Appendices by Master thesis report

Master thesis:

Maximum possible diameter of the Great Dubai Wheel

Final Appendices by report
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Appendices

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A. Appendix A: Static Strength Joints

A.1. Failure modes

When the parameters of the joint are in the correct area see literature [5] the modes of failure and the welds are said to be strong enough, the governing modes of failure can be then reduced from the six modes of failure, see Figure A.1, to two following modes of failure:

- Chord plastification;
- Chord punching shear;

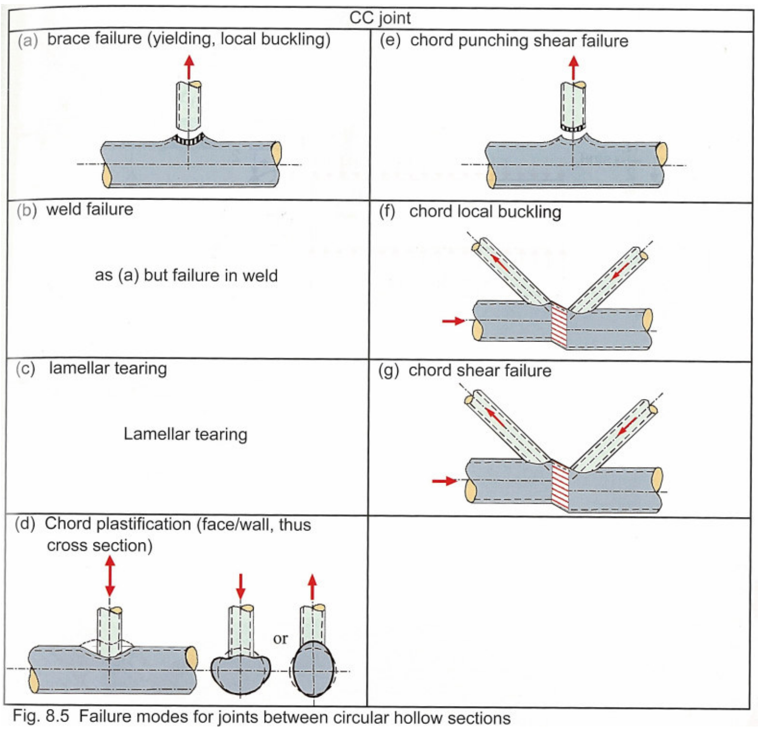


Figure A.1: Failure modes Error! Reference source not found.

A.2. Parameters

For all CHS joint verifications the following parameters need to be known.

- $\beta = \frac{d_1}{d_0}$ Ratio of diameter of the brace and chord;
- $\gamma = \frac{d_0}{2 * t_0}$ Ratio of diameter of the chord to the wall thickness of the chord;
- $\tau = \frac{t_1}{t_0}$ Ratio of the wall thickness of the brace and chord,
- θ Angle between the chord and brace;

For the sections used in the Great Dubai Wheel the following values are found:

- $\beta = \frac{1440}{2220} = 0.65$ This value is for the capacity of the joint a very bad value.
- $\gamma = \frac{2220}{2 * 40} = 27.75$ This value is for the capacity of the joint a very bad value.
- $\tau = \frac{40}{40} = 1$

A.3. Joint efficiency T-joint

From "CIDECT, Design guide for circular hollow section (CHS) joints under predominantly static loading" [1] equation 4.2.1 follows that:

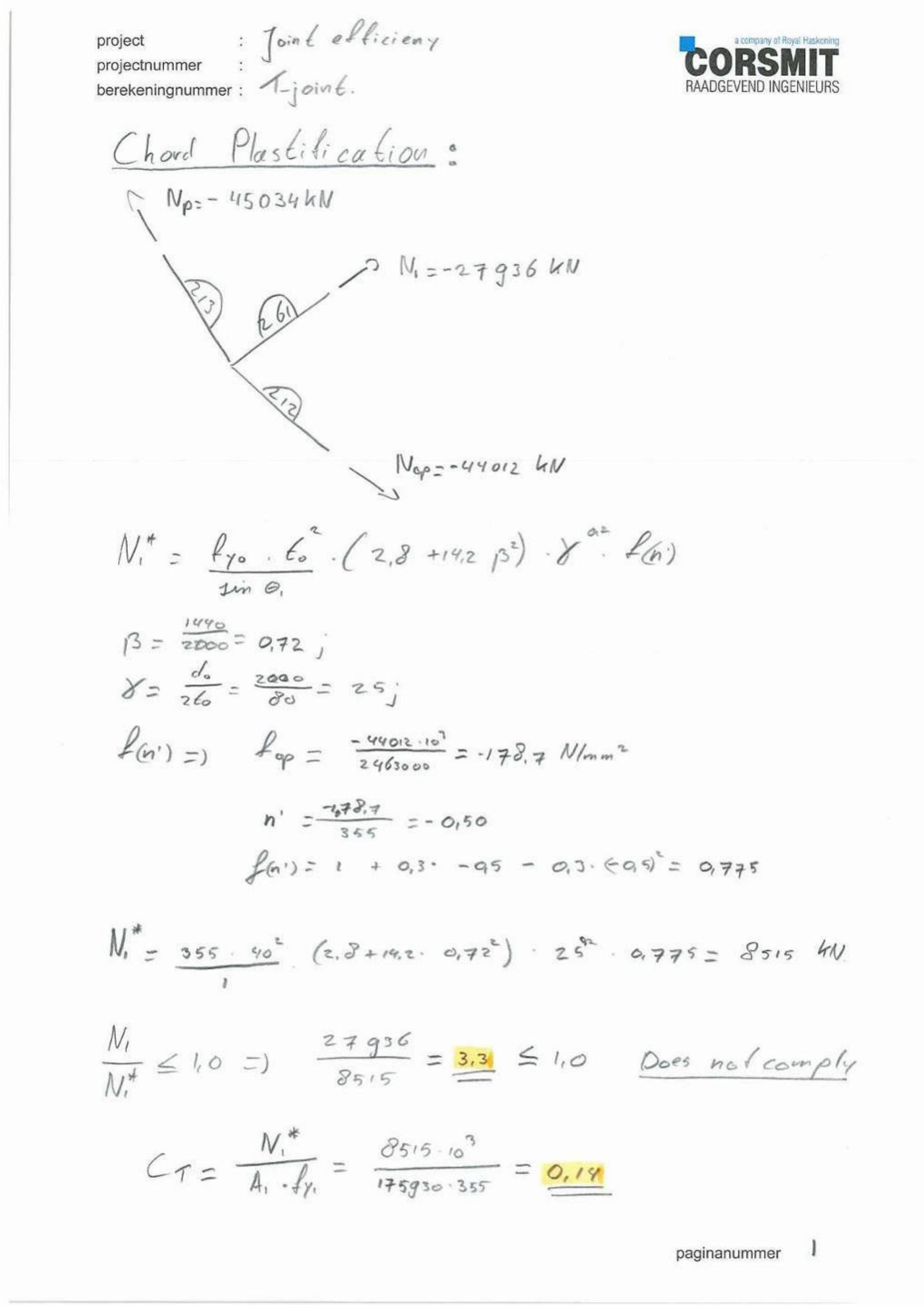
- Chord plastification: $\rightarrow N_1^* = \frac{f_{yo} * t_o^2}{\sin(\theta)} * (2.8 + 14.2 * \beta^2) * \gamma^{0.2} * f(n')$
- Punching shear $\rightarrow N_i^* = \frac{f_{yo}}{\sqrt{3}} * t_0 * \pi * d_i * \frac{1+\sin(\theta_i)}{2*\sin^2(\theta_i)}$

These formulas are only valid when the parameters are in the validity range mentioned in tTable A.1 below.

β-ratio	γ-ratio (brace)	angle	γ –ratio (chord)
$0.2 < \frac{d_i}{d_0} \leq 1.0$	$\frac{d_i}{2*t_i} \leq 28$ And $C_e \leq 0.9$	$30^\circ \leq \theta_i \leq 90^\circ$ $-0.55 \leq \frac{e}{d_0} \leq 0.25$	$\gamma \leq 25$
$0.2 < \frac{1440}{2000} \leq 1.0$ $0.2 < 0.71 \leq 1.0$	$\frac{1440}{2*40} \leq 28$ $18 \leq 28$	$30^\circ \leq \theta_i \leq 90^\circ$ $30^\circ \leq 50^\circ \leq 90^\circ$ $-0.55 \leq \frac{0}{2000} \leq 0.25$	$\gamma \leq 25$ $27.75 \triangleleft 25$

Table A.1: Validity ranges fatigue graphs

* The γ –ratio is not in the validity range of the graphs but because the calculation is indicative, the calculation is still performed; when the final design is done the correct calculation should be done.



project : Joint efficiency
projectnummer :
berekeningnummer : T-joint.

