


# **APOLLO LATTICE BEAM RIDGE PIECES DESIGN CALCULATIONS**

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|                   |  |           |              |  |
|-------------------|--|-----------|--------------|--|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam |           |              |  |
|                   | Element : Brief and design criteria      |           |              |  |
|                   | Job Number : G0041                       | By : anw  | Date: Mar 03 |  |
|                   | Document No : 001                        | Checked : | Date:        |  |

**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 BS8118**

Max moment on the beam is

|                         |                 |
|-------------------------|-----------------|
| <b>Allowable moment</b> | <b>15.7 kNm</b> |
| <b>Ultimate moment</b>  | <b>20.9 kNm</b> |

and Maximum Shear is

|                        |                 |
|------------------------|-----------------|
| <b>Allowable shear</b> | <b>13.90 kN</b> |
| <b>Ultimate shear</b>  | <b>18.50 kN</b> |

**Based on Eurocode 9**

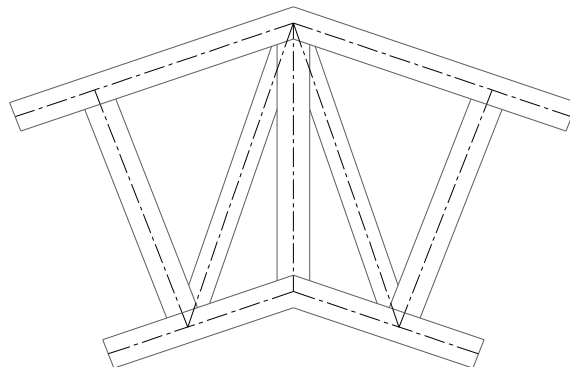
Max moment on the beam is

|                                    |                 |
|------------------------------------|-----------------|
| <b>Failure moment</b>              | <b>27.6 kNm</b> |
| <b>Short term Allowable moment</b> | <b>18.4 kNm</b> |
| <b>Long term allowable moment</b>  | <b>15.7 kNm</b> |


and Maximum Shear is

|                                   |                 |
|-----------------------------------|-----------------|
| <b>Failure shear</b>              | <b>18.9 kN</b>  |
| <b>Short term allowable shear</b> | <b>14.5 kN</b>  |
| <b>Long term Allowable shear</b>  | <b>12.70 kN</b> |

**Geometry**



Both the 10 degree and 20 degree ridges are to be modelled

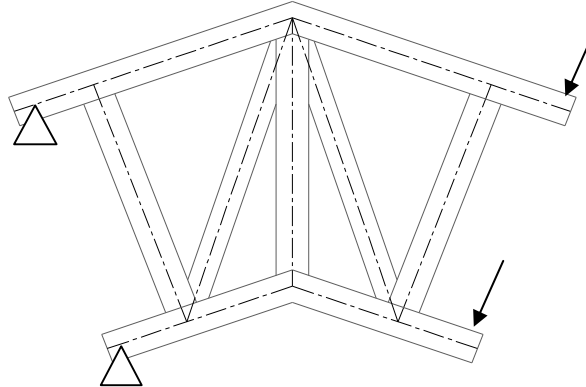
|                   |  |           |              |  |
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**Loading**

For the shear load case the applied forces are

$$\begin{aligned}
 V &= 12.7/2 \\
 &= \mathbf{6.35 \text{ kN}}
 \end{aligned}$$

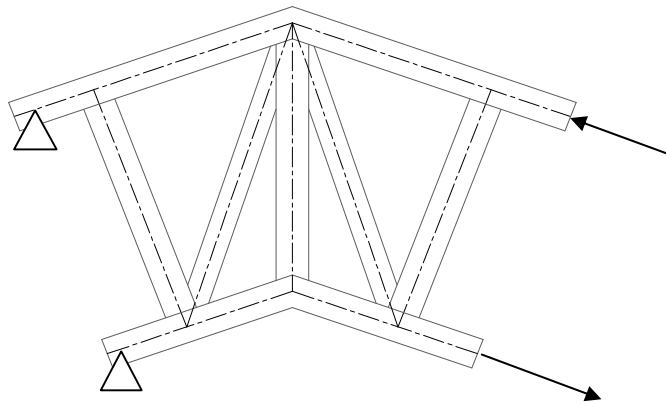
These are applied at the top and bottom booms as below




