076-001:

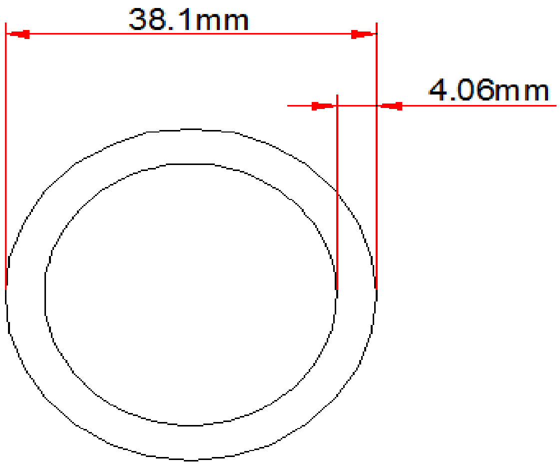
Moment	1.04	kNm
Shear	48.74	kNm
Tension	91.69	kN
Compression	120.2	kN

Design capacities

From above the spigots require to have the following capacities

Moment	**1.04**	**kNm**
Shear	**48.74**	**kNm**
Tension	**91.69**	**kN**
Compression	**120.20**	**kN**

Steel Spigot Section
38.1 x 4.06 CHS S355



Steel Spigot Section

$A=$	434 mm^2
$I=$	63781 mm^4
$W_{el,x}=$	3348 mm^3
$W_{pl,x}=$	4520 mm^3
$r_y=$	12 mm

Applied Loads

Moment	$M_{Rd,x}=$	1.04 kNm
Shear	$V_{Rd}=$	48.74 kN
Tension	$N_{u,Rd}=$	91.69 kN
Compression	$N_{b,Rd}=$	120.20 kN

Steel Spigot Bending moment

$M_{cr,x}=$ $W_{p,l}.f_y/\gamma_{m0}$

$W_{pl,x}=$ 4.52 cm^3
$f_y=$ 355 N/mm^2
$\gamma_{m0}=$ 1.00

= 4.52*355/1000
= 1.60 kNm
> 1.04 kNm ok

Steel Spigot Shear

$V_{cr}=$ $A_v.f_y/sqrt(3)/\gamma_{m0}$

$A_v=$ 0.6A
$A_v=$ 260 mm^2
$f_y=$ 355 N/mm^2
$\gamma_{m0}=$ 1.00

= 260*355/sqrt(3)/1000
= 53.29 kN
> 48.74 kN ok

Steel Spigot Tension

plastic resistance

$N_{plr} = A.f_y/\gamma_{m0}$

$A_e = A - A_{(2\ bolt\ holes)}$

$A_e = 434-2*13*4.06$

$A_e = 328.44\ mm^2$

$f_y = 355\ N/mm^2$

$\gamma_{m0} = 1.00$

= 328.44*355/1000

= 116.60 kN

ultimate resistance

$N_{ur} = 0.9A.f_u/\gamma_{m2}$

$0.9A = 296\ mm^2$

$f_u = 510\ N/mm^2$

$\gamma_{m2} = 1.25$

= 296*510/1250

= 120.77 kN

Lesser Value= 116.60 kN

> 91.69 kN ok

.

Steel Spigot Compression

$N_{b,Rd} = X\ A\ f_y/\gamma_{m2}$

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

$\varphi = 0.5(1+\alpha(\bar{\lambda}-0.2)+\lambda^{-2}$

$\bar{\lambda} = \sqrt{A.f_y/N_{cr}}$

$\alpha = 0.21$ Table 6.1

$N_{cr} = \pi^2 EI/L^2$

$E = 210000\ N/mm^2$

$I = 63781\ mm^4$

$L = 220\ mm$

= pi()^2*210000*63781/(220^2)