Chord Plastification:

$$N_1^* = \frac{f_{y0} \cdot t_0^2}{\sin \theta_1} \cdot (2{,}8 + 14{,}2\,\beta^2) \cdot \gamma^{0.2} \cdot f(n')$$

$\beta = \frac{1440}{2000} = 0{,}72$;

$\gamma = \frac{d_0}{2t_0} = \frac{2000}{80} = 25$;

$f(n') \Rightarrow \quad f_{op} = \frac{-44012 \cdot 10^3}{2463000} = -178{,}7$ N/mm²

$n' = \frac{-178{,}7}{355} = -0{,}50$

$f(n') = 1 + 0{,}3 \cdot -0{,}5 - 0{,}3 \cdot (-0{,}5)^2 = 0{,}775$

$$N_1^* = \frac{355 \cdot 40^2}{1} \cdot (2{,}8 + 14{,}2 \cdot 0{,}72^2) \cdot 25^{0.2} \cdot 0{,}775 = 8515 \text{ kN}$$

$\frac{N_1}{N_1^*} \leq 1{,}0 \Rightarrow \quad \frac{27936}{8515} = 3{,}31 \leq 1{,}0$ Does not comply

$$C_T = \frac{N_1^*}{A_1 \cdot f_{y1}} = \frac{8515 \cdot 10^3}{175930 \cdot 355} = 0{,}14$$

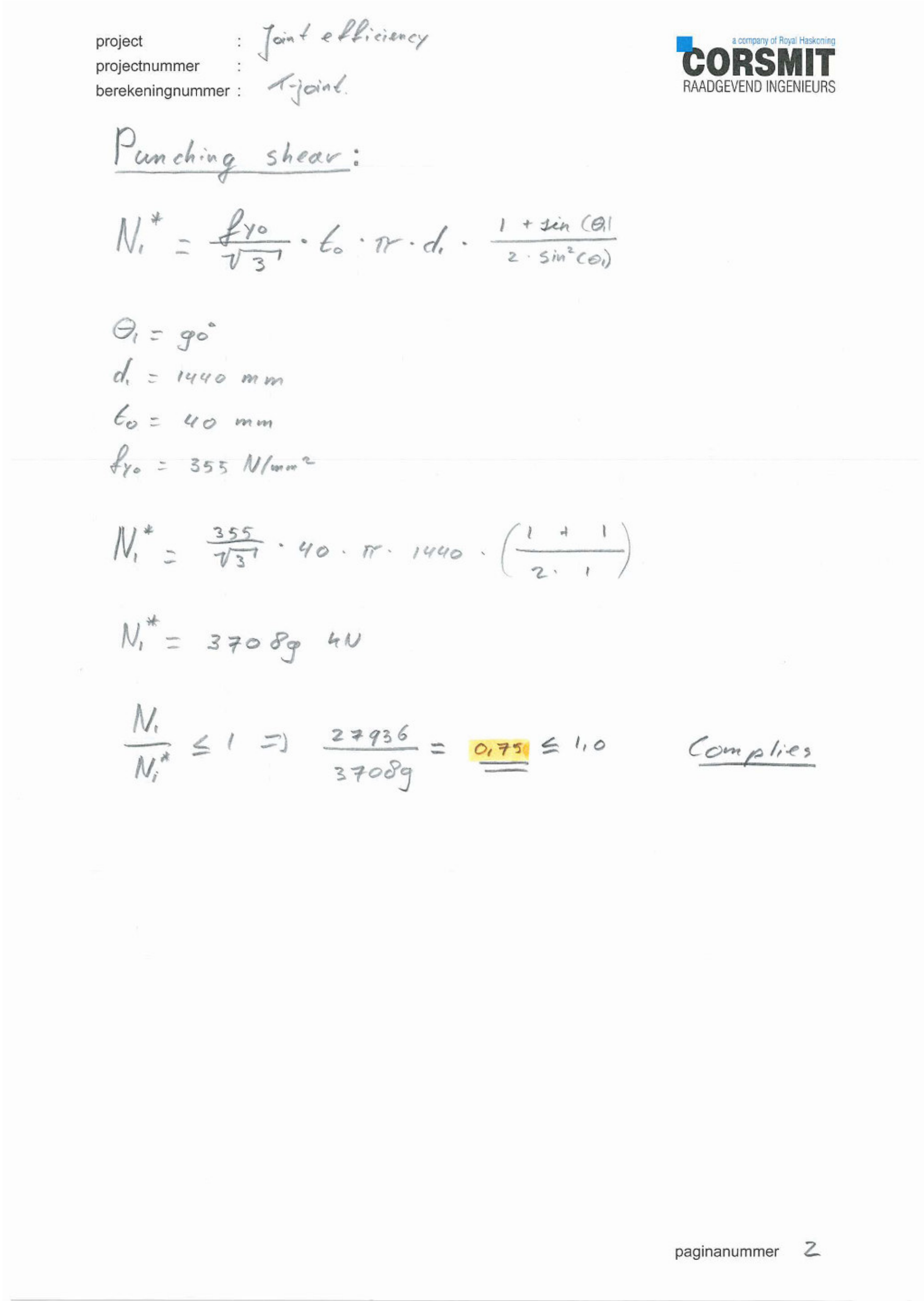
paginanummer 1

Figure A.2: Hand calculation T-joint efficiency 1

In the calculation as seen in Figure A.2 the joint efficiency is determined. In this calculation also the loading is put in this efficiency parameter. When taking this f(n′) out of this parameter the real efficiency parameter becomes:

$$0.14 = C_t * f(n') \rightarrow C_t = \frac{0.14}{f(n')} = \frac{0.14}{0.775} = 0.18$$

So the joint efficiency of a T-joint as in the Great Dubai Wheel is a meagre 18 %. This with the almost constant normal force in the inner and outer rings the efficiency becomes 14%.



project : Joint efficiency
projectnummer :
berekeningnummer : T-joint

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Punching shear:

$$N_1^* = \frac{f_{y0}}{\sqrt{3}} \cdot t_0 \cdot \pi \cdot d_1 \cdot \frac{1 + \sin(\theta_1)}{2 \cdot \sin^2(\theta_1)}$$

$\theta_1 = 90^\circ$
$d_1 = 1440$ mm
$t_0 = 40$ mm
$f_{y0} = 355$ N/mm^2

$$N_1^* = \frac{355}{\sqrt{3}} \cdot 40 \cdot \pi \cdot 1440 \cdot \left(\frac{1+1}{2 \cdot 1}\right)$$

$$N_1^* = 37089 \text{ kN}$$

$$\frac{N_1}{N_1^*} \leq 1 \Rightarrow \frac{27936}{37089} = 0{,}75 \leq 1{,}0$$ Complies

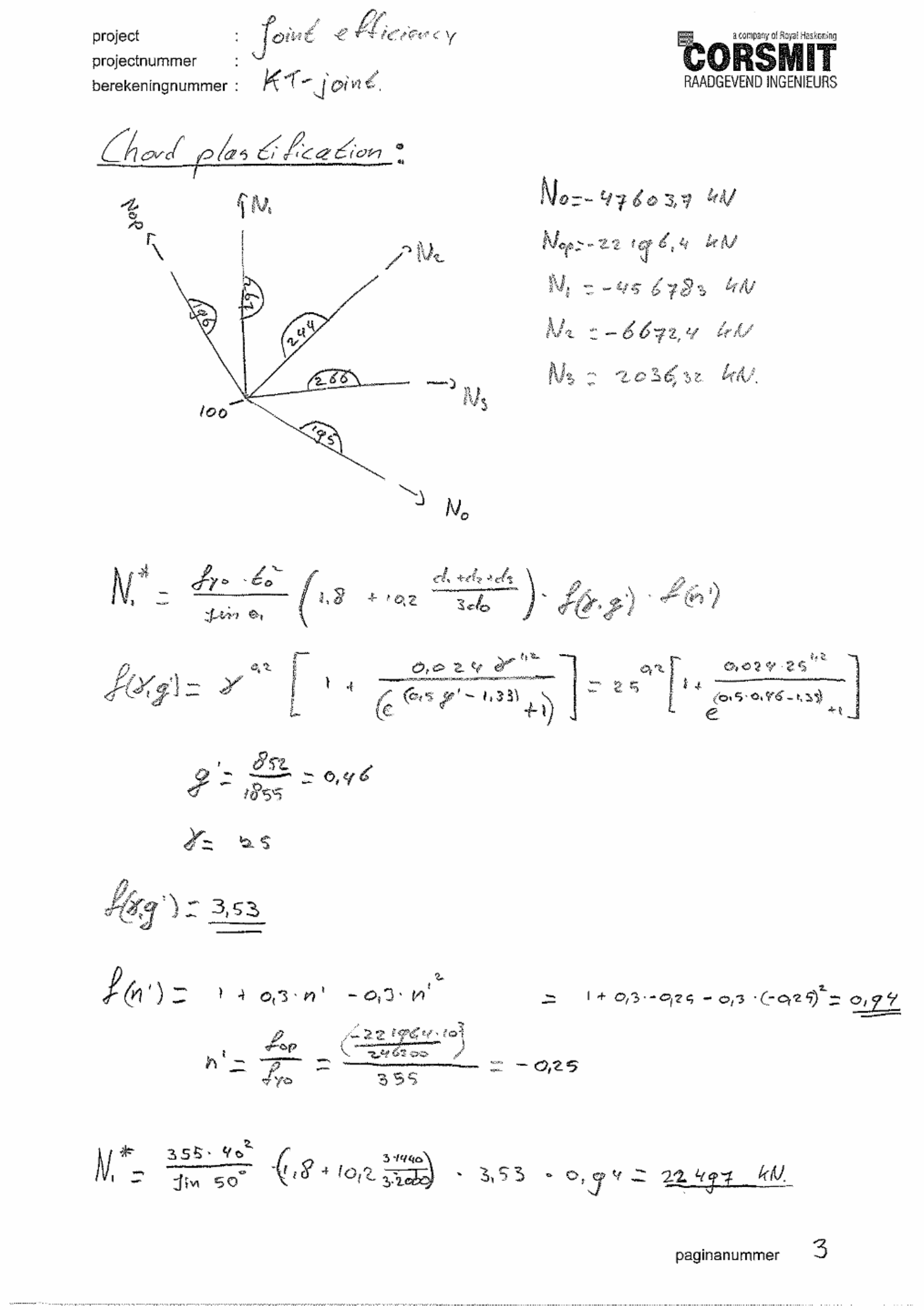
paginanummer 2

Figure A.3: Hand calculation T-joint efficiency 2

The calculated joint efficiency means that only 14% of the capacity of the verticals can be used. The reason for this low joint efficiency has got a few explanations, but the most important causes are the β-ratio the γ-ratio. Because the wall is thin in comparison to the diameter it is prone to deform relatively easy.