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

For the moment load case

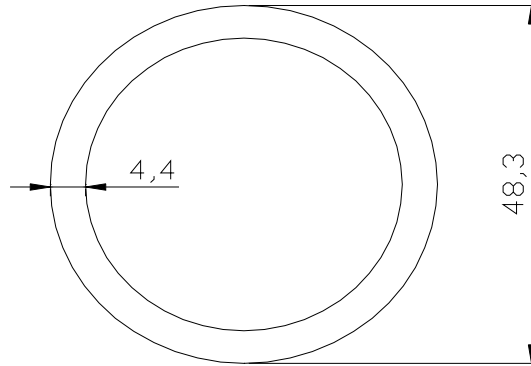
$$\begin{aligned}
 P &= 15.7/0.4 \\
 &= \mathbf{39.25 \text{ kN}}
 \end{aligned}$$



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

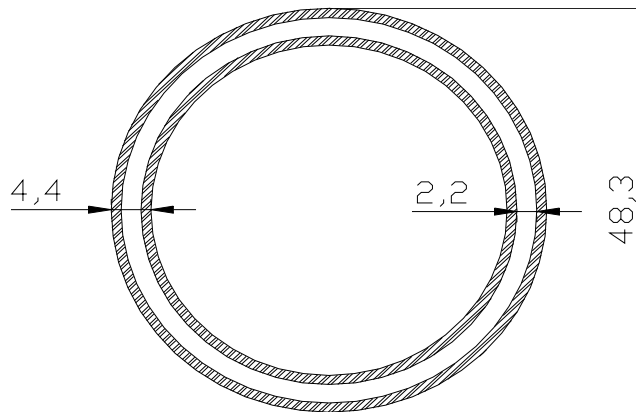
|                   |  |           |              |  |
|-------------------|--|-----------|--------------|--|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam |           |              |  |
|                   | Element : Properties                     |           |              |  |
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**Main boom and verticals**




|                     |  |
|---------------------|--|
| Area:               | 606.83 mm <sup>2</sup>                                       |
| Bounding box:       | X: -24.15 - 24.15 mm<br>Y: -24.15 - 24.15 mm                 |
| Moments of inertia: | X: 147654.64 mm <sup>4</sup><br>Y: 147654.64 mm <sup>4</sup> |
| Radii of gyration:  | X: 15.60 mm<br>Y: 15.60 mm                                   |
| Elastic Modulus     | X: 6114.06 mm <sup>3</sup><br>Y: 6114.06 mm <sup>3</sup>     |
| Plastic Modulus     | X: 8253.99 mm <sup>3</sup><br>Y: 8253.99 mm <sup>3</sup>     |

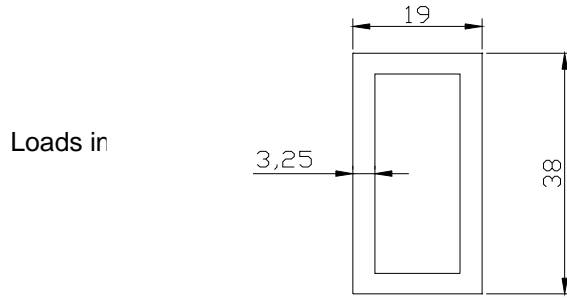
**Boom - HAZ**




|                     |  |
|---------------------|--|
| Area:               | 303.42 mm <sup>2</sup>                                     |
| Bounding box:       | X: -23.05 -- 23.05 mm<br>Y: -23.05 -- 23.05 mm             |
| Moments of inertia: | X: 73276.60 mm <sup>4</sup><br>Y: 73276.60 mm <sup>4</sup> |
| Radii of gyration:  | X: 15.54 mm<br>Y: 15.54 mm                                 |
| Elastic Modulus     | X: 3179.03 mm <sup>3</sup><br>Y: 3179.03 mm <sup>3</sup>   |
| Plastic Modulus     | X: 4291.69 mm <sup>3</sup><br>Y: 4291.69 mm <sup>3</sup>   |

