



Queensland
Hydraulics Pty Ltd

Hydraulic & Pneumatic Systems
Design - Manufacture - Installation - Repair



Hydro Power Station
Intake Gate Cylinder
Cylinder Design Calculation and FEA summary

Building C, Phoenix Estate
210 Evans Road Salisbury QLD 4107
PO Box 379 Salisbury QLD 4107

Phone: 07 3276 7533
Facsimile: 07 3276 8233
Email: engineering@hydraulics.net.au

Table of Contents

CYLINDER SIZE AND WORKING PRESSURE	4
CYLINDER BARREL STRESS	4
STRESS IN THE WELDS BETWEEN MOUNTING TRUNNION AND CYLINDER BARREL.....	4
PISTON ROD BUCKLING LOAD	5
PISTON ROD TENSILE STRESS	5
SHEAR STRESS - THREADS BETWEEN PISTON ROD AND PISTON	6
SHEAR STRESS - THREADS BETWEEN PISTON ROD AND ROD EYE	7
TENSILE STRESS - SHC SCREWS ON HEAD CAP.....	8
TENSILE STRESS - SHC SCREWS ON END CAP.....	8
SHEAR STRESS - HEAD CAP TRUNNIONS.....	8
TENSILE STRESS - ROD EYE BEARING HOUSING	9
FEA RESULT ON CYLINDER BARREL.....	10
FEA RESULT ON ROD EYE.....	12
SUMMARY	14

We have completed the design on the intake gate cylinder a Hydro Power Station project.

As part of our design process, we have reviewed the below listed factors.

- Cylinder Barrel Stress
- Stress in the welds between mounting trunnion and cylinder barrel
- Piston rod buckling load
- Piston rod tensile stress
- Shear stress - threads between piston rod and piston
- Shear stress - threads between piston rod and rod eye
- Tensile stress - SHC screws on head cap and end cap
- Shear stress - head cap trunnion journals
- FEA on cylinder barrel
- FEA on rod eye

Refer to drawing AC- 10878 for cylinder details.

Prepared by: Jasper Chan

Date: 10-09-2019

CYLINDER SIZE AND WORKING PRESSURE

Cylinder bore size: Ø450 mm

Cylinder rod size: Ø 280 mm

Cylinder stroke: 6900 mm

Cylinder load at relief valves / working pressure

Extension: 1511 kN approx. @ 95 bar relief valve setting

Retraction: 2437 kN approx. @ 250 bar relief valve setting / working pressure

CYLINDER BARREL STRESS

Barrel OD: Ø530 mm

Barrel ID: Ø450 mm

Barrel Material: ST52.3 BK+S Honed tube

Min yield Strength: 520 MPa.

Hoop Stress

At working pressure of 25 MPa in retraction

154 MPa

Axial stress

At working pressure of 25 MPa in retraction

39.6 MPa

von Mises yield criterion

$\sqrt{\sigma}$

138.5 MPa

STRESS IN THE WELDS BETWEEN MOUNTING TRUNNION AND CYLINDER BARREL

Barrel OD: Ø530 mm

Fillet welding size: 30 mm, both sides

Maximum working load on welds: 2437 kN

Min Shear strength of filler metal: 203 MPa

Stress in welds: 24.4 MPa

PISTON ROD BUCKLING LOAD

Piston Rod details:

Diameter: Ø 280 mm

Hole Diameter for transducer probe: ~Ø30 mm

Open pin to pin distance: ~8400 mm

Euler's formula

E = Young's modulus = 210 GPa

I = Moment of Inertia

P = Ultimate load

$P = 8845 \text{ kN}$

Maximum compression load on piston rod at relief valve pressure of 95 MPa: 1511 kN

PISTON ROD TENSILE STRESS

The weakest point on the piston rod for tensile stress should be at the thread undercut area, located at the piston rod and piston thread.