A.4. Joint efficiency KT-joint

The KT-joint will have a higher efficiency than the T-joint. This is because the braces stiffen the chord, which will then be less prone to deform. The calculation can be found in Figure A.4.


project : Joint efficiency
projectnummer :
berekeningnummer : KT-joint.

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Chord plastification:

$N_0 = -47603{,}7$ kN
$N_{op} = -22196{,}4$ kN
$N_1 = -45678{,}3$ kN
$N_2 = -6672{,}4$ kN
$N_3 = 2036{,}32$ kN

$$N_1^* = \frac{f_{y0} \cdot t_0^2}{\sin\theta_1}\left(1{,}8 + 10{,}2\,\frac{d_1+d_2+d_3}{3 d_0}\right) \cdot f(\gamma, g') \cdot f(n')$$

$$f(\gamma, g') = \gamma^{0,2}\left[1 + \frac{0{,}024\,\gamma^{1,2}}{e^{(0,5 g' - 1,33)} + 1}\right] = 25^{0,2}\left[1 + \frac{0{,}024 \cdot 25^{1,2}}{e^{(0,5 \cdot 0,46 - 1,33)} + 1}\right]$$

$$g' = \frac{852}{1855} = 0{,}46$$

$$\gamma = 25$$

$$f(\gamma, g') = 3{,}53$$

$$f(n') = 1 + 0{,}3 \cdot n' - 0{,}3 \cdot n'^2 = 1 + 0{,}3 \cdot -0{,}25 - 0{,}3 \cdot (-0{,}25)^2 = 0{,}94$$

$$n' = \frac{f_{op}}{f_{y0}} = \frac{\left(\frac{-22196{,}4 \cdot 10^3}{246200}\right)}{355} = -0{,}25$$

$$N_1^* = \frac{355 \cdot 40^2}{\sin 50^\circ}\left(1{,}8 + 10{,}2\,\frac{3 \cdot 1440}{3 \cdot 2080}\right) \cdot 3{,}53 \cdot 0{,}94 = 22497 \text{ kN.}$$

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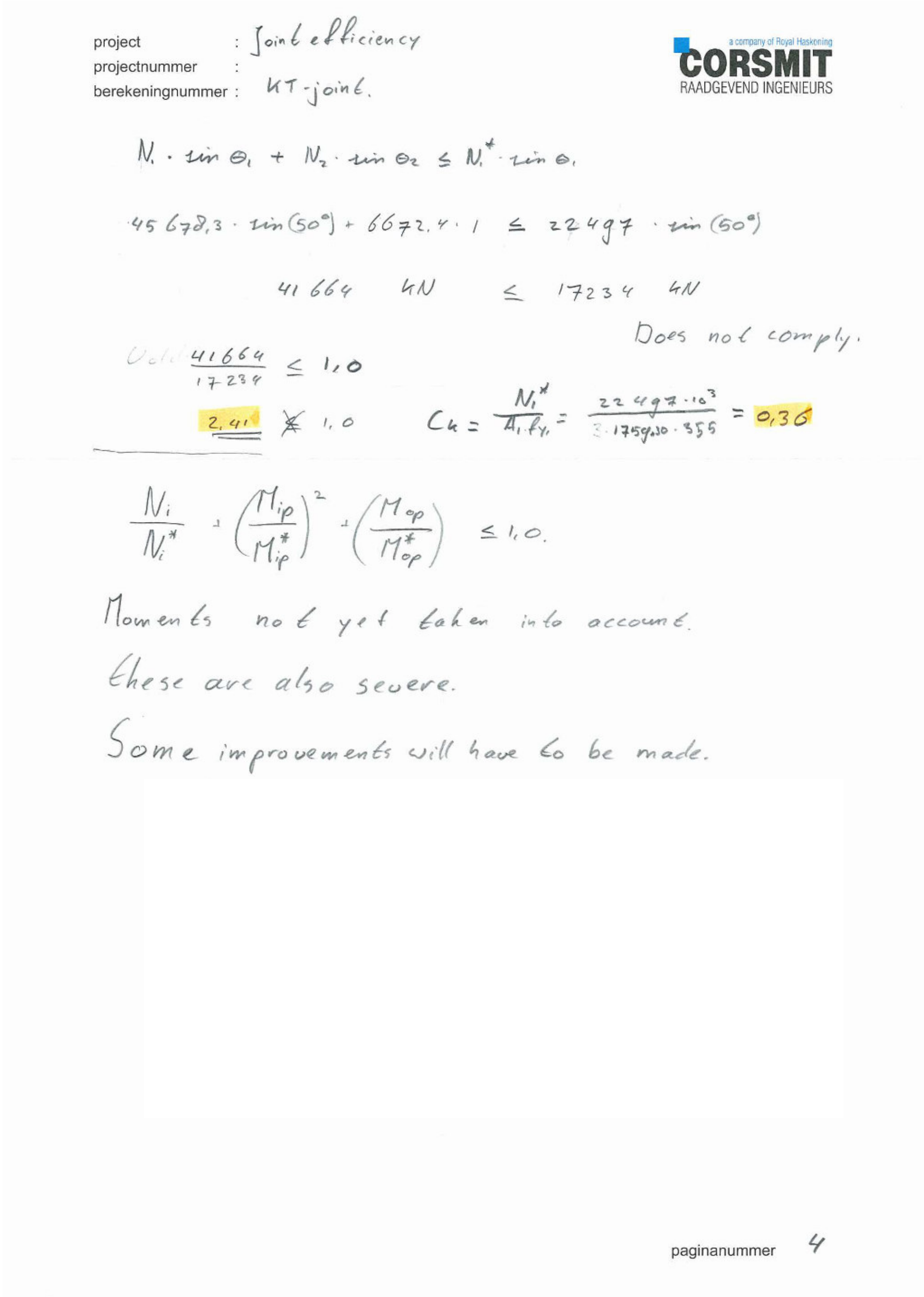
Figure A.4: Hand calculation KT-joint efficiency 1



project : Joint efficiency
projectnummer :
berekeningnummer : KT-joint.

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$N_1 \cdot \sin\theta_1 + N_2 \cdot \sin\theta_2 \le N_1^* \cdot \sin\theta_1$

$45678{,}3 \cdot \sin(50°) + 6672{,}4 \cdot 1 \le 22497 \cdot \sin(50°)$

$41664 \text{ kN} \le 17234 \text{ kN}$

Does not comply.

$U.C. \ \frac{41664}{17234} \le 1{,}0$

$2{,}41 \not\le 1{,}0 \qquad C_k = \frac{N_1^*}{A_1 \cdot f_{y1}} = \frac{22497 \cdot 10^3}{3 \cdot 17590{,}30 \cdot 355} = 0{,}36$

$\frac{N_i}{N_i^*} + \left(\frac{M_{ip}}{M_{ip}^*}\right)^2 + \left(\frac{M_{op}}{M_{op}^*}\right) \le 1{,}0.$

Moments not yet taken into account.

These are also severe.

Some improvements will have to be made.

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Figure A.5: Hand calculation T-joint efficiency 2

As expected the KT-joint has a higher joint-efficiency then the T-joint, namely:

$$0.36 = C_{kt} * f(n') \rightarrow C_{kt} = \frac{0.36}{f(n')} = \frac{0.36}{0.94} = 0.38$$

This means that for the KT-joint only 38% of the yield stress can be admitted in the braces.
This is still a low value for the admissible yield stress.

B. Appendix B: Fatigue

B.1. Joints

Multiplanar joints are in practice, for design purposes, broken down in their simple uniplanar constituent parts. Also it can be taken into consideration that overlapping in the joints as exists in the Great Dubai Wheel is advantageous since the brace loadings are directly transferred from one brace to another, and thus bypassing the weaker chord wall.
Parameters affecting fatigue in joints of circular hollow sections:

- $\beta = \frac{d_1}{d_0}$ ratio of diameter of the brace and chord;
- $\gamma = \frac{d_0}{2 * t_0}$ ratio of diameter of the chord to the wall thickness of the chord;
- $\tau = \frac{t_1}{t_0}$ ratio of the wall thickness of the brace and chord;
- θ angle between the chord and brace;

In the graphs of the SCF’s for circular hollow sections it is seen that the biggest SCF’s are found in the region of the sections of the Great Dubai Wheel, see Figure B.1.

