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 calculations for the lattice beam S0072-001:

- 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:

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moment</td>
<td>1.04 kNm</td>
</tr>
<tr>
<td>Shear</td>
<td>48.74 kNm</td>
</tr>
<tr>
<td>Tension</td>
<td>91.69 kN</td>
</tr>
<tr>
<td>Compression</td>
<td>120.20 kN</td>
</tr>
</tbody>
</table>
Steel Spigot Section

38.1 x 4.06 CHS S355

Steel Spigot Section

\[
A = 434 \text{ mm}^2
\]

\[
I = 63781 \text{ mm}^4
\]

\[
W_{el,x} = 3348 \text{ mm}^3
\]

\[
W_{pl,x} = 4520 \text{ mm}^3
\]

\[
r_y = 12 \text{ mm}
\]

Applied Loads

<table>
<thead>
<tr>
<th></th>
<th>Moment</th>
<th>Shear</th>
<th>Tension</th>
<th>Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_{Rd,x} )</td>
<td>1.04 kNm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V_{Rd} )</td>
<td>48.74 kN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( N_{u,Rd} )</td>
<td>91.69 kN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( N_{b,Rd} )</td>
<td>120.20 kN</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Steel Spigot Bending moment

\[
M_{cr,x} = W_{pl,x} f_y/\gamma_m \]

\[
= 4.52 \times 355/1000 = 1.60 \text{ kNm}
\]

\( \gamma_m = 1.00 \)

\[
> 1.04 \text{ kNm} \quad \text{ok}
\]

Steel Spigot Shear

\[
V_{cr} = A_v f_y/\sqrt{3} \gamma_m \]

\[
A_v = 0.6 A
\]

\[
A_v = 260 \text{ mm}^2
\]

\[
f_y = 355 \text{ N/mm}^2
\]

\[
\gamma_m = 1.00
\]

\[
= 260 \times 355/\sqrt{3} = 53.29 \text{ kN}
\]

\( > 48.74 \text{ kN} \quad \text{ok} \)
Steel Spigot Tension

plastic resistance
\[ N_{pl} = A_e f_y / Y_{m0} \]

\[ A_e = A - A_{(2 \text{ bolt holes})} \]
\[ A_e = 434 - 2 \times 13 \times 4.06 \]
\[ A_e = 328.44 \text{ mm}^2 \]
\[ f_y = 355 \text{ N/mm}^2 \]
\[ Y_{m0} = 1.00 \]
\[ N_{pl} = 328.44 \times 355 / 1000 \]
\[ = 116.60 \text{ kN} \]

ultimate resistance
\[ N_{ur} = 0.9 A_e f_y / Y_{m2} \]
\[ A_e = A - 2 \times 13 \times 4.06 \]
\[ A_e = 328.44 \text{ mm}^2 \]
\[ f_y = 510 \text{ N/mm}^2 \]
\[ Y_{m2} = 1.25 \]
\[ N_{ur} = 296 \times 510 / 1250 \]
\[ = 120.77 \text{ kN} \]

Lesser Value = 116.60 kN
\[ > 91.69 \text{ kN} \]

Steel Spigot Compression

\[ N_{b, Rd} = \frac{X A f_y / Y_{m2}}{\sqrt{A f_y / N_{cr}}} \]
\[ X = 1 / (\varphi + \sqrt{\varphi^2 - \lambda^2}) \]
\[ \varphi = 0.5 (1 + \alpha (\lambda - 0.2) + \lambda^2) \]
\[ \lambda = \sqrt{A f_y / N_{cr}} \]
\[ = 0.24 \]
\[ \alpha = 0.21 \text{ Table 6.1} \]
\[ \varphi = 0.5 (1 + \alpha (\lambda - 0.2) + \lambda^2) \]
\[ = 0.99 \]
\[ X = 1 / (\varphi + \sqrt{\varphi^2 - \lambda^2}) \]
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Bearing in spigot

Bolts are M12 grade 8.8

\[ F_{b,Ref} = k_1 \alpha_b f_u d t / \gamma_M \]

\[ d_v = 13 \text{ mm} \]
\[ e_1 = 40 \text{ mm} \]
\[ e_2 = 40 \text{ mm} \]
\[ k_1 = 6.92 > 2.5 \]