|                   |  |           |              |  |
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**Diagonals**



|                     |  |
|---------------------|--|
| Area:               | 328.25 mm <sup>2</sup>                                     |
| Bounding box:       | X: -9.5 -- 9.5 mm<br>Y: -19.00 -- 19.00 mm                 |
| Moments of inertia: | X: 54322.46 mm <sup>4</sup><br>Y: 16593.21 mm <sup>4</sup> |
| Radii of gyration:  | X: 12.86 mm<br>Y: 7.11 mm                                  |
| Elastic Modulus     | X: 2859.08 mm <sup>3</sup><br>Y: 1746.65 mm <sup>3</sup>   |
| Plastic Modulus     | X: 3758.22 mm <sup>3</sup><br>Y: 2199.03 mm <sup>3</sup>   |

|                   |  |           |              |  |
|-------------------|--|-----------|--------------|--|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam |           |              |  |
|                   | Element : Boom properties                |           |              |  |
|                   | Job Number : G0041                       | By : anw  | Date: Mar 03 |  |
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**Classification**

4.3.1

$$\begin{aligned} \beta &= 3*((D/t)^{0.5}) \\ &= 3*((48.4-4.31)/4.31)^{0.5} \\ &= 9.595169899 \end{aligned}$$

$$\begin{aligned} \epsilon &= (250/p_0)^{0.5} \\ &= (250/255)^{0.5} \\ &= 0.99 \end{aligned}$$

$$\begin{aligned} \beta_1 &= 15\epsilon \\ &= 15*0.99 \\ &= 14.85 \\ &> 9.6 \end{aligned}$$

**Section is compact**

**Bending capacity** 4.5.2.2

$$\begin{aligned} M_{rs} &= p_0 S_n / \gamma_m && p_0 = 255 \text{ N/mm}^2 \\ & && S_n = 8.17 \text{ cm}^3 \\ & && \gamma_m = 1.2 \\ &= 255 * 8.17 / 1200 \\ &= \mathbf{1.74 \text{ kNm}} \end{aligned}$$

**Bending capacity - HAZ**


$$\begin{aligned} M_{rsz} &= p_0 S_z / \gamma_m && p_0 = 255 \text{ N/mm}^2 \\ & && S_z = 4.29 \text{ cm}^3 \\ & && \gamma_m = 1.3 \\ &= 255 * 4.29 / 1300 \\ &= \mathbf{0.84 \text{ kNm}} \end{aligned}$$

**Shear** 4.5.3.2

$$\begin{aligned} V_{rs} &= p_v A_v / \gamma_m && p_v = 155 \text{ N/mm}^2 \\ & && A_v = 0.6A \\ & && = 0.6 * 597 \\ & && = 358.2 \text{ mm}^2 \\ & && \gamma_m = 1.2 \\ &= 155 * 358.2 / 1200 \\ &= \mathbf{46.27 \text{ kN}} \end{aligned}$$

**Lateral Torsional Buckling**

No check required for CHS

|                   |  |           |              |  |
|-------------------|--|-----------|--------------|--|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam |           |              |  |
|                   | Element : Boom properties                |           |              |  |
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**Tension**

4.6  
for General Tension

$$Prs = \frac{p_o A}{\gamma_m} = \frac{255 \times 597}{1.3} = 117.10 \text{ kN}$$

For local at splice

$$Prs = \frac{p_a A_n}{\gamma_m} = \frac{280 \times 476.32}{1.3} = 102.59 \text{ kN}$$