= 2,731,272.31 N

$\bar{\lambda} = \sqrt{Af_y/N_{cr}}$

$A = 434\ mm^2$

$f_y = 355\ N/mm^2$

= 0.24

$\varphi = 0.5(1+\alpha(\bar{\lambda}-0.2)+\lambda^{-2})$

$\alpha = 0.21$ Table 6.1

= 0.53

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

= 0.99

$N_{b,Rd} = X\ A\ f_y/\gamma_{m0}$

$N_{b,Rd} = 152.85$ kN

> 120.20 kN ok

Bearing in spigot

Bolts are M12 grade 8.8

$F_{b,Rd}$= $k_1\ \alpha_b\ f_u\ d\ t\ /\ \gamma_{M2}$

d_o=	13 mm
e_1=	40 mm
e_2=	40 mm
k_1=	6.92 >2.5
therefore k_1=	2.5
t=	4.06 mm
d=	12 mm
f_u=	510 N/mm^2
f_{ub}=	800 N/mm^2
γ_{M2}=	1.25
α_b=	1.03 >1
Therefore, α_b=	1.00

$F_{b,Rd}$= (2.5*1.00*510*12*4.06)/1250
= 49.69 kN

Load transferred via 2No Bolts with 2No holes leading to 4No Bearing surfaces

Total Bearing capacity= 4*49.69
$F_{b,Rd}$= 198.76 kN
> 120.20 kN ok

Bearing in boom

Bolts are M12 grade 8.8

$F_{b,Rd}$= $k_1\ \alpha_b\ f_u\ d\ t\ /\ \gamma_{M2}$

d_o=	13 mm
e_1=	40 mm
e_2=	40 mm
k_1=	6.92 >2.5
therefore k_1=	2.5
t=	4.4 mm
d=	12 mm
f_u=	295 N/mm^2
f_{ub}=	800 N/mm^2
γ_{M2}=	1.25
α_b=	1.03 >1
Therefore, α_b=	1.00

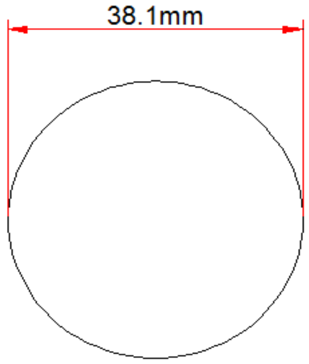
$F_{b,Rd}$= (2.5*1*295*12*4.4)/1250
= 31.15 kN

Load transferred via 2No Bolts with 2No holes leading to 4No Bearing surfaces

Total Bearing capacity= 4*31.15
$F_{b,Rd}$= 124.60 kN
> 120.20 kN ok

Aluminium Spigot Section

38.1 mm CHS — The section of the aluminium spigot is a solid bar with 2 holes through each end to match the holes in the end of the booms.



Aluminium Spigot Section

$A =$ 1140 mm^2

$I =$ 103435 mm^4

$W_{el,x} =$ 5430 mm^3

$W_{pl,x} =$ 9230 mm^3

$r_y =$ 10 mm

Applied Loads

Moment	$M_{Rd,x} =$	1.04 kNm
Shear	$V_{Rd} =$	48.74 kN
Tension	$N_{u,Rd} =$	91.69 kN
Compression	$N_{b,Rd} =$	120.20 kN

Aluminium Spigot Moment Capacity (6.2.5.1)

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

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

$=$ 1.70

$W_{el} =$ 5.43 cm^3

$f_o =$ 255 N/mm^2

$\gamma_{M1} =$ 1.10 (6.1.3)

= 1.70*5.43*255/1100

$M_{c,Rd} =$ 2.14 kNm

> 1.0 kNm ok

Aluminium Spigot Shear Capacity (6.2.6)

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

$A_v =$ $0.8A_e$

$=$ 912 mm^2

$\gamma_{M1} =$ 1.10

$f_o =$ 255 N/mm^2

= 912*255/(SQRT(3)*1100)

$V_{Rd} =$ 122.06 kN

> 48.7 kN

Aluminium Spigot Axial Tension Capacity (6.2.3)