Therefore \( k_1 = 2.5 \)
\[ t = 4.06 \text{ mm} \]
\[ d = 12 \text{ mm} \]
\[ f_u = 510 \text{ N/mm}^2 \]
\[ f_{ub} = 800 \text{ N/mm}^2 \]
\[ \gamma_M = 1.25 \]
\[ \alpha_b = 1.03 > 1 \]

Therefore, \( \alpha_b = 1.00 \)

\[ F_{b,Ref} = (2.5 \times 1.00 \times 510 \times 12 \times 4.06) / 1250 = 49.69 \text{ kN} \]

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

Total Bearing capacity = 4\( \times \)49.69 kN

\[ 198.76 \text{ kN} > 120.20 \text{ kN} \quad \text{ok} \]

Bearing in boom

Bolts are M12 grade 8.8

\[ F_{b,Ref} = k_1 \alpha_b f_u d t / \gamma_M \]

\[ d_v = 13 \text{ mm} \]
\[ e_1 = 40 \text{ mm} \]
\[ e_2 = 40 \text{ mm} \]
\[ k_1 = 6.92 > 2.5 \]

Therefore \( k_1 = 2.5 \)
\[ t = 4.4 \text{ mm} \]
\[ d = 12 \text{ mm} \]
\[ f_u = 295 \text{ N/mm}^2 \]
\[ f_{ub} = 800 \text{ N/mm}^2 \]
\[ \gamma_M = 1.25 \]
\[ \alpha_b = 1.03 > 1 \]

Therefore, \( \alpha_b = 1.00 \)

\[ F_{b,Ref} = (2.5 \times 1 \times 295 \times 12 \times 4.4) / 1250 = 31.15 \text{ kN} \]

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

Total Bearing capacity = 4\( \times \)31.15 kN

\[ 124.60 \text{ kN} > 120.20 \text{ kN} \quad \text{ok} \]
Aluminium Spigot Section

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.

\[ A = 1140 \text{ mm}^2 \]
\[ I = 103435 \text{ mm}^4 \]
\[ W_{el,x} = 5430 \text{ mm}^3 \]
\[ W_{pl,x} = 9230 \text{ mm}^3 \]
\[ r_y = 10 \text{ mm} \]

Applied Loads

<table>
<thead>
<tr>
<th>Load Type</th>
<th>( M_{Rd,x} )</th>
<th>( V_{Rd} )</th>
<th>( N_{u,Rd} )</th>
<th>( N_{b,Rd} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moment</td>
<td>1.04 kNm</td>
<td>48.74 kN</td>
<td>91.69 kN</td>
<td>120.20 kN</td>
</tr>
</tbody>
</table>

Aluminium Spigot Moment Capacity

\[ M_{c,Rd} = \alpha W_{el} f_o / \gamma_{M1} \]
\[ \alpha = 1.70 \]
\[ W_{el} = 5.43 \text{ cm}^3 \]
\[ f_o = 255 \text{ N/mm}^2 \]
\[ \gamma_{M1} = 1.10 \text{ (6.1.3)} \]
\[ M_{c,Rd} = 2.14 \text{ kNm} \]
\[ > 1.0 \text{ kNm} \text{ ok} \]

Aluminium Spigot Shear Capacity

\[ V_{Rd} = A_v f_o / \sqrt{3} \gamma_{M1} \]
\[ A_v = 0.8 A_e \]
\[ A_e = 912 \text{ mm}^2 \]
\[ f_o = 255 \text{ N/mm}^2 \]
\[ \gamma_{M1} = 1.10 \text{ (6.1.3)} \]
\[ V_{Rd} = 122.06 \text{ kN} \]
\[ > 48.7 \text{ kN} \]

\[ V_{Rd} = 912 * 255 / (\sqrt{3} * 1100) \]
**Aluminium Spigot Axial Tension Capacity**

(6.2.3) General yielding

\[ N_{o,Rd} = \frac{f_o A_g}{\gamma_M1} \]

\[ f_o = 255 \text{ N/mm}^2 \]

\[ A_g = 1140 \text{ mm}^2 \]

\[ \gamma_M1 = 1.1 \]

\[ N_{o,Rd} = \frac{1140 \times 255}{1100} = 264.27 \text{ kN} \]