**Compression**

4.7


$$Pr = \frac{p_s A}{\gamma_m}$$

for 1m bracing on ridge piece

$$\lambda = \frac{KL}{r} = \frac{0.7 \times 950}{15.66} = 42.46$$

Fig 4.10b gives

$$Pr = \frac{205 \times 597}{1.2} = 101.99 \text{ kN}$$

|                   |  |           |              |   |
|-------------------|--|-----------|--------------|---|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam |           |              | <br>ALAN WHITE DESIGN |
|                   | Element : Diag properties                |           |              |   |
|                   | Job Number : G0041                       | By : anw  | Date: Mar 03 |   |
|                   | Document No : 001                        | Checked : | Date:        |   |

### Classification

4.3.1

$$\begin{aligned}\beta &= 3*((D/t)^{0.5}) \\ &= 3*((40-3.5)/3.5)^{0.5} \\ &= 9.69\end{aligned}$$

$$\begin{aligned}\epsilon &= (250/p_0)^{0.5} \\ &= (250/255)^{0.5} \\ &= 0.99\end{aligned}$$

$$\begin{aligned}\beta_1 &= 15\epsilon \\ &= 15*0.99 \\ &= 14.85 \\ &> 9.7\end{aligned}$$

Section is compact

### Bending capacity 4.5.2.2

$$\begin{aligned}M_{rs} &= p_0 S_n / \gamma_m && p_0 = 255 \text{ N/mm}^2 \\ & && S_n = 3.24 \text{ cm}^3 \\ & && \gamma_m = 1.3 \\ &= 255 * 3.24 / 1300 \\ &= \mathbf{0.64 \text{ kNm}}\end{aligned}$$

### Shear 4.5.3.2

$$\begin{aligned}V_{rs} &= p_v A_v / \gamma_m && p_v = 155 \text{ N/mm}^2 \\ & && A_v = 0.6A \\ & && = 0.6 * 333.8 \\ & && = 200 \text{ mm}^2 \\ & && \gamma_m = 1.3 \\ &= 155 * 200 / 1300 \\ &= \mathbf{23.85 \text{ kN}}\end{aligned}$$

### Lateral Torsional Buckling


No check required for CHS

### Tension

4.6

for General Tension only ( no local holes)

$$\begin{aligned}P_{rs} &= p_0 A / \gamma_m && p_0 = 255 \text{ N/mm}^2 \\ & && A = 333.8 \text{ mm}^2 \\ & && \gamma_m = 1.2 \\ &= 255 * 333.8 / 1200 \\ &= \mathbf{70.93 \text{ kN}}\end{aligned}$$

|                   |  |           |              |   |
|-------------------|--|-----------|--------------|---|
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|                   | Element : Diag properties                |           |              |   |
|                   | Job Number : G0041                       | By : anw  | Date: Mar 03 |   |
|                   | Document No : 001                        | Checked : | Date:        |   |

### Compression

4.7

$$Pr = psA/\gamma m$$

$$L = 0.57 \text{ m}$$

$$r = 8.15 \text{ mm}$$

$$\lambda = KL/r$$

$$= 0.7 * 570 / 8.15$$

$$= 48.96$$

$$K = 0.7$$

Fig 4.10b gives

$$ps = 140.00 \text{ N/mm}^2$$

$$A = 283.6 \text{ mm}^2$$

$$\gamma m = 1.2$$

$$Pr = 140 * 283.6 / 1200$$

$$= \mathbf{33.09 \text{ kN}}$$

for local squashing

$$Prs = paAe/\gamma m$$

$$pa = 280 \text{ N/mm}^2$$


$$Ae = 141.8$$

$$\gamma m = 1.2$$

$$= 280 * 141.8 / 1200$$

$$= \mathbf{33.09 \text{ kN}}$$

Use local squashing value

|                   |  |           |              |   |
|-------------------|--|-----------|--------------|---|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam |           |              | <br>ALAN WHITE DESIGN |
|                   | Element : Diag properties HAZ            |           |              |   |
|                   | Job Number : G0041                       | By : anw  | Date: Mar 03 |   |
|                   | Document No : 001                        | Checked : | Date:        |   |

