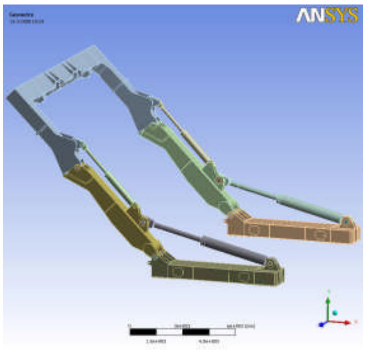
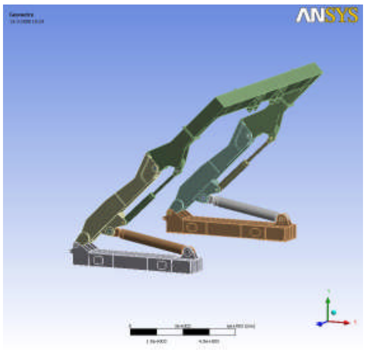
A-frame

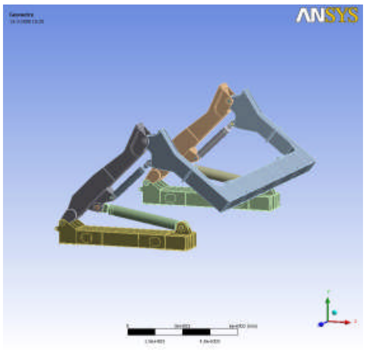
Stress calculations

Report number:	R08010_001
Revision:	0.1
Date:	March 5 2008
Author:	ing. B.P. Dullaart

Ordered by:







Contents

1 Introduction ... 2

2 Criteria and Classifications ... 3

2.1 Load considerations (Lloyds Register §2.2) ... 3
2.2 Load combinations (Lloyds Register §2.16) ... 3
2.3 Allowable stress – Elastic failure (Lloyds Register §2.18) ... 4
2.4 Used materials and their criteria ... 5

3 Stress calculations ... 6

3.1 Inboard Lift ... 7
3.1.1 Geometry ... 7
3.1.2 Connections ... 7
3.1.3 Mesh ... 8
3.1.4 Loadcase: Inboardlift case 1 ... 9
3.1.5 Solution: Inboard lift case 1 ... 11
3.1.6 Loadcase: Inboardlift case 2 ... 13
3.1.7 Solution: Inboardlift case 2 ... 15
3.2 Outboard Lift ... 17
3.2.1 Geometry ... 17
3.2.2 Connections ... 17
3.2.3 Mesh ... 18
3.2.4 Loadcase: Outboardlift case 1 ... 19
3.2.5 Solution: Outboardlift case 1 ... 21
3.2.6 Loadcase: Outboardlift case 2 ... 23
3.2.7 Solution: Outboardlift case 2 ... 25
3.3 Stowed ... 27
3.3.1 Geometry ... 27
3.3.2 Connections ... 27
3.3.3 Mesh ... 28
3.3.4 Loadcase: Stowed ... 29
3.3.5 Solution: Stowed ... 31
3.4 Buckling analysis ... 33
3.5 Shaft calculations ... 34
3.5.1 Shaft 1 ... 35
3.5.2 Shaft 2 ... 35
3.5.3 Shaft 4 ... 36
3.5.4 Shaft 5 ... 36
3.5.5 Shaft 6 ... 37
3.5.6 Shaft 7 ... 37