Thread detail: M245 x 4.0

Minor diameter of M245 x 4.0 external thread is Ø239.6 mm

Hole Diameter for transducer probe: ~Ø30 mm

Tensile stress = Force / Area

Cylinder retraction force at 25 MPa is approximately 2437 kN

)

Tensile stress: 54.9 MPa

Minimum yield strength of 4140 chromed bar is 550 MPa

SHEAR STRESS - THREADS BETWEEN PISTON ROD AND PISTON

Thread: M245 x 4.0. Length of thread engagement: 170 mm

$$AS_n = 3.1416 (1/P)(LE)(d \text{ min.}) \times \left[\frac{1}{2(1/P)} + 0.57735 (d \text{ min.} - D_2 \text{ max.}) \right]$$

$$AS_s = 3.1416 (1/P)(LE)(D_1 \text{ max.}) \times \left[\frac{1}{2(1/P)} + 0.57735 (d_2 \text{ min.} - D_1 \text{ max.}) \right]$$

where

AS_n = minimum thread shear area for internal threads

AS_s = minimum thread shear area for external threads

$1/P$ = number of threads per mm

LE = length of engagement

$d \text{ min.}$ = minimum major diameter of external thread

$d_2 \text{ min.}$ = minimum pitch diameter of external thread

$D_1 \text{ max.}$ = maximum minor diameter of internal thread

$D_2 \text{ max.}$ = maximum pitch diameter of internal thread

Reference: ASME B1.1-2003

$D_1 \text{ max}$ (max minor diameter of internal thread) = 241.27 mm

$d_2 \text{ min}$ (min pitch diameter of external thread) = 242.1 mm

$d \text{ min}$ (min major diameter of external thread) = 244.5 mm

$D_2 \text{ max}$ (max pitch diameter of internal thread) = 242.78 mm

LE (thread engagement) Engagement length = 170 mm

$$AS_n = 97708 \text{ mm}^2$$

$$AS_s = 79864 \text{ mm}^2$$

Minimum yield strength of 4140 piston rod: 550 MPa

Minimum yield strength of 1045 piston: 350 MPa

Minimum shear strength of 4140 piston rod: 319 MPa

Minimum shear strength of 1045 piston: 203 MPa

Maximum shear load on external thread = 25476 kN

Maximum shear load on internal thread = 19834 kN

Cylinder retraction force at 25 MPa: 2437 kN

SHEAR STRESS - THREADS BETWEEN PISTON ROD AND ROD EYE

Thread: M245 x 4.0. Length of thread engagement: 240 mm

$$AS_n = 3.1416 (1/P)(LE)(d \text{ min.}) \times \left[\frac{1}{2(1/P)} + 0.57735 (d \text{ min.} - D_2 \text{ max.}) \right]$$

$$AS_s = 3.1416 (1/P)(LE)(D_1 \text{ max.}) \times \left[\frac{1}{2(1/P)} + 0.57735 (d_2 \text{ min.} - D_1 \text{ max.}) \right]$$