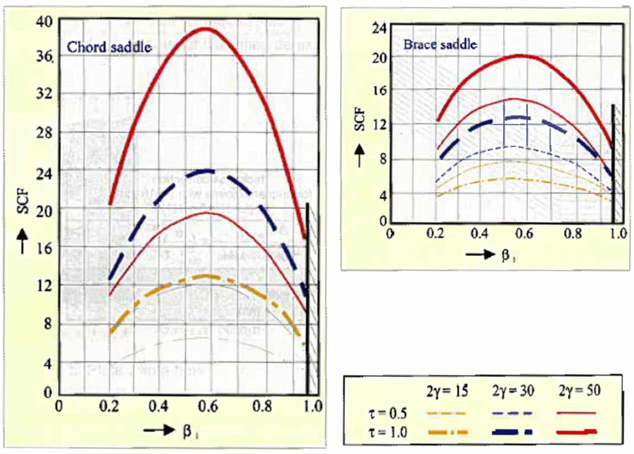


Figure B.1: SCF's for axially loaded circular hollow sections [5]

For the sections used in the Great Dubai Wheel the following values are found:

- $\beta = \frac{1440}{2220} = 0.65$
- $\gamma = \frac{2220}{2 * 40} = 27.75$
- $\tau = \frac{40}{40} = 1$
- $\theta = 47^\circ$

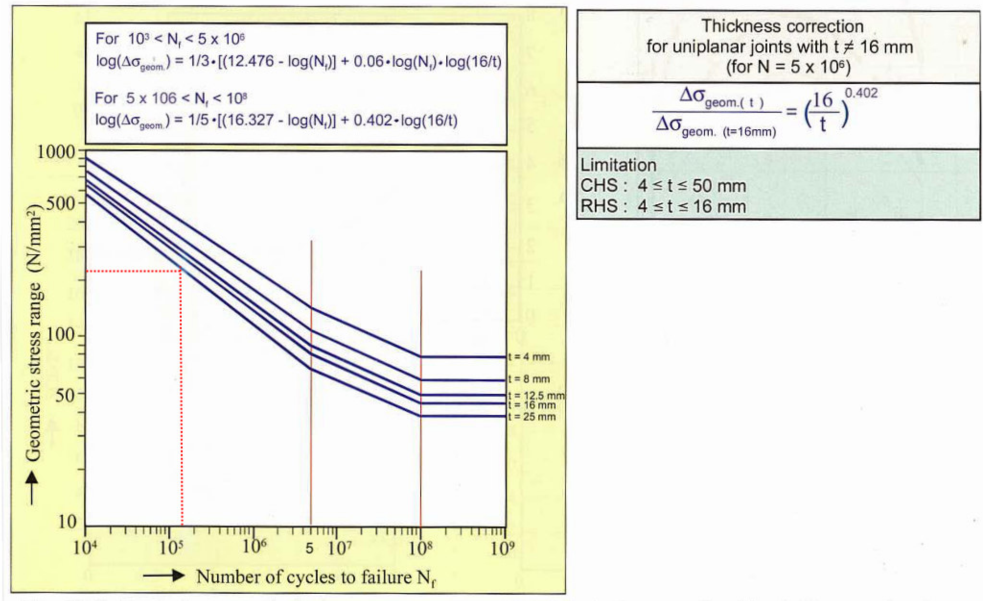


Figure B.2: S-N curve for hollow section joints [5]

For hollow section joints an S-N curve are made (Eurocode 3), see Figure B.2. It is seen that a thickness correction has to be applied. In the Great Dubai Wheel a thickness of 40mm is used throughout the whole structure.

B.2. Thickness correction factor

This thickness correction factor is:

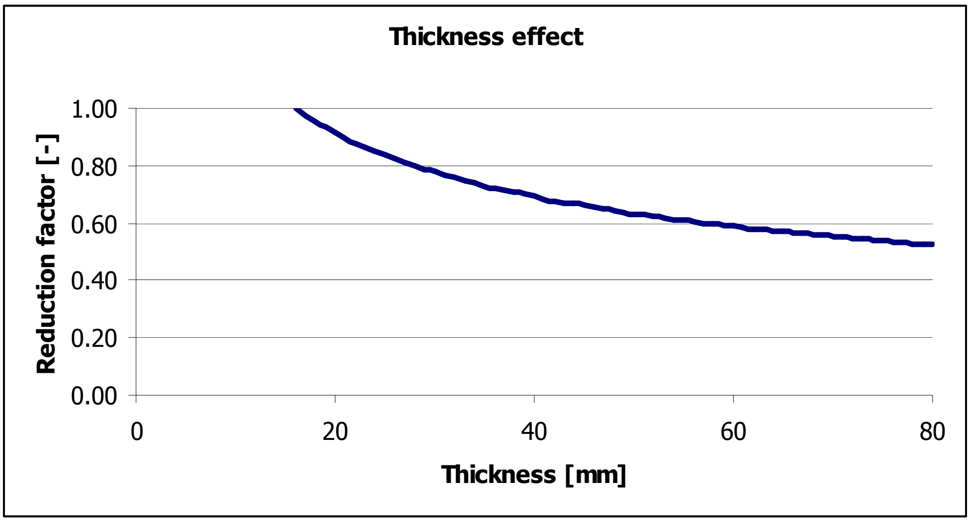


Figure B.3: Thickness effect

$$\frac{\Delta\sigma_{geom.(t)}}{\Delta\sigma_{geom.(t=16mm)}} = \left(\frac{16}{t}\right)^{0.402};$$

$$\Delta\sigma_{geom.(t)} = \Delta\sigma_{geom.(t=16mm)} * \left(\frac{16}{t}\right)^{0.402}$$

$$\Delta\sigma_{geom.(40)} = \Delta\sigma_{geom.(t=16mm)} * 0.69$$

B.3. Stress cycles

To be able to give the Δσ for the Great Dubai Wheel, the number of stress cycles has to be known. It is chosen to estimate the number of stress cycles by taking the number of rotations and multiply this by two (symmetrical loading).

$\left(\left((2*4)_{day} * 365\right)_{year} * 50\right)_{lifetime} = 146000$ cycles.

B.4. Stress range

This gives an allowable Δσ of:

$$\log\left(\Delta\sigma_{geom.(t)}\right) = \tfrac{1}{3}*\left[12.476 - \log\left(N_f\right)\right] + 0.06*\log\left(N_f\right)*\log\left(\tfrac{16}{t}\right)$$

$$\log\left(\Delta\sigma_{geom.(40)}\right) = \tfrac{1}{3}*\left[12.476 - \log\left(146000\right)\right] + 0.06*\log\left(146000\right)*\log\left(\tfrac{16}{40}\right)$$

$$\Delta\sigma_{geom.(40)} = 206 \, N/mm^2$$

This means that the geometrical stress range must be less then 206 N/mm^2.

B.5. Effect of the number of cycles

But what will happen to the allowable Δσ if the Great Dubai Wheel rotates instead of 4 times a day only 3, 2 or even 1 time a day? This is easily checked when looked at figure b.2, when decreasing the number of cycles the allowable stress ranges is increased. For instance when the Great Dubai Wheel only rotates 2 times a day the allowable Δσ becomes:

$$\log\left(\Delta\sigma_{geom.(40)}\right) = \tfrac{1}{3}*\left[12.476 - \log\left(73000\right)\right] + 0.06*\log\left(73000\right)*\log\left(\tfrac{16}{40}\right)$$

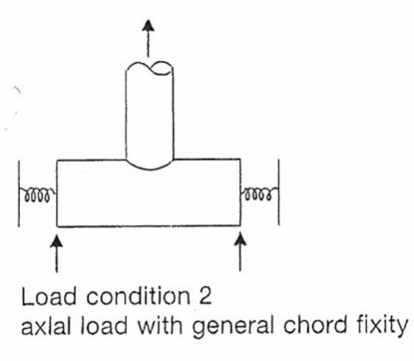
$$\Delta\sigma_{geom.(40)} = 263 \, N/mm^2$$

This means that the number of rotations per day greatly influences the allowable stress range. To maximize the fatigue life of the Great Dubai Wheel it is therefore possible to lower the number of rotations per day. But for the further analysis the number of cycles is kept at 4 times a day.

