APOLLO CRADLES LTD
LADDER BOX BEAM CANTILEVER
DESIGN CHECK CALCULATIONS

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Brief

To produce design check calculations for the maximum cantilever for an Apollo ladder beam box used to support the winch loads from cradles.

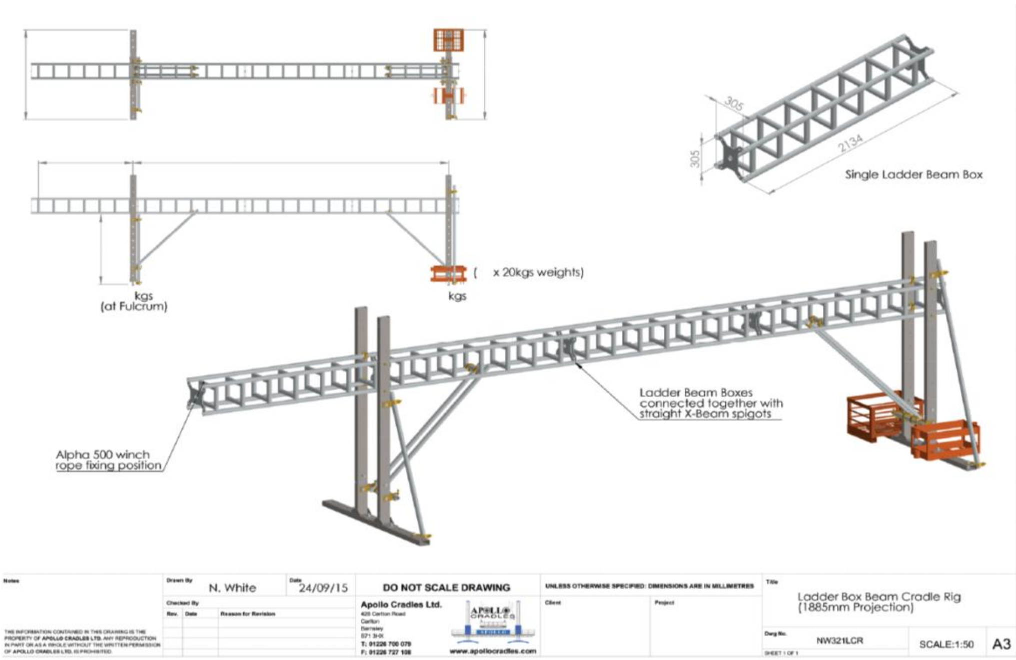
The frame is constructed from standard scaffold components, ladder beams, GKN beams and scaffold tubes.

The winches will be Alpha 500 or Alpha 800

Design check is only valid for the extent of the cantilever. Counterweight and support reactions will be dependent on the length of the back span.

Layout

Drawings below have been provided by the client:



Design	Design of aluminium structures	EN 1999-1-1
	Design of steel structures	EN 1993-1-1
	Technical guidance	TG20:13

Design assumptions

Scaffold components must be as per TG20:13.

GKN steelwork grade must be S355.

Aluminium components to be 6082T6 alloy

This design does not include a check of the existing structure.

Design check is only valid for the extent of the cantilever. Counterweight and support reactions will be dependent on the length of the back span.

Wind Loading

Wind calculation procedures are taken from the European standards:

Eurocode 1 Actions on structures - Wind — BS EN 1991-1-4

NA: Actions on Structures - Wind — NA BS EN 1991-1-4

Safety Requirements on Suspended Access Equipment — BS EN 1808

Working Wind Loading

Maximum wind pressure applied at working wind speed is:

Basic Wind Speed V_b= 14.00 m/s (BS EN 1808 T.6)

Dynamic Wind Pressure q_b= $k{*}V_e^2$ k=0.613

= 0.12 kN/m^2

Storm Wind Loading

Maximum wind pressure applied at storm wind speed is:

Basic Wind Speed V_b= 36.00 m/s (BS EN 1808 T.7)

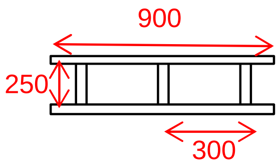
Dynamic Wind Pressure q_b= $k{*}V_e^2$ k=0.613

= 0.79 kN/m^2

Applied Wind Pressure

The wind pressure is applied to the members of the box beam.

for a 900mm length of beam there are



horizontals	2* 900	1800		
Verticals	3*250	750		
		2550	mm	per 900mm

so wind area of 50mm tube is 2550*50

= 127,500 mm^2 per 900mm

Take 50% as shielding for other parallel beam
so wind area permeter length is

A= 1.5*127500/0.9

= 212,500.00 mm^2 per m

= 0.2125 m^2 per m

Cpe= 1.2 for cylinder

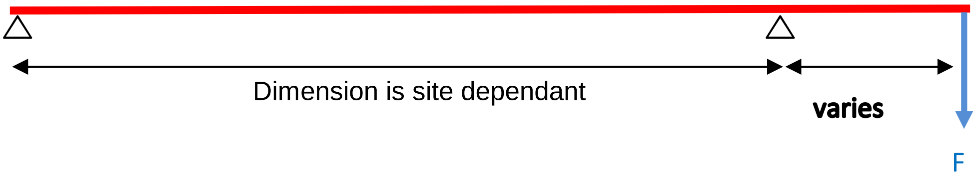
Applied Working Wind Pressure = 0.12*0.2125*1.2