where

AS_n = minimum thread shear area for internal threads

AS_s = minimum thread shear area for external threads

$1/P$ = number of threads per mm

LE = length of engagement

$d \text{ min.}$ = minimum major diameter of external thread

$d_2 \text{ min.}$ = minimum pitch diameter of external thread

$D_1 \text{ max.}$ = maximum minor diameter of internal thread

$D_2 \text{ max.}$ = maximum pitch diameter of internal thread

Reference: ASME B1.1-2003

$D_1 \text{ max}$ (max minor diameter of internal thread) = 241.27 mm

$d_2 \text{ min}$ (min pitch diameter of external thread) = 242.1 mm

$d \text{ min}$ (min major diameter of external thread) = 244.5 mm

$D_2 \text{ max}$ (max pitch diameter of internal thread) = 242.78 mm

LE (thread engagement) Engagement length = 240 mm

$$AS_n = 137940 \text{ mm}^2$$

$$AS_s = 112749 \text{ mm}^2$$

Minimum yield strength of 4140 piston rod: 550 MPa

Minimum yield strength of 1045 piston: 350 MPa

Minimum shear strength of 4140 piston rod: 319 MPa

Minimum shear strength of 1045 piston: 203 MPa

Maximum shear load on external thread = 35966 kN

Maximum shear load on internal thread = 28001 kN

Cylinder retraction force at 25 MPa: 2437 kN

TENSILE STRESS - SHC SCREWS ON HEAD CAP

Size of the SHC screws: M20 x 2.5 x 220 Long

Number of SHC screws: 38

Manufacturer and Grade: Unbrako 12.9

Cylinder retraction force at 25 MPa: 2437 kN

Manufacturer Rated yield strength/force: 276 kN min

$276 \text{ kN} \times 38 = 10488 \text{ kN}$

TENSILE STRESS - SHC SCREWS ON END CAP

Size of the SHC screws: M20 x 2.5 x 190 Long

Number of SHC screws: 38

Manufacturer and Grade: Unbrako 12.9

Cylinder retraction force at 25 MPa: 2437 kN

Manufacturer Rated yield strength/force: 276 kN min

$276 \text{ kN} \times 38 = 10488 \text{ kN}$

SHEAR STRESS - HEAD CAP TRUNNIONS

Diameter: Ø 250 mm

Material: 1045 / 350 Grade plate

Cylinder retraction force at 25 MPa: 2437 kN

Shear strength: 203 MPa min

Max loading before shear: 19929 kN

TENSILE STRESS - ROD EYE BEARING HOUSING

Material: 1045 / 350 Grade plate

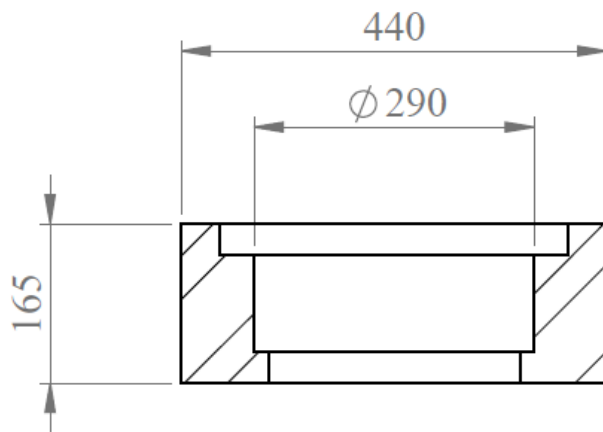
Cylinder retraction force at 25 MPa: 2437 kN