Local failure

\[ N_{u,Rd} = 0.9 A_{net} f_u / \gamma_M2 \]

\[ f_u = 295 \text{ N/mm}^2 \]

\[ A_{net} = A - A_{(1 \text{ Bolt Hole)}} = 644.7 \text{ mm}^2 \]

\[ \gamma_M2 = 1.25 \]

\[ N_{u,Rd} = 0.9 \times 644.7 \times 295 / 1250 = 136.79 \text{ kN} \]

Lesser Value = 136.79 kN > 91.7 kN

**Aluminium Spigot Compression Capacity**

\[ N_{b,Rd} = k \times A_{eff} f_o / \gamma_M1 \]

\[ k = 0.65 \]

\[ \omega_x = \frac{p_{u,haz} f_u}{\gamma_M2} \]

\[ f_u = 295 \text{ N/mm}^2 \]

\[ p_{u,haz} = 644.7 \text{ mm}^2 \]

\[ \gamma_M2 = 1.25 \]

\[ N_{b,Rd} = \frac{(0.64 \times 290 / 1.25) / (250 / 1.1)}{0.85} = 0.85 \]

\[ L = 220 \text{ mm} \]

\[ N_{cr} = \frac{\pi^2 E I}{k^2 L^2} \]

\[ E = 70,000 \text{ N/mm}^2 \]

\[ I = 103,435 \text{ mm}^4 \]

\[ k = 0.50 \]

\[ L = 220 \text{ mm} \]

\[ N_{cr} = \frac{(\pi^2) \times 70,000 \times 103,435}{(0.5^2) \times (220^2)} = 5,905,816.30 \text{ N} \]

\[ \lambda = \sqrt{A_{eff} f_o / N_{cr}} \]

\[ A_{eff} = 1,140 \text{ mm}^2 \]

\[ \lambda = 0.22 \]

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

\[ \Phi = 0.5(1 + 0.2(\lambda - \lambda_o) + \lambda_o^2) \]

\[ \lambda_o = 0.20 \text{ Table 6.6} \]

\[ \Phi = 0.54 \]

\[ X = 0.94 \]

\[ N_{b,Rd} = 0.65 \times 0.94 \times 1140 \times 255 / 1100 = 161.47 \text{ kN} \]

> 120.2 kN
Bearing in spigot

Bolts are M12 grade 8.8

\[ F_{b,\text{Spigot}} = k_1 \alpha_b f_u d t / \gamma_{M2} \]

- \( d_1 = 13 \text{ mm} \)
- \( e_1 = 40 \text{ mm} \)
- \( e_2 = 40 \text{ mm} \)
- \( k_1 = 6.92 > 2.5 \)

Therefore, \( k_1 = 2.5 \)

- \( t = 38.1 \text{ mm} \)
- \( d = 12 \text{ mm} \)
- \( f_u = 295 \text{ N/mm}^2 \)
- \( f_{ub} = 800 \text{ N/mm}^2 \)
- \( \gamma_{M2} = 1.25 \)
- \( \alpha_b = 1.03 > 1 \)

Therefore, \( \alpha_b = 1.00 \)

\[ F_{b,\text{Spigot}} = (2.5 \times 1.00 \times 295 \times 12 \times 38.1) / 1250 = 269.75 \text{ kN} \]

\[ > 120.20 \text{ kN} \quad \text{ok} \]

Bearing in boom

Bolts are M12 grade 8.8

\[ F_{b,\text{Boom}} = k_1 \alpha_b f_u d t / \gamma_{M2} \]

- \( d_1 = 13 \text{ mm} \)
- \( e_1 = 40 \text{ mm} \)
- \( e_2 = 40 \text{ mm} \)
- \( k_1 = 6.92 > 2.5 \)

Therefore, \( k_1 = 2.5 \)

- \( t = 4.4 \text{ mm} \)
- \( d = 12 \text{ mm} \)
- \( f_u = 295 \text{ N/mm}^2 \)
- \( f_{ub} = 800 \text{ N/mm}^2 \)
- \( \gamma_{M2} = 1.25 \)
- \( \alpha_b = 1.03 > 1 \)

Therefore, \( \alpha_b = 1.00 \)

\[ F_{b,\text{Boom}} = (2.5 \times 1.00 \times 295 \times 12 \times 4.4) / 1250 = 31.15 \text{ kN} \]

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

Total Bearing capacity: \( 4 \times 31.15 \text{ kN} = 124.60 \text{ kN} \)

\[ > 120.20 \text{ kN} \quad \text{ok} \]
## Results

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