### Classification

4.3.1

$$\begin{aligned}\beta &= 3*((D/t)^{0.5}) \\ &= 3*((40-3.5)/3.5)^{0.5} \\ &= 9.69\end{aligned}$$

$$\begin{aligned}\epsilon &= (250/p_0)^{0.5} \\ &= (250/255)^{0.5} \\ &= 0.99\end{aligned}$$

$$\begin{aligned}\beta_1 &= 15\epsilon \\ &= 15*0.99 \\ &= 14.85 \\ &> 9.7\end{aligned}$$

**Section is compact**

**Bending capacity** 4.5.2.2  
**HAZ**

$$\begin{aligned}M_{rs} &= p_0 S_n / \gamma_m & p_0 &= 255 \text{ N/mm}^2 \\ & & S_n &= 1.61 \text{ cm} \\ & & \gamma_m &= 1.3 \\ &= 255 * 1.61 / 1300 \\ &= \mathbf{0.32 \text{ kNm}}\end{aligned}$$

**Shear** 4.5.3.2  
**HAZ**

$$\begin{aligned}V_{rs} &= p_v A_v / \gamma_m & p_v &= 90 \text{ N/mm}^2 \\ & & A_v &= 0.6 A_e \\ & & &= 0.6 * 166.9 \\ & & &= 100 \text{ mm}^2 \\ & & \gamma_m &= 1.3 \\ &= 90 * 100 / 1300 \\ &= \mathbf{6.92 \text{ kN}}\end{aligned}$$

### Lateral Torsional Buckling

No check required for CHS


**Tension** 4.6

for General Tension only ( no local holes)

$$\begin{aligned}P_{rs} &= p_0 A / \gamma_m & p_0 &= 255 \text{ N/mm}^2 \\ & & A &= 333.8 \text{ mm}^2 \\ & & \gamma_m &= 1.3 \\ &= 255 * 333.8 / 1300 \\ &= \mathbf{65.48 \text{ kN}}\end{aligned}$$

for local softening

$$\begin{aligned}P_{rs} &= p_a A_e / \gamma_m & p_a &= 280 \text{ N/mm}^2 \\ & & A_e &= 141.6 \text{ mm}^2 \\ & & \gamma_m &= 1.2 \\ &= 280 * 141.6 / 1200 \\ &= \mathbf{33.04 \text{ kN}}\end{aligned}$$

|                   |  |           |              |   |
|-------------------|--|-----------|--------------|---|
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|                   | Element : Diag properties HAZ            |           |              |   |
|                   | Job Number : G0041                       | By : anw  | Date: Mar 03 |   |
|                   | Document No : 001                        | Checked : | Date:        |   |

**Compression**

4.7

$$Pr = \quad psA/\gamma_m$$

$$L = \quad 0.57 \text{ m}$$

$$r = \quad 8.15 \text{ mm}$$

$$\lambda = \quad KL/r$$

$$K = \quad 0.85$$

$$= \quad 0.85 * 570 / 8.15$$

$$= \quad 59.45$$

Fig 4.10b gives


$$ps = \quad 109.00 \text{ N/mm}^2$$

$$A = \quad 283.6 \text{ mm}^2$$

$$\gamma_m = \quad 1.2$$

$$Pr = \quad 109 * 283.63 / 1200$$

$$= \quad \mathbf{25.76 \text{ kN}}$$


|                   |   |           |             |   |
|-------------------|---|-----------|-------------|---|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam- 20deg |           |             | <br>ALAN WHITE DESIGN |
|                   | Element : Loadcase 1 - Shear                    |           |             |   |
|                   | Job Number : G0041                              | By : anw  | Date:Mar 03 |   |
|                   | Document No : 001                               | Checked : | Date:       |   |