Rod eye bearing housing thickness: 165 mm

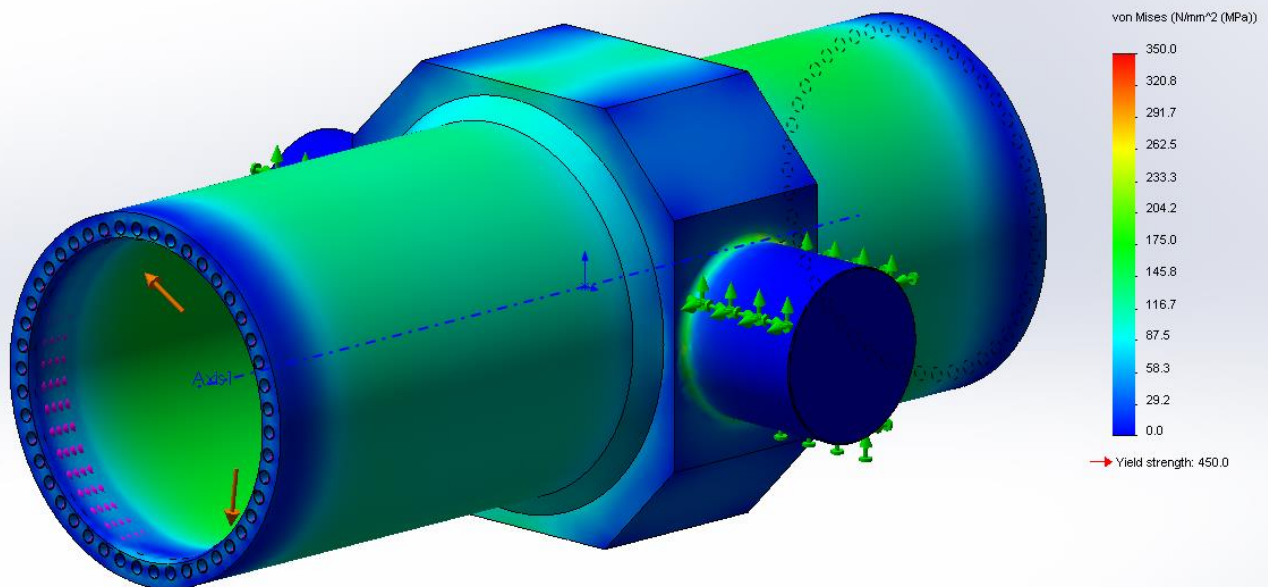
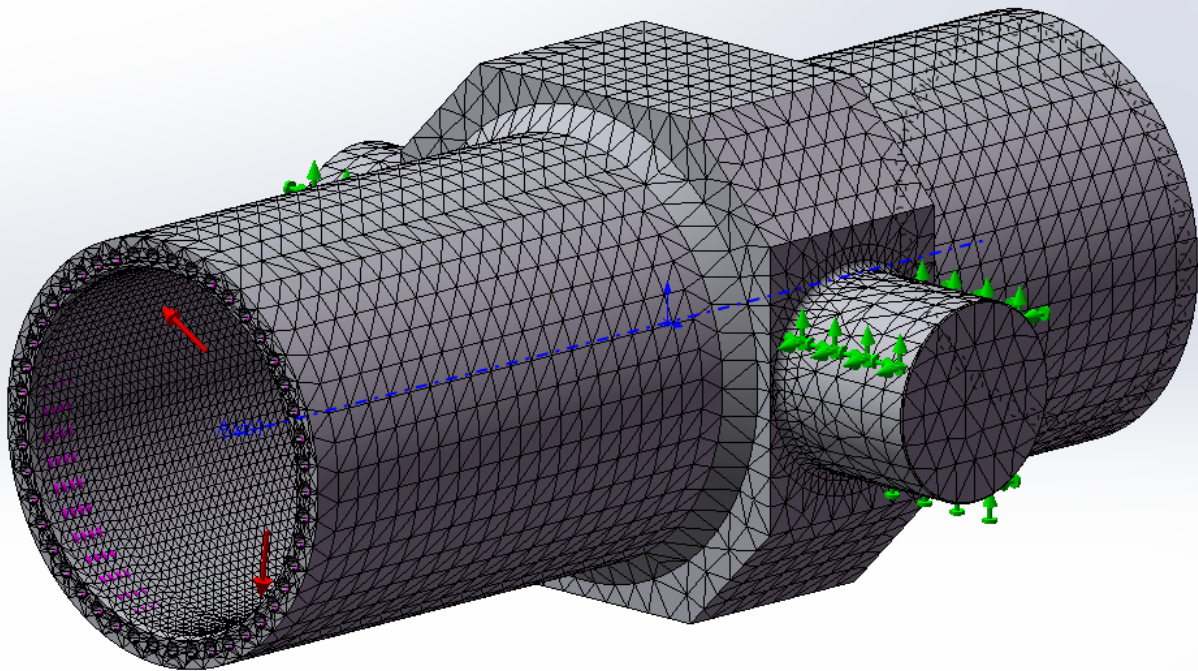
Bearing OD: Ø290 mm