These geometrical stresses are calculated by taking the nominal stress in a member, and multiply it by the appropriate SCF for that location. $\sigma_{geom} = SCF * \sigma_{nom}$

B.6. Stress concentration factors

B.6.1. Summary SCF's



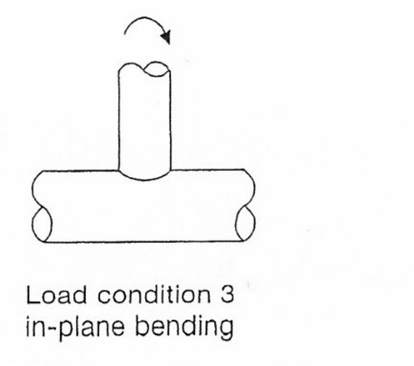
$$SCF_{ch\_saddle,\ ax,\ lc2} = 21.1$$

$$SCF_{ch\_crown,\ ax,\ lc2} = 5.84$$

$$SCF_{b\_saddle,\ ax,\ lc2} = 10.8$$

$$SCF_{b\_crown,\ ax,\ lc2} = 1.80$$

Figure B.4: Load condition 2, SCF's T-joint



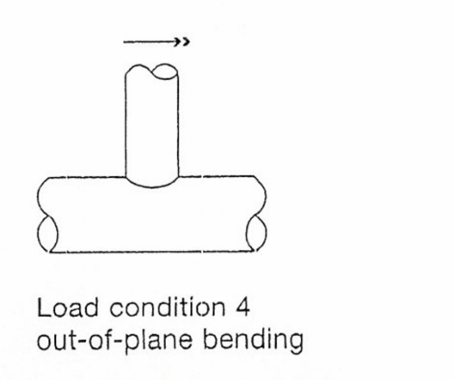
$$SCF_{ch\_saddle,\ ax,\ lc3} = 0$$

$$SCF_{ch\_crown,\ ax,\ lc3} = 4.99$$

$$SCF_{b\_saddle,\ ax,\ lc3} = 0$$

$$SCF_{b\_crown,\ ax,\ lc3} = 3.53$$

Figure B.5: Load condition 3, SCF's T-joint



$$SCF_{ch\_saddle,\ ax,\ lc4} = 15.0$$

$$SCF_{ch\_crown,\ ax,\ lc4} = 0$$

$$SCF_{b\_saddle,\ ax,\ lc4} = 11.3$$

$$SCF_{b\_crown,\ ax,\ lc4} = 0$$

Figure B.6: Load condition 4, SCF's T-joint

B.6.2. Maple sheet for determining the SCF's for a T-joint

The SCF's are calculated according to "Design guide for circular and rectangular hollow sections welded joints under fatigue loading (8) CIDECT" [2].

```
> restart;
```

Load Condition 1

```
> T[1]:=Gamma*tau^1.1*(1.11-3*(beta-0.52)^2)*sin(theta)^1.6;
T[2]:=Gamma^0.2*tau*(2.65+5*(beta-0.65)^2)+tau*beta*(0.25*
alpha-3)*sin(theta);
T[3]:=1.3+Gamma*tau^0.52*alpha^0.1*(0.187-1.25*beta^1.1*
(beta-0.96))*sin(theta)^(2.7-0.01*alpha);
T[4]:=3+Gamma^1.2*(0.12*exp(-4*beta)+0.011*beta^2-0.045)+
beta*tau*(0.1*alpha-1.2);
```

$$T_1 := \Gamma\,\tau^{1.1}\left(1.11 - 3\,(\beta - 0.52)^2\right)\sin(\theta)^{1.6}$$

$$T_2 := \Gamma^{0.2}\,\tau\left(2.65 + 5\,(\beta - 0.65)^2\right) + \tau\,\beta\,(0.25\,\alpha - 3)\sin(\theta)$$

$$T_3 := 1.3 + \Gamma\,\tau^{0.52}\,\alpha^{0.1}\left(0.187 - 1.25\,\beta^{1.1}\,(\beta - 0.96)\right)\sin(\theta)^{(2.7 - 0.01\,\alpha)}$$

$$T_4 := 3 + \Gamma^{1.2}\left(0.12\,e^{(-4\beta)} + 0.011\,\beta^2 - 0.045\right) + \beta\,\tau\,(0.1\,\alpha - 1.2) \qquad (1.1)$$

```
> F[1]:=piecewise(alpha>=12,1.0,alpha<12,1-(0.83*beta-0.56*
beta^2-0.02)*Gamma^0.23*exp(-0.21*Gamma^(-1.16)*alpha^2.5))
;
```

$$F_1 := \begin{cases} 1.0 & 12 \le \alpha \\ 1 - \left(0.83\,\beta - 0.56\,\beta^2 - 0.02\right)\Gamma^{0.23}\,e^{\left(-\frac{0.21\,\alpha^{2.5}}{\Gamma^{1.16}}\right)} & \alpha < 12 \end{cases} \qquad (1.2)$$

Parameters

```
> d[0]:=2000;
d[1]:=1440;
t[0]:=40;
t[1]:=40;
```

$$d_0 := 2000$$

$$d_1 := 1440$$

$$t_0 := 40$$

$$t_1 := 40 \qquad (1.3)$$

```
> alpha:=12;
beta:=d[1]/d[0];
Gamma:=d[0]/(2*t[0]);
tau:=t[1]/t[0];
theta:=90;
```

$$\alpha := 12$$

$$\beta := \frac{18}{25}$$

$$\Gamma := 25$$

$$\tau := 1$$
$$\theta := 90 \quad (1.4)$$

SCF's for the chord

```
> SCF[ch_saddle,ax,lc1]=evalf(T[1]*F[1]);
  SCF[ch_crown,ax,lc1]=evalf(T[2]);
```

$$SCF_{ch\_saddle,\,ax,\,lc1} = 20.68772050$$
$$SCF_{ch\_crown,\,ax,\,lc1} = 5.091322460 \quad (1.5)$$

SCF's for the brace

```
> SCF[b_saddle,ax,lc1]=evalf(T[3]*F[1]);
  SCF[b_crown,ax,lc1]=evalf(T[4]);
```

$$SCF_{b\_saddle,\,ax,\,lc1} = 10.80651690$$
$$SCF_{b\_crown,\,ax,\,lc1} = 1.450357711 \quad (1.6)$$

Load condition 2

```
> unassign('alpha','beta','Gamma','tau','theta');
> T[5]:=Gamma*tau^1.1*(1.11-3*(beta-0.52)^2)*sin(theta)^1.6+C
  [1]*(0.8*alpha-6)*tau*beta^2*(1-beta^2)^0.5*sin(theta)^2;
  T[6]:=Gamma^0.2*tau*(2.65+5*(beta-0.65)^2)+tau*beta*(C[2]*
  alpha-3)*sin(theta);
  T[7]:=3+Gamma^1.2*(0.12*exp(-4*beta)+0.011*beta^2-0.045)+
  beta*tau*(C[3]*alpha-1.2);
```

$$T_5 := \Gamma\,\tau^{1.1}\left(1.11 - 3\left(\beta - 0.52\right)^2\right)\sin(\theta)^{1.6} + C_1\left(0.8\,\alpha - 6\right)\tau\,\beta^2\left(1-\beta^2\right)^{0.5}\sin(\theta)^2$$
$$T_6 := \Gamma^{0.2}\,\tau\left(2.65 + 5\left(\beta - 0.65\right)^2\right) + \tau\,\beta\left(C_2\,\alpha - 3\right)\sin(\theta)$$
$$T_7 := 3 + \Gamma^{1.2}\left(0.12\,e^{(-4\beta)} + 0.011\,\beta^2 - 0.045\right) + \beta\,\tau\left(C_3\,\alpha - 1.2\right) \quad (2.1)$$

```
> F[2]:=piecewise(alpha>=12,1.0,alpha<12,1-(1.43*beta-0.97*
  beta^2-0.03)*Gamma^0.04*exp(-0.71*Gamma^(-1.38)*alpha^2.5))
  ;
```

$$F_2 := \begin{cases} 1.0 & 12 \le \alpha \\ 1 - \left(1.43\,\beta - 0.97\,\beta^2 - 0.03\right)\Gamma^{0.04}\,e^{\left(-\frac{0.71\,\alpha^{2.5}}{\Gamma^{1.38}}\right)} & \alpha < 12 \end{cases} \quad (2.2)$$

```
> C[1]:=2*(c-0.5);
  C[2]:=c/2;
  C[3]:=c/5;
```

$$C_1 := 2\,c - 1.0$$
$$C_2 := \frac{1}{2}\,c$$
$$C_3 := \frac{1}{5}\,c \quad (2.3)$$

```
> c:=0.7;
```

```
alpha:=12;
beta:=d[1]/d[0];
Gamma:=d[0]/(2*t[0]);
tau:=t[1]/t[0];
theta:=90;
```

$$c := 0.7$$
$$\alpha := 12$$
$$\beta := \frac{18}{25}$$
$$\Gamma := 25$$
$$\tau := 1$$
$$\theta := 90 \quad (2.4)$$

SCF's for the chord

```
> SCF[ch_saddle,ax,lc2]=evalf(T[5]*F[2]);
  SCF[ch_crown,ax,lc2]=evalf(T[6]);
```

$$SCF_{ch\_saddle,\, ax,\, lc2} = 21.10176071$$
$$SCF_{ch\_crown,\, ax,\, lc2} = 5.863735577 \quad (2.5)$$

SCF's for the brace

```
> SCF[b_saddle,ax,lc2]=evalf(T[3]*F[2]);
  SCF[b_crown,ax,lc2]=evalf(T[7]);
```

$$SCF_{b\_saddle,\, ax,\, lc2} = 10.80651690$$
$$SCF_{b\_crown,\, ax,\, lc2} = 1.795957711 \quad (2.6)$$

Load Condition 3

```
> unassign('alpha','beta','Gamma','tau','theta','c');
> T[8]:=1.45*beta*tau^0.85*Gamma^(1-0.68*beta)*sin(theta)
  ^0.7;
  T[9]:=1+0.65*beta*tau^0.4*Gamma^(1.09-0.77*beta)*sin(theta)
  ^(0.06*Gamma-1.16);
```

$$T_8 := 1.45\,\beta\,\tau^{0.85}\,\Gamma^{(1-0.68\,\beta)}\,\sin(\theta)^{0.7}$$
$$T_9 := 1 + 0.65\,\beta\,\tau^{0.4}\,\Gamma^{(1.09-0.77\,\beta)}\,\sin(\theta)^{(0.06\,\Gamma-1.16)} \quad (3.1)$$