= 0.03 kN/m

Applied Storm Wind Pressure = 0.79*0.2125*1.2

= 0.20 kN/m

Loading



for an alpha 500 winch the force

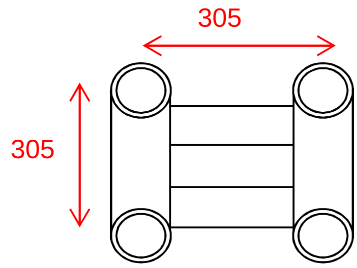
F=	$500\gamma_L$	γ_L=	2.5	BS EN 1808
=	500*2.5			
=	1,250 kg			
=	12.5 kN			

for an alpha 800 winch the force

F=	$800\gamma_L$	γ_L=	2.5	BS EN 1808
=	800*2.5			
=	2,000 kg			
=	20 kN			

In addition there will be a horizontal force equal to 10% of the above loads

Box Beam Section



conservatively only considering 4No tubes , 48.3 by 4.4mm wall

Tube 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

Box Properties

A=	2,427	mm^2
I=	57,040,977	mm^4
W_{el}=	374,039	mm^3
W_{pl}=	448,847	mm^3
r_y=	153	mm

Restraint

The tubes are restrained at a distance of 305mm by cross members.

This assumption is only valid up to the length where the whole section acts as a beam and lateral torsional buckling of the box occurs.

This occurs when

λ_{LT}= 0.4 BE EN 1999-1-1 Cl 6.3.2.1.c

λ_{LT}= sqrt($\alpha W_{el}.f_o/M_{cr}$)

where a= 0.768 Table 6.4

W_{el}= 374,039 mm^3

f_0= 250 N/mm^2 Table 3.2b

M_{cr}= π^2 EI / L^2*sqrt($L^2 GI_t/\pi^2 EI$)

E=	70000	N/mm^2
I=	57,040,977	mm^4
L=	2,568	mm
It=	1.25E+06	mm^4 (shapecad)
G=	27000	N/mm^2

= 449422521

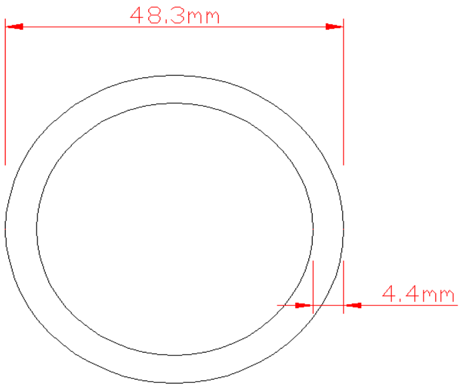
λ_{LT}= 0.40

Under 2.5m cantilever then section acts with top booms in compression as struts

Over 2.5m, then section acts together as beam with lateral buckling on whole section.

Boom 48.3 x 4.4mm CHS

Boom CHS Layout



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= 48.3
	=	10.98		t = 4.4
	ε=	sqrt(250/f_o)		f_o= 250N/mm^2
	=	1.00		(PD6702 Table3)
Class A, without welds, Internal parts	β_1=	11ε		
	=	11*1		
	=	11.00		
	<	10.98	Not Class 1	
	β_2=	13ε		
	=	13*1		
	=	13.00		
	>	10.98	Class 2	

Section is class 2

Boom 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)
$=$ 1.35
$W_{el} =$ 6.11 cm^3
$f_o =$ 250 N/mm^2
$\gamma_{M1} =$ 1.1 (6.1.3)

= 1.35*6.11*250/1100
$M_{c,Rd} =$ 1.87 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
$f_u =$ 290 N/mm^2
$\gamma_{M2} =$ 1.25 (6.1.3)

= 3.91*290/1250
$M_{u,Rd} =$ 0.91 kNm

$M_{Rd,x} =$ 0.91 kNm — lesser value of $M_{c,Rd}$ / $M_{u,Rd}$

Boom 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

Boom CHS Axial Comp Capacity @ 257mm (effective length of boom)

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

$k =$ 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

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

E = 70,000 N/mm^2
I = 147,654 mm^4
k = 0.50
L = 257 mm

N_{cr} = ((PI()^2)*70000*147654)/((0.5^2)*(257^2))
= 6,177,841.29 N

$\lambda = \sqrt{A_{eff} f_o / N_{cr}}$ (6.3.1.2)
= 0.16 A_{eff} = 607 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

$N_{b,Rd}$ = 0.65*0.97*607*250/1100
= 86.98 kN

Boom 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 = 607mm^2
γ_{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
= 388.5mm^2
γ_{M1} = 1.25