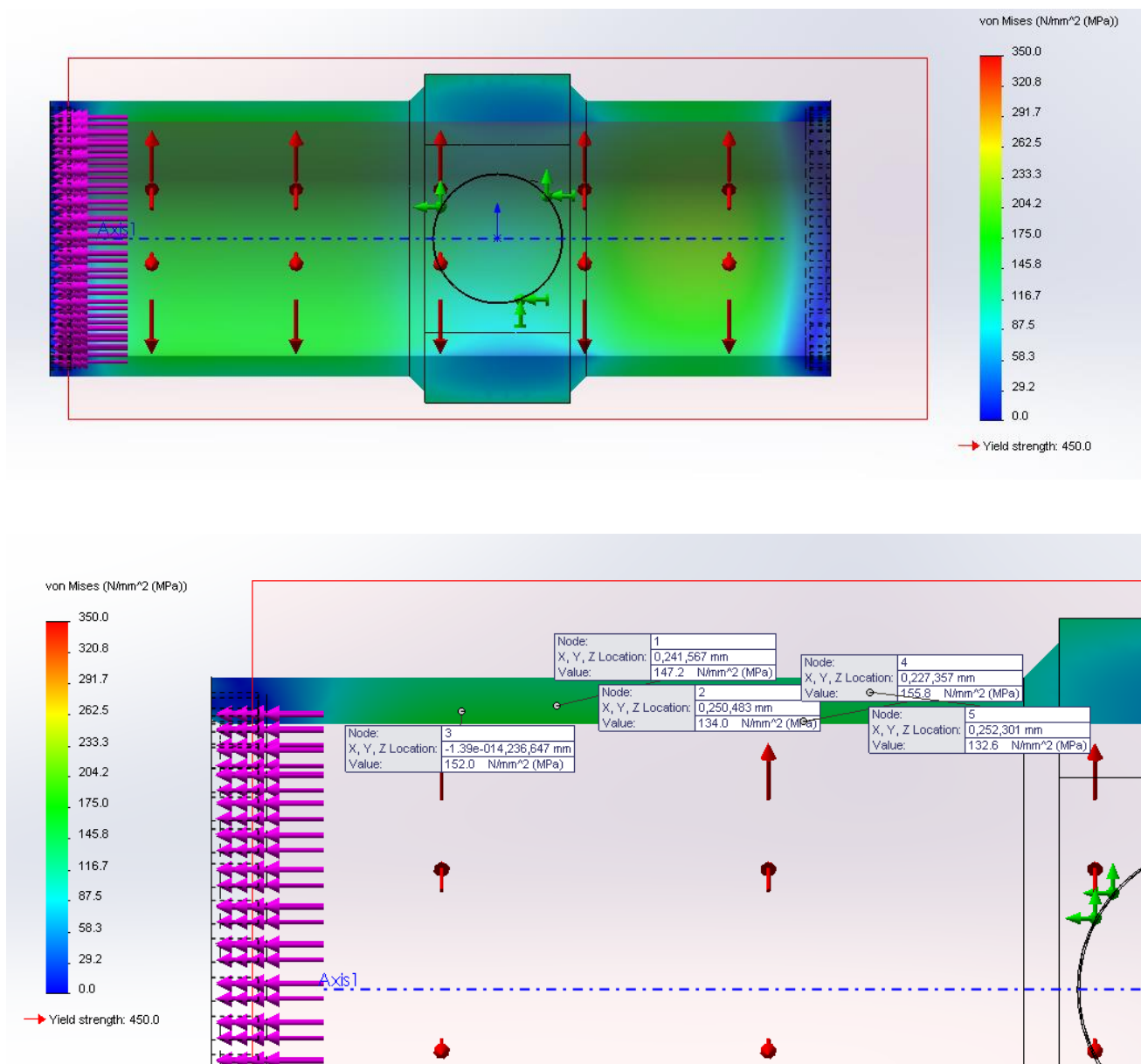
Bearing body width: 100 mm

Rod eye width: 440 mm



Estimated tensile stress: $2437 \text{ kN} / (75 \text{ mm} \times 100 \text{ mm} \times 2) = 162 \text{ MPa}$

FEA RESULT ON CYLINDER BARREL



Note: Barrel length on the FEA model has been reduced

Total Force applied (shown as purple arrows): 2437 kN

Internal Pressure applied (shown as red arrows) : 25 MPa

Maximum stress shown: 228 MPa (Located at the trunnion journal fillets)