Parameters

```
> alpha:=12;
  beta:=d[1]/d[0];
  Gamma:=d[0]/(2*t[0]);
  tau:=t[1]/t[0];
  theta:=90;
```

$$\alpha := 12$$
$$\beta := \frac{18}{25}$$
$$\Gamma := 25$$

$$\tau := 1$$

$$\theta := 90 \quad (3.2)$$

SCF's for the chord

```
> SCF[ch_saddle,ax,lc3]=0;
  SCF[ch_crown,ax,lc3]=evalf(T[8]);
```

$$SCF_{ch\_saddle,\,ax,\,lc3} = 0$$

$$SCF_{ch\_crown,\,ax,\,lc3} = 4.990501697 \quad (3.3)$$

SCF's for the brace

```
> SCF[b_saddle,ax,lc3]=0;
  SCF[b_crown,ax,lc3]=evalf(T[9]);
```

$$SCF_{b\_saddle,\,ax,\,lc3} = 0$$

$$SCF_{b\_crown,\,ax,\,lc3} = 3.526019664 \quad (3.4)$$

Load condition 4

```
> unassign('alpha','beta','Gamma','tau','theta');
> T[10]:=Gamma*tau*beta(1.7-1.05*beta^3)*sin(theta)^1.6;
  T[11]:=Gamma^0.95*tau^0.46*beta*(1.7-1.05*beta^3)*(0.99
  -0.47*beta+0.08*beta^4)*sin(theta)^1.6;
```

$$T_{10} := \Gamma\,\tau\,\beta\left(1.7 - 1.05\,\beta^3\right)\sin(\theta)^{1.6}$$

$$T_{11} := \Gamma^{0.95}\,\tau^{0.46}\,\beta\left(1.7 - 1.05\,\beta^3\right)\left(0.99 - 0.47\,\beta + 0.08\,\beta^4\right)\sin(\theta)^{1.6} \quad (4.1)$$

```
> F[3]:=piecewise(alpha>=12,1.0,alpha<12,1-0.55*beta^1.8*
  Gamma^0.16*exp(-0.49*Gamma^(-0.89)*alpha^1.8));
```

$$F_3 := \begin{cases} 1.0 & 12 \le \alpha \\ 1 - 0.55\,\beta^{1.8}\,\Gamma^{0.16}\,e^{\left(-\frac{0.49\,\alpha^{1.8}}{\Gamma^{0.89}}\right)} & \alpha < 12 \end{cases} \quad (4.2)$$

Parameters

```
> alpha:=12;
  beta:=d[1]/d[0];
  Gamma:=d[0]/(2*t[0]);
  tau:=t[1]/t[0];
  theta:=90;
```

$$\alpha := 12$$

$$\beta := \frac{18}{25}$$

$$\Gamma := 25$$

$$\tau := 1$$

$$\theta := 90 \quad (4.3)$$

SCF's for the chord

```
> SCF[ch_saddle,ax,lc4]=evalf(T[10]*F[3]);
  SCF[ch_crown,ax,lc4]=0;
```

$$SCF_{ch\_saddle,\,ax,\,lc4} = 15.04561491$$
$$SCF_{ch\_crown,\,ax,\,lc4} = 0 \qquad (4.4)$$

SCF's for the brace

```
> SCF[b_saddle,ax,lc4]=evalf(T[11]*F[3]);
  SCF[b_crown,ax,lc4]=evalf(0);
```

$$SCF_{b\_saddle,\,ax,\,lc4} = 11.27793103$$
$$SCF_{b\_crown,\,ax,\,lc4} = 0. \qquad (4.5)$$

SCF's

```
> unassign('alpha','beta','Gamma','tau','theta');
> d[0]:=2000: d[1]:=1440: t[0]:=40: t[1]:=40:
> c:=0.7: alpha:=12: beta:=d[1]/d[0]: Gamma:=d[0]/(2*t[0]):
  tau:=t[1]/t[0]: theta:=90:
```

SCF's for the chord

```
> SCF[ch_saddle,ax,lc1]=evalf[3](T[1]*F[1]);
  SCF[ch_crown,ax,lc1]=evalf[3](T[2]);
```

$$SCF_{ch\_saddle,\,ax,\,lc1} = 20.7$$
$$SCF_{ch\_crown,\,ax,\,lc1} = 5.07 \quad (5.1)$$

SCF's for the brace

```
> SCF[b_saddle,ax,lc1]=evalf[3](T[3]*F[1]);
  SCF[b_crown,ax,lc1]=evalf[3](T[4]);
```

$$SCF_{b\_saddle,\,ax,\,lc1} = 10.8$$
$$SCF_{b\_crown,\,ax,\,lc1} = 1.45 \quad (5.2)$$

SCF's for the chord

```
> SCF[ch_saddle,ax,lc2]=evalf[3](T[5]*F[2]);
  SCF[ch_crown,ax,lc2]=evalf[3](T[6]);
```

$$SCF_{ch\_saddle,\,ax,\,lc2} = 21.1$$
$$SCF_{ch\_crown,\,ax,\,lc2} = 5.84 \quad (5.3)$$

SCF's for the brace

```
> SCF[b_saddle,ax,lc2]=evalf[3](T[3]*F[2]);
  SCF[b_crown,ax,lc2]=evalf[3](T[7]);
```

$$SCF_{b\_saddle,\,ax,\,lc2} = 10.8$$
$$SCF_{b\_crown,\,ax,\,lc2} = 1.80 \quad (5.4)$$

SCF's for the chord

```
> SCF[ch_saddle,ax,lc3]=0;
  SCF[ch_crown,ax,lc3]=evalf[3](T[8]);
```

$$SCF_{ch\_saddle,\,ax,\,lc3} = 0$$
$$SCF_{ch\_crown,\,ax,\,lc3} = 4.99 \quad (5.5)$$

SCF's for the brace

```
> SCF[b_saddle,ax,lc3]=0;
  SCF[b_crown,ax,lc3]=evalf[3](T[9]);
```

$$SCF_{b\_saddle,\,ax,\,lc3} = 0$$
$$SCF_{b\_crown,\,ax,\,lc3} = 3.53 \quad (5.6)$$

SCF's for the chord

```
> SCF[ch_saddle,ax,lc4]=evalf[3](T[10]*F[3]);
  SCF[ch_crown,ax,lc4]=0;
```

$$SCF_{ch\_saddle,\,ax,\,lc4} = 15.0$$

(5.7)

$$SCF_{ch\_crown,\ ax,\ lc4} = 0 \quad (5.7)$$

SCF's for the brace

```
> SCF[b_saddle,ax,lc4]=evalf[3](T[11]*F[3]);
  SCF[b_crown,ax,lc4]=0;
```

$$SCF_{b\_saddle,\ ax,\ lc4} = 11.3$$

$$SCF_{b\_crown,\ ax,\ lc4} = 0 \quad (5.8)$$

C. Appendix C: Joint requirements

For this Master thesis the joints are given a joint efficiency of 80%. This is thought to be achievable when the joints are improvement with for instance the stated solutions in chapter 8.3.1, see Figure C.1.

Figure C.1: Joint improvements

In this appendix the requirements for a KT-joint and a multiplanar KTK-joint in the Great Dubai Wheel are stated. The requirements for a multiplanar joint are broken down in uniplanar constituent parts because multiplanar joints are for analysis broken down in their uniplanar constituent parts according to [6]. The governing KT-joint in the Great Dubai Wheel is the joint given in Figure C.2, and the governing KTK-joint is given in Figure C.8.