Load Case 1

Shear loads

12.7kN applied


| Element    | Action   | Formula       | Ultimate | Calculated    | Factor      |
|------------|----------|---------------|----------|---------------|-------------|
| Boom       | Moment   | Mrs           | 1.74     | 0.38          | 4.57        |
|            | Shear    | Vrs           | 46.27    | 7.99          | 5.79        |
|            | Axial    | Pry           | 101.99   | 26.54         | 3.84        |
|            |          | coexist M     |          | 0.36          |             |
|            | Combined | P/Prs+M/Mrs<1 |          | 0.47          | 2.14        |
| Boom joint | Moment   | Mrs           | 0.84     | 0.2           | 4.20        |
|            | Axial    | Pry           | 101.99   | 15.2          | 6.71        |
|            | Combined | P/Prs+M/Mrs<1 |          | 0.39          | 2.58        |
| Vertical   | Moment   | Mrs           | 1.74     | 0.37          | 4.69        |
|            | Shear    | Vrs           | 46.27    | 1.74          | 26.59       |
|            | Axial    | Pry           | 101.99   | 7.16          | 14.24       |
|            |          | coexist M     |          | 0.13          |             |
|            | Combined | P/Prs+M/Mrs<1 |          | 0.15          | 6.89        |
| Diagonal   | Axial    | Pry           | 25.76    | 19.6          | 1.31        |
|            |          |               |          | <b>Factor</b> | <b>1.31</b> |

|                   |   |           |              |   |
|-------------------|---|-----------|--------------|---|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam- 20deg |           |              | <br>ALAN WHITE DESIGN |
|                   | Element : Loadcase 2 - Moment                   |           |              |   |
|                   | Job Number : G0041                              | By : anw  | Date: Mar 03 |   |
|                   | Document No : 001                               | Checked : | Date:        |   |

Loadcase 2 moment applied at end

15.7kN moment applied

| Element    | Action      | Formula       | Ultimate | Calculated    | Factor      |
|------------|-------------|---------------|----------|---------------|-------------|
| Boom       | Moment      | Mrs           | 1.74     | 0.46          | 3.77        |
|            | Shear       | Vrs           | 46.27    | 3.71          | 12.47       |
|            | Axial       | Pry           | 101.99   | 52.04         | 1.96        |
|            |             | coexist M     |          | 0.07          |             |
|            | Combined    | P/Prs+M/Mrs<1 |          | 0.55          | 1.82        |
| Boom joint | Moment      | Mrs           | 0.84     | 0.03          | 28.00       |
|            | Axial       | Pry           | 101.99   | 52.32         | 1.95        |
|            | Combined    | P/Prs+M/Mrs<1 |          | 0.55          | 1.82        |
| Vertical   | Moment      | Mrs           | 1.74     | 0.07          | 24.80       |
|            | Shear       | Vrs           | 46.27    | 0.22          | 210.32      |
|            | Axial       | Pry           | 101.99   | 27.32         | 3.73        |
|            |             | coexist M     |          | 0.003         |             |
|            | Combined    | P/Prs+M/Mrs<1 |          | 0.27          | 3.71        |
| Diagonal   | Compression | Pry           | 25.76    | 4.46          | 5.78        |
|            |             |               |          | <b>Factor</b> | <b>1.82</b> |


|                   |   |           |              |   |
|-------------------|---|-----------|--------------|---|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam- 10deg |           |              | <br>ALAN WHITE DESIGN |
|                   | Element : Loadcase 1 - Shear                    |           |              |   |
|                   | Job Number : G0041                              | By : anw  | Date: Mar 03 |   |
|                   | Document No : 001                               | Checked : | Date:        |   |