General yielding

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

$f_o =$ 255 N/mm^2

$A_g =$ 1140 mm^2

$\gamma_{M1} =$ 1.1

= 1140*255/1100

= 264.27 kN

Local failure

$N_{u,Rd} = 0.9 A_{net} f_u / \gamma_{M2}$

$f_u =$ 295 N/mm^2

$A_{net} = A - A_{(1\ Bolt\ Hole)}$

= 644.7 mm^2

$\gamma_{M1} =$ 1.25

= 0.9*644.7*295/1250

= 136.79 kN

Lesser Value= 136.79 kN

> 91.7 kN

Aluminium Spigot Compression Capacity

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

k= ω_x

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

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

= 0.65

k= 0.65

$N_{cr} = \pi^2 EI / k^2 L^2$

E = 70,000 N/mm^2

I = 103,435 mm^4

k= 0.50

L = 220 mm

N_{cr} = ((PI()^2)*70000*103435)/((0.5^2)*(220^2))

= 5,905,816.30 N

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

A= 1,140 mm^2

= 0.22

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

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

$\alpha =$ 0.20 Table 6.6

$\lambda_o =$ 0.10 Table 6.6

$\Phi =$ 0.54

X = 0.94

$N_{b,Rd}$ = 0.65*0.94*1140*255/1100

= 161.47 kN

> 120.2 kN

Bearing in spigot

Bolts are M12 grade 8.8

$F_{b,Rd}=\ k_1\ \alpha_b\ f_u\ d\ t/\gamma_{M2}$

d_o=	13	mm
e_1=	40	mm
e_2=	40	mm
k_1=	6.92	>2.5
therefore k_1=	2.5	
t=	38.1	mm
d=	12	mm
f_u=	295	N/mm^2
f_{ub}=	800	N/mm^2
γ_{M2}=	1.25	
α_b=	1.03	>1
Therefore, α_b=	1.00	

$F_{b,Rd}$= (2.5*1.00*295*12*38.1)/1250

= 269.75 kN

> 120.20 kN ok

Bearing in boom

Bolts are M12 grade 8.8

$F_{b,Rd}=\ k_1\ \alpha_b\ f_u\ d\ t/\gamma_{M2}$

d_o=	13	mm
e_1=	40	mm
e_2=	40	mm
k_1=	6.92	>2.5
therefore k_1=	2.5	
t=	4.4	mm
d=	12	mm
f_u=	295	N/mm^2
f_{ub}=	800	N/mm^2
γ_{M2}=	1.25	
α_b=	1.03	>1
Therefore, α_b=	1.00	

$F_{b,Rd}$= (2.5*1.00*295*12*4.4)/1250

= 31.15 kN

Load transferred via 2No Bolts with 2No holes leading to 4No Bearing surfaces

Total Bearing capacity= 4*31.15

$F_{b,Rd}$= 124.60 kN

> 120.20 kN ok

Results

	Action	Formula	Ultimate	Calculated	Factor
Steel Spigot Capacity					
	Moment	$M_{Rd,x}$	1.60	1.04	0.65
	Shear	V_{Rd}	53.29	48.74	0.92
	Tension	$N_{u,Rd}$	116.60	91.69	0.79
	Compression	$N_{b,Rd}$	152.85	120.20	0.79
	Bearing - Spigot	$F_{b,Rd}$	198.76	120.20	0.61
	Bearing - Boom	$F_{b,Rd}$	124.60	120.20	0.97
Alu Spigot Capacity					
	Moment	$M_{Rd,x}$	2.14	1.04	0.49
	Shear	V_{Rd}	122.06	48.74	0.40
	Tension	$N_{u,Rd}$	136.79	91.69	0.68
	Compression	$N_{b,Rd}$	161.47	120.20	0.75
	Bearing - Spigot	$F_{b,Rd}$	269.75	120.20	0.45
	Bearing - Boom	$F_{b,Rd}$	124.60	120.20	0.97

Summary

The required capacities for the three different beams listed below were extracted from their design calculations and the capacities of spigots made from two different materials were compared.

The beams were

Apollo alloy ladder beam
Apollo alloy lattice beam
Apollo alloy X-beam

The spigots that were checked were:

Steel	38.1mm diameter 4.06mm seamless tube to Grade S355.
Aluminium	38.1 diameter solid bar made from 6082T6 aluminium alloy

The calculations showed that both of these spigots have the required capacities and are suitable for use in these beams.