C.1. KT-joint

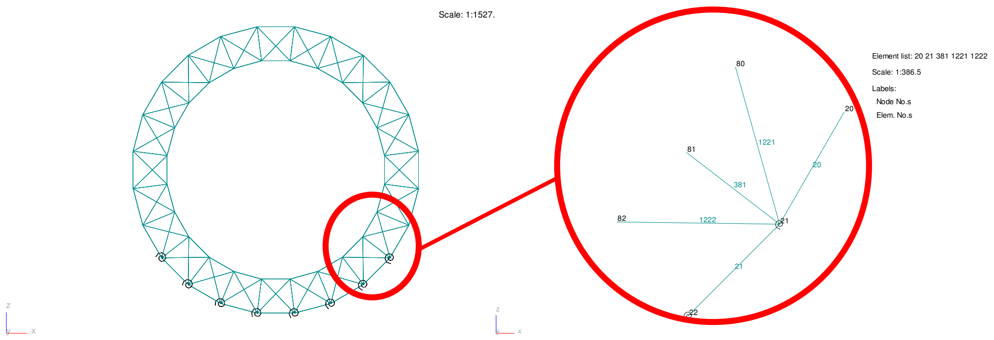


Figure C.2: Governing KT-joint

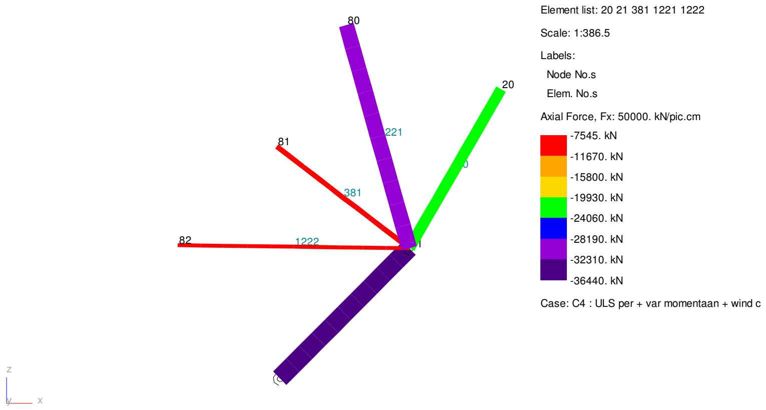


Figure C.3: Governing KT-joint axial forces

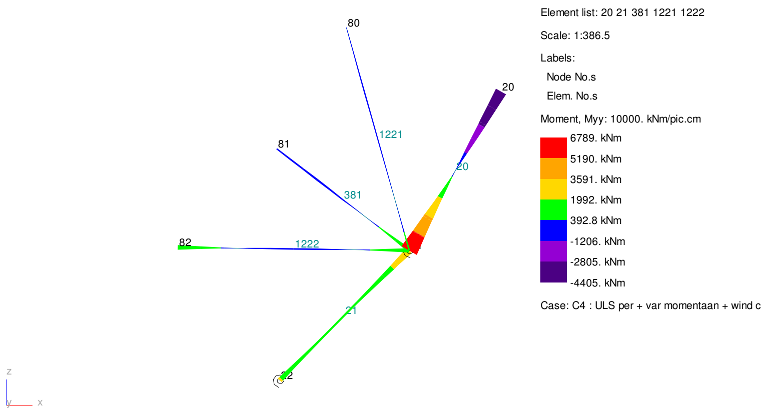


Figure C.4: Governing KT-joint Myy

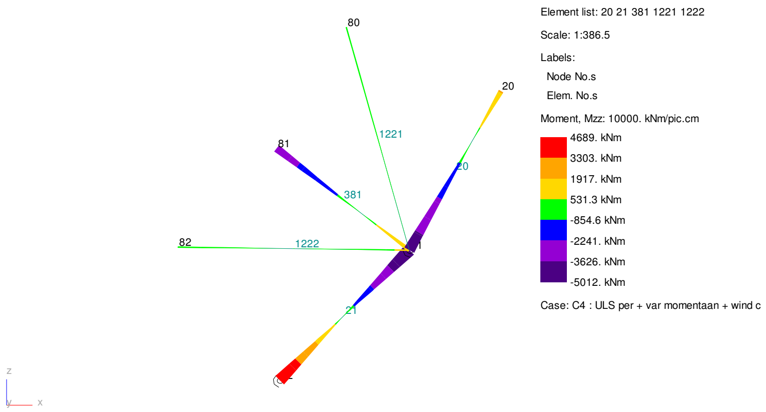


Figure C.5: Governing KT-joint Mzz

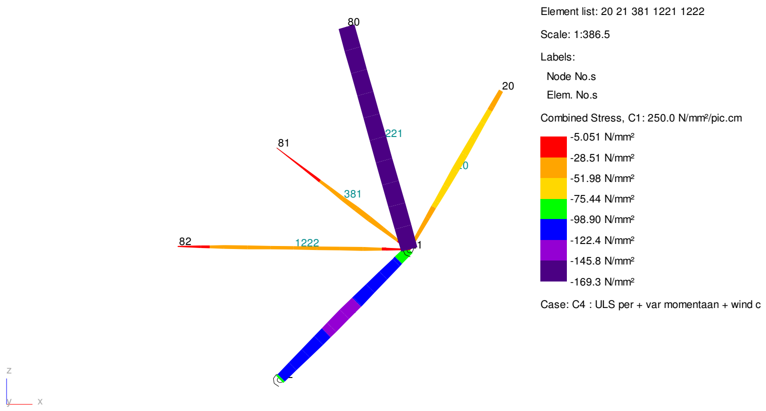


Figure C.6: Governing KT-joint Combined stresses C1

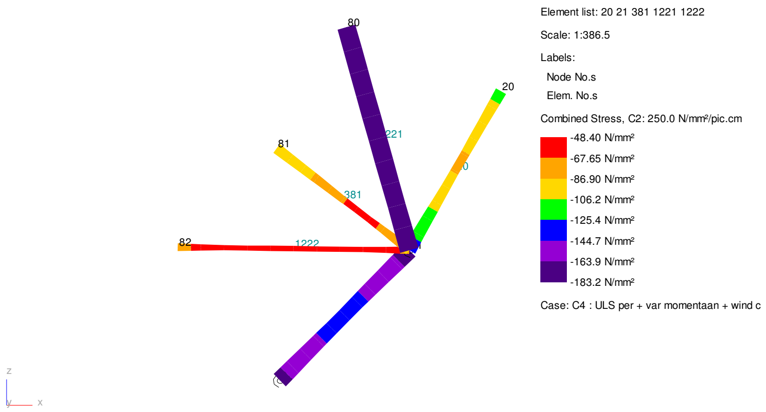


Figure C.7: Governing KT-joint Combined stresses C2

It is seen in Figure C.6 and Figure C.7 that the maximum stresses are only about 180N/mm^2 for the KT-joint. This means that the joint efficiency of the KT-joint in the Great Dubai Wheel only has to be:

$$C_e = \frac{\sigma_d}{f_y} * 100\% = \frac{180}{355} * 100\% = 51\%$$

This is less as the 80% joint efficiency which is used in the Master thesis.

C.2. Multiplanar KTK-joint

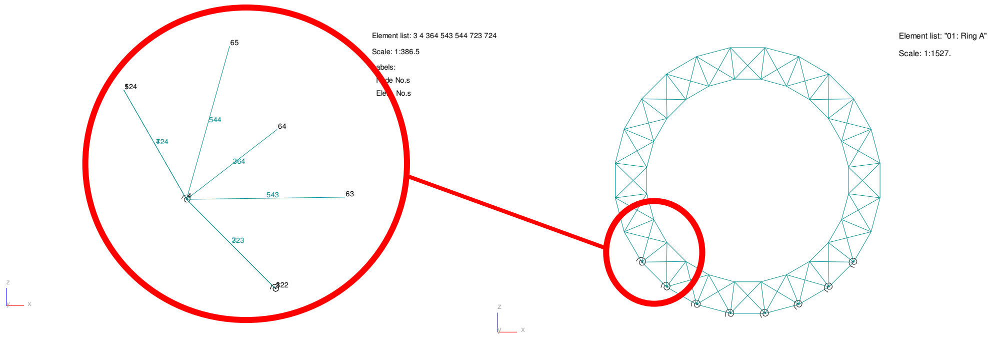


Figure C.8: Governing KTK-joint

The multiplanar joint is broken down in a KT-joint and a K-joint.