Load Case 1

Shear loads


12.7kN applied

| Element    | Action   | Formula       | Ultimate | Calculated    | Factor      |
|------------|----------|---------------|----------|---------------|-------------|
| Boom       | Moment   | Mrs           | 1.74     | 0.45          | 3.86        |
|            | Shear    | Vrs           | 46.27    | 10.49         | 4.41        |
|            | Axial    | Pry           | 101.99   | 23.45         | 4.35        |
|            |          | coexist M     |          | 0.45          |             |
|            | Combined | P/Prs+M/Mrs<1 |          | 0.49          | 2.04        |
| Boom joint | Moment   | Mrs           | 0.84     | 0.09          | 9.33        |
|            | Axial    | Pry           | 101.99   | 16.46         | 6.20        |
|            | Combined | P/Prs+M/Mrs<1 |          | 0.27          | 3.72        |
| Vertical   | Moment   | Mrs           | 1.74     | 0.3           | 5.79        |
|            | Shear    | Vrs           | 46.27    | 1.42          | 32.58       |
|            | Axial    | Pry           | 101.99   | 8.3           | 12.29       |
|            |          | coexist M     |          | 0.3           |             |
|            | Combined | P/Prs+M/Mrs<1 |          | 0.25          | 3.93        |
| Diagonal   | Axial    | Pry           | 25.76    | 18.94         | 1.36        |
|            |          |               |          | <b>Factor</b> | <b>1.36</b> |

|                   |   |           |              |  |
|-------------------|---|-----------|--------------|--|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam- 10deg |           |              |  |
|                   | Element : Loadcase 2 - Moment                   |           |              |  |
|                   | Job Number : G0041                              | By : anw  | Date: Mar 03 |  |
|                   | Document No : 001                               | Checked : | Date:        |  |

Loadcase 2          moment applied at end  
15.7kN moment applied

| Element    | Action      | Formula       | Ultimate | Calculated    | Factor      |
|------------|-------------|---------------|----------|---------------|-------------|
| Boom       | Moment      | Mrs           | 1.74     | 0.26          | 6.68        |
|            | Shear       | Vrs           | 46.27    | 1.97          | 23.49       |
|            | Axial       | Pry           | 101.99   | 52.36         | 1.95        |
|            |             | coexist M     |          | 0.26          |             |
|            | Combined    | P/Prs+M/Mrs<1 |          | 0.66          | 1.51        |
| Boom joint | Moment      | Mrs           | 0.84     | 0.25          | 3.36        |
|            | Axial       | Pry           | 101.99   | 51.2          | 1.99        |
|            | Combined    | P/Prs+M/Mrs<1 |          | 0.80          | 1.25        |
| Vertical   | Moment      | Mrs           | 1.74     | 0.03          | 57.87       |
|            | Shear       | Vrs           | 46.27    | 0.07          | 661.00      |
|            | Axial       | Pry           | 101.99   | 14.05         | 7.26        |
|            |             | coexist M     |          | 0             |             |
|            | Combined    | P/Prs+M/Mrs<1 |          | 0.14          | 7.26        |
| Diagonal   | Compression | Pry           | 25.76    | 2.29          | 11.25       |
|            |             |               |          | <b>Factor</b> | <b>1.25</b> |

|                   |  |           |              |   |
|-------------------|--|-----------|--------------|---|
| CALCULATION SHEET | Project : Ridge Connector - Lattice beam |           |              | <br>ALAN WHITE DESIGN |
|                   | Element : Summary                        |           |              |   |
|                   | Job Number : G0041                       | By : anw  | Date: Mar 03 |   |
|                   | Document No : 001                        | Checked : | Date:        |   |

**Sections**

Both the 20 degree and the 10 degree ridge pieces have been checked.

**Results**

20 degree

FOS against bending                    **1.82**

FOS against shear                        **1.31**

10 degree

FOS against bending                    **1.25**

FOS against shear                        **1.36**

**Conclusions**

**This geometry for the ridge pieces is stronger than the lattice beams and suitable to form the ridge joints.**