= 388.5*290/1250
= 90.13 kN

Lesser Value= 90.13 kN

Alpha 500 - 2.5m length

Max moment from winch is

M_y= PL

P= 12.50 kN

L= 2.50 m

= 31.25 kNm

M_z= 0.1PL

P= 12.50 kN

L= 2.50 m

= 3.125 kNm

max moment from wind is

M_z= wL*L/2

w= 0.03 kN/m

L= 2.50 m

= 0.10 kNm

so total Mz= 3.22 kNm

The max compression in a boom from My is

F= $0.5M_y/l_a$

M_y= 31.25 kNm

l_a= 0.3 m

= 52.08 kN

The max compression in a boom from Mz is

F= $0.5M_z/l_a$

M_z= 3.22 kNm

l_a= 0.3 m

= 5.37 kN

so total compression force in boom is

N_E= 57.45 kN

From previous calc the max ultimate compression load in the boom is

N_c= 86.98 kN

Alpha 500 > 2.5m for lateral torsional buckling

$M_{b,Rd} = \chi_{LT}.W_y.f_y/\gamma_{M1}$

$\chi_{LT} = 1/(\phi_{LT}+\sqrt{}(\phi_{LT}^2-\lambda_{LT}^2)$

$\phi_{LT} = 0.5*(1+\alpha_{LT}*(\lambda_{LT}-0.2)+\lambda_{LT}^2)$

$\lambda_{LT} = \sqrt{}(W_{pl,y}.f_y/M_{cr})$

$\lambda_{LT} = sqrt(\alpha W_{el}.f_o/M_{cr})$

where $\alpha =$ 0.768 Table 6.4

$W_{el} =$ 374,039 mm^3

$f_0 =$ 250 N/mm^2 Table 3.2b

$M_{cr} = \pi^2 EI / L2*sqrt(L^2GI_t/\pi^2EI)$

E= 70000 N/mm^2

I= 57,040,977 mm^4

L= 7,877 mm

$I_t =$ 1.25E+06 mm^4 (shapecad)

G= 27000 N/mm^2

= 146529923 Nmm

$\lambda_{LT} =$ 0.70

$\phi_{LT} =$ 0.75

$\chi_{LT} =$ 0.98

so $M_{b,Rd} =$ 110.09 kNm

$M_{Rz} = W_{pl}\ f_o / \gamma_{M1}$

$W_{pl} =$ 448,847 mm^3

$f_o =$ 250 N/mm^2

$\gamma_{M1} =$ 1

= 112.21 kNm

for

L= 7.88 m

$M_y =$ PL

P= 12.50 kN

L= 7.88 m

= 98.46 kNm

$M_z =$ 0.1PL

P= 12.50 kN

L= 7.88 m

= 9.85 kNm

max moment from wind is

M_z=	wL*L/2				
			w=	0.03	kN/m
			L=	7.88	m
=	0.95	kNm			
so total Mz=	10.80	kNm			
so $M_y/M_{ry}+M_z/M_{rz}$=	0.99	<1 ok			

Deflection

Cantilever max is L/180

d=	$PL^3/3EI$		P=	5000	N
			L=	3648	mm
			E=	70000	N/mm^2
			I=	57,040,977	mm^4
d=	20.27	mm			
d_{allow}=	L/180				
=	20.27	mm			
diff=	0.0	mm			

Cantilever length limited by deflection to 3.6m

Alpha 800 <3m length

Max moment from winch is

$M_y =$ PL

P= 20.00 kN

L= 2.34 m

= 46.83 kNm (goalseek result)

$M_z =$ 0.1PL

P= 20.00 kN

L= 2.34 m

= 4.68 kNm

max moment from wind is

$M_z =$ wL*L/2

w= 0.03 kN/m

L= 2.34 m

= 0.08 kNm

so total $M_z =$ 4.77 kNm

The max compression in a boom from My is

F= $0.5M_y/l_a$

$M_y =$ 46.83 kNm

$l_a =$ 0.3 m

= 78.05 kN

The max compression in a boom from Mz is

F= $0.5M_z/l_a$

$M_z =$ 4.77 kNm

$l_a =$ 0.3 m

= 7.95 kN

so total compression force in boom is

$N_E =$ 86.00 kN

From previous calc the max ultimate compression load in the boom is

Nc= 86.98 kN

so the max cantilever length for an alpha 800 winch is 2.34m

Deflection

Cantilever max is L/180

d= $PL^3/3EI$

P=	8000	N
L=	2884	mm
E=	70000	N/mm^2
I=	57,040,977	mm^4

d= 16.02 mm

d_{allow}= L/180

= 16.02 mm

diff= 0.0 mm

As 2.34m<2.884m, canitlever is limited to 2.34m.

Summary

Scaffold components must be as per TG20:13.

GKN steelwork grade must be S355.

Aluminium components to be 6082T6 alloy

This design does not include a check of the existing structure.

Design check is only valid for the extent of the cantilever. Counterweight and support reactions will be dependent on the length of the back span.

Max Cantilever for Alpha 500= 3.60 m

Max Cantilever for Alpha 800= 2.34 m