C.2.1. KT-joint

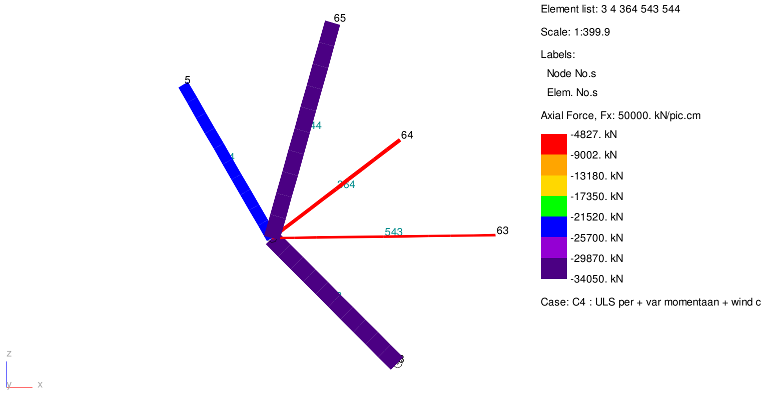


Figure C.9: Governing KT-joint axial forces

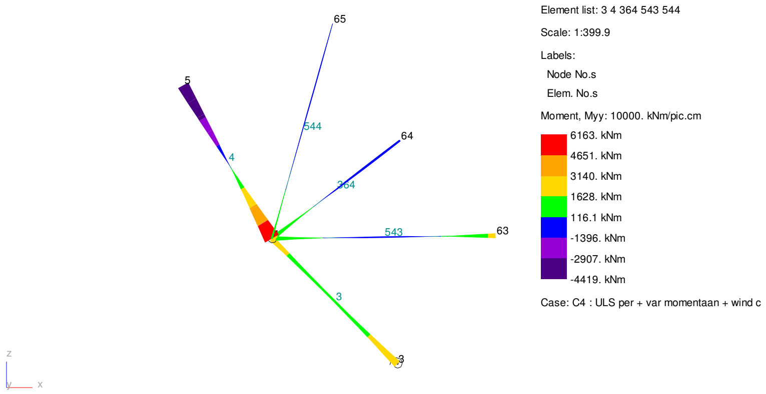


Figure C.10: Governing KT-joint Myy

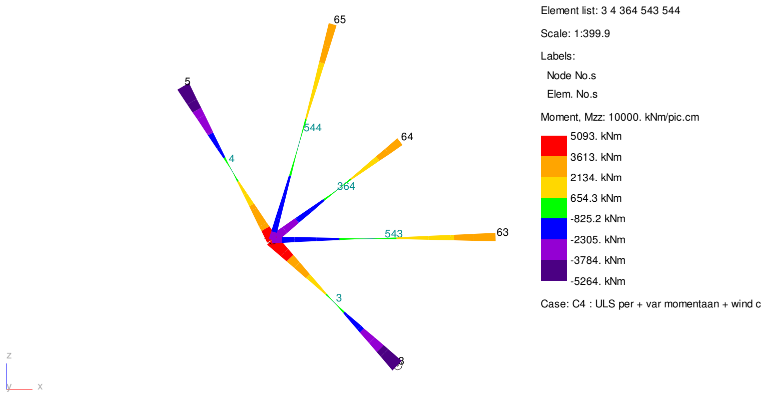


Figure C.11: Governing KT-joint Mzz

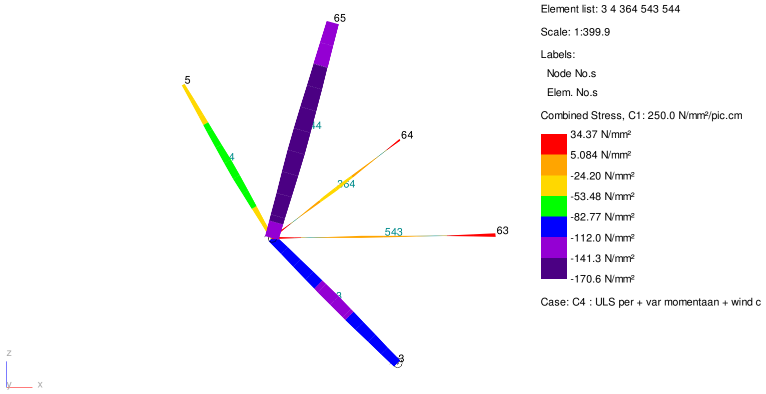


Figure C.12: Governing KT-joint Combined stresses C1

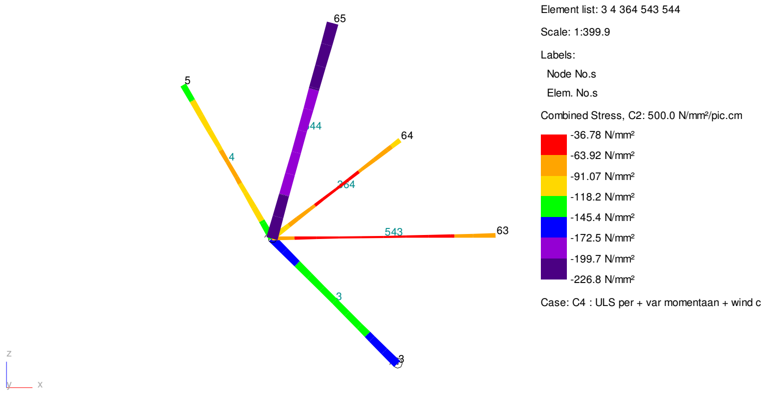


Figure C.13: Governing KT-joint Combined stresses C2

It is seen in Figure C.12 and Figure C.13 that the maximum stresses are only about 230N/mm^2 for the KT-joint. This means that the joint efficiency of the KT-joint in the Great Dubai Wheel only has to be:

$$C_e = \frac{\sigma_d}{f_y} * 100\% = \frac{230}{355} * 100\% = 65\%$$

This is less as the 80% joint efficiency which is used in the Master thesis.

C.2.2. K-joint

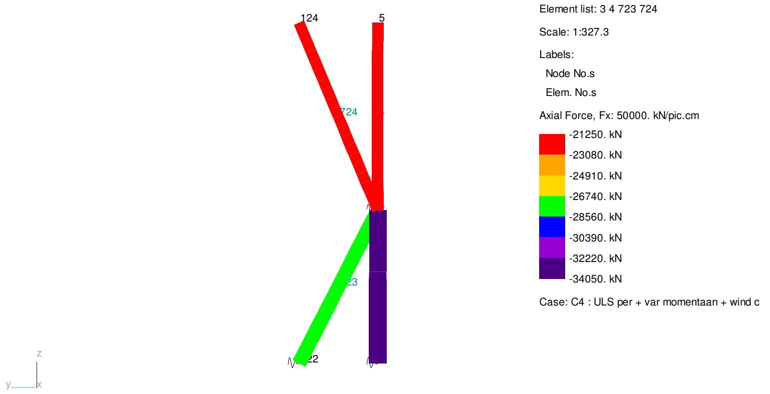


Figure C.14: Governing K-joint axial forces

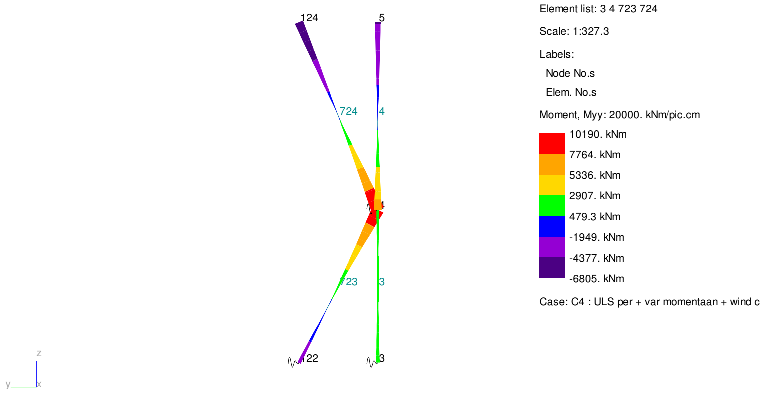


Figure C.15: Governing K-joint Myy

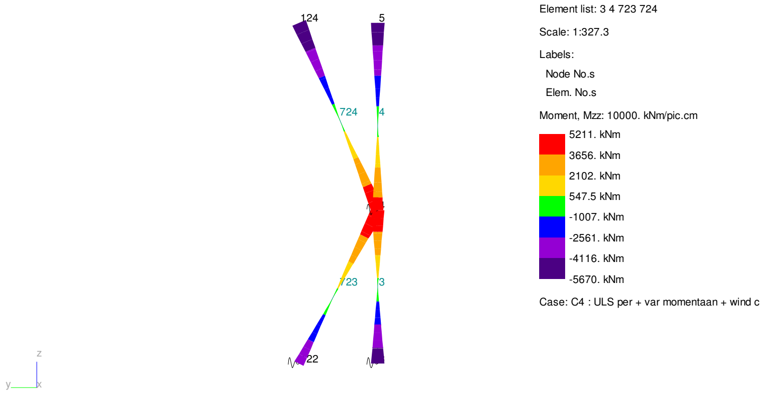


Figure C.16: Governing K-joint Mzz

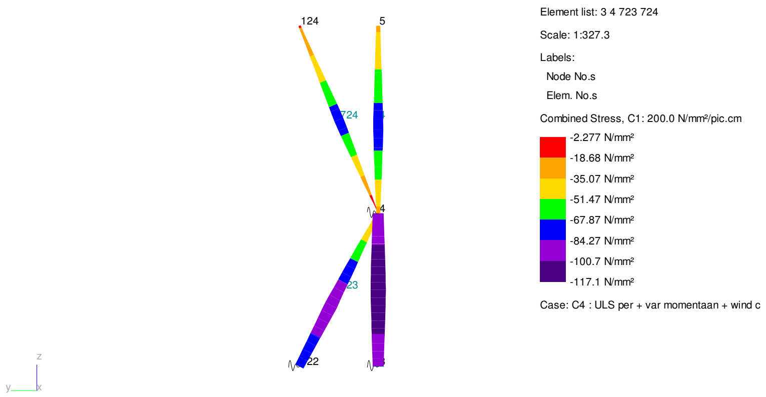


Figure C.17: Governing K-joint Combined stresses C1

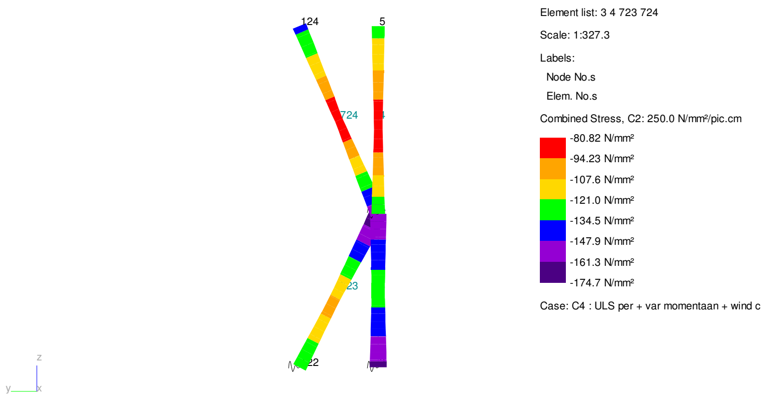


Figure C.18: Governing K-joint Combined stresses C2

It is seen in Figure C.12 and Figure C.13 that the maximum stresses are only about 175N/mm^2 for the KT-joint. This means that the joint efficiency of the KT-joint in the Great Dubai Wheel only has to be:

$$C_e = \frac{\sigma_d}{f_y} * 100\% = \frac{175}{355} * 100\% = 50\%$$

This is less as the 80% joint efficiency which is used in the Master thesis.

C.3. Conclusion joint requirements

The minimal joint efficiency that is needed for the improved design of chapter 12 with a diameter of 210m and the sections as given in chapter 11 is 50%. This is less as the value of 80% which is considered. But as the design is also fatigue sensitive the demands to come to the fatigue life that is needed are somewhat stricter.

C.3.1. Fatigue

It can not be said at this time what the requirements are for the joints regarding fatigue, this because when changing the geometry of the joint, or to improve the joint in some way the SCF's of the joints directly change. Therefore the demand that the geometrical stress should be below 206 N/mm^2, as seen in appendix B is still in effect.