Barrel Stress in general: 150 MPa

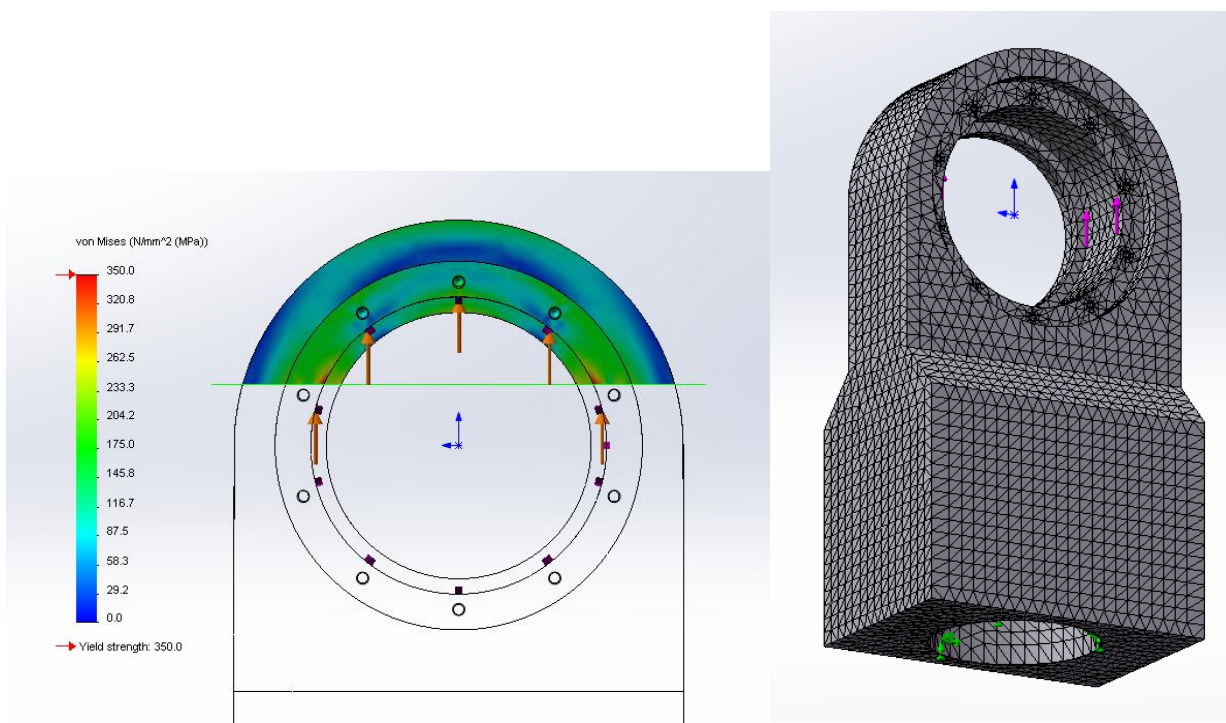
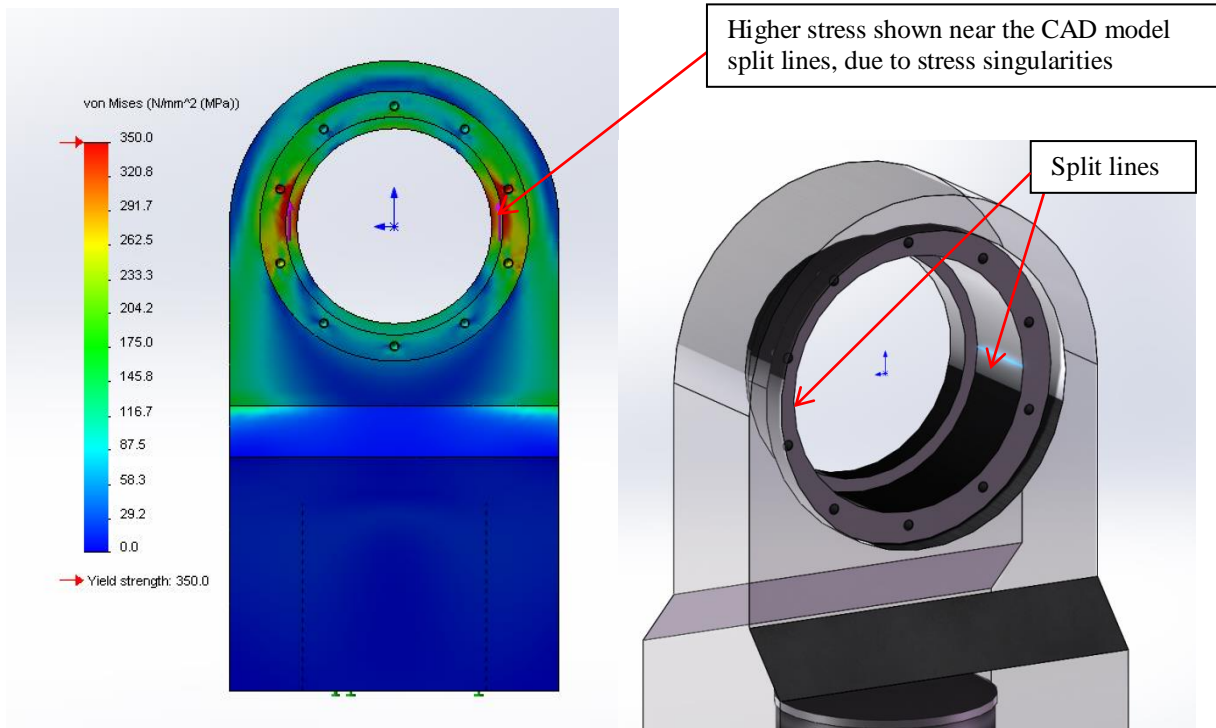
von Mises yield criterion from previous calculation: 138.5 MPa

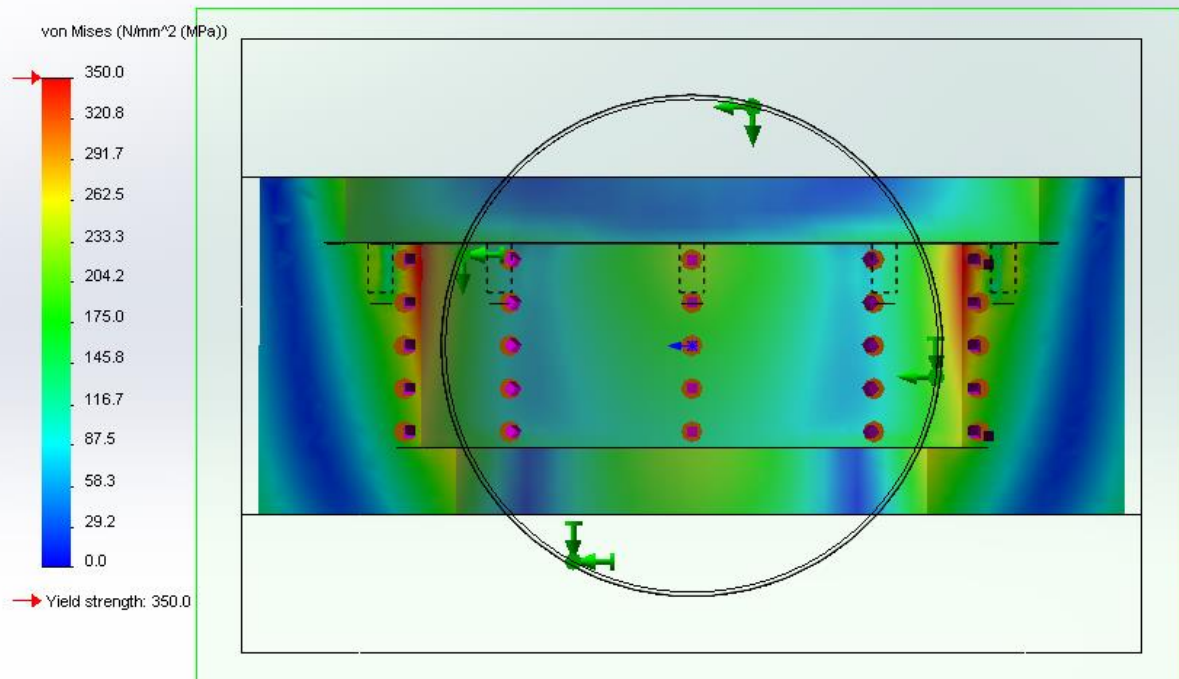
Barrel Material : ST52.3 BK+S Honed tube

Min yield Strength : 520 MPa

Comment: FEA result is within acceptable range of difference, comparing to hand calculation result.

FEA RESULT ON ROD EYE





Total Force applied: 2437 kN

Stress in general: 175 MPa (Ignoring the higher stress concentration near the split lines)

Estimated stress from previous calculation: 162 MPa

Comment: FEA result is within acceptable range of difference, comparing to hand calculation result.

SUMMARY

Below is the summary of our design review

Cylinder load of 2437 kN in retraction (25 MPa working pressure)

Components	Factor of Safety
Cylinder barrel	3.7
Stress in the welds between mounting trunnion and cylinder barrel	8.3
Piston rod buckling	5.8
Piston rod tensile stress	10
Shear stress - threads between piston rod and piston	8.1
Shear stress - threads between piston rod and rod eye	11.4
Tensile stress - SHC screws on head cap	4.3
Tensile stress - SHC screws on end cap	4.3
Shear stress - head cap trunnion	8.1
Tensile stress - rod eye bearing housing	2.1