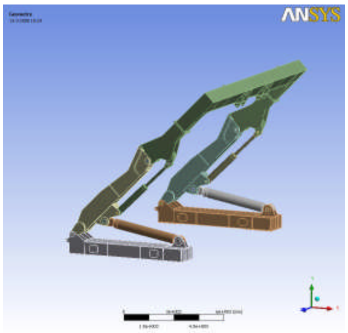
4 Conclusion ... 38

Appendices

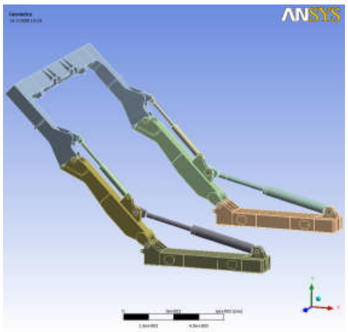
Design criteria ... A

1 Introduction

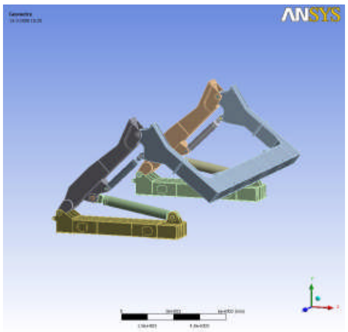
An A-frame is required for maximum lifting load of 35 ton. Several load cases are to be checked for appearing stress levels with a finite elements analysis.



Inboard lift



Outboard lift



Stowed

A specification of the design criteria can be found in appendix A.

2 Criteria and Classifications

The Stress calculations are made according to the Lloyd's Register rules: "Code for Lifting Appliances in a Marine Environment"

2.1 Load considerations (Lloyds Register §2.2)

Consideration is to be given to the utilization and duty of the particular type of crane in the 'in service' condition with respect to the following forces and loads:

a) Dead Loads
b) Live loads
c) Dynamic forces due to the various crane movements
d) Forces du to ship inclination
e) Load swing caused by non-vertical lift
f) Wind forces and environmental effects
g) Loads on access ways, platforms, etc.
h) Snow and ice when considered relevant

2.2 Load combinations (Lloyds Register §2.16)

For the calculation several load combinations are possible:

Case 1 Crane operation without wind
Case 2 Crane operation with wind
Case 3 Crane in stowed condition
Case 4 Crane subjected to exceptional loading

2.3 Allowable stress – Elastic failure (Lloyds Register §2.18)

The allowable stress, σ_a, is to be taken as the failure stress of the component concerned multiplied by a stress factor, Sf, which depends on the load case concerned. The allowable stress is given by the general expression:

$$\sigma_a = Sf \cdot \sigma$$

where
σ_a = allowable stress, in N/mm^2
sf = stress factor
σ = failure stress, in N/mm^2

The stress factor, sf, for steels in which $\frac{\sigma_y}{\sigma_u} \leq 0{,}7$

where
σ_Y = yield stress of material, in N/mm^2
σ_u = ultimate tensile stress of material, in N/mm^2

are given in table below

Load case	1	2	3 and 4
Stress factor, Sf	0,67	0,75	0,85

For steel with $\frac{\sigma_y}{\sigma_u} > 0{,}7$ the allowable stress is to be derived from the following expression:

$$\sigma_a = 0{,}41 Sf \cdot (\sigma_u + \sigma_y)$$

$$\tau_a = 0{,}24 Sf \cdot (\sigma_u + \sigma_y)$$

where
τ_a = allowable shear stress.

The failure stress for the elastic modes of failure are given in table below

Mode of failure	Symbol	Failure stress
Tension	σ_t	$1{,}0\sigma_y$
Compression	σ_c	$1{,}0\sigma_y$
Shear	τ_a	$0{,}58\sigma_y$
Bearing	σ_{br}	$1{,}0\sigma_y$

For components subjected to combined stresses the following allowable stress criteria are to be used:
(a) $\sigma_{xx} < Sf\sigma_t$
(b) $\sigma_{yy} < Sf\sigma_t$
(c) $\tau_O < Sf\tau$
(d) $\sigma = (\sigma_{xx}^2 + \sigma_{yy}^2 - \sigma_{xx}\,\sigma_{yy} + 3\tau_O^2)^{1/2} \leq 1{,}1 Sf\sigma_t$
where
σ_{xx} = applied stress in x direction, in N/mm^2
σ_{yy} = applied stress in y direction, in N/mm^2
τ_O = applied shear stress, in N/mm^2.

2.4 Used materials and their criteria

- The construction can be fabricated out of the material **S355J2G3** (St.52-3) with the following specifications:

$\sigma_u = 520 \, N/mm^2$ and $\sigma_y = 355 \, N/mm^2$

$$\frac{\sigma_y}{\sigma_u} = \frac{355}{520} = 0,68 \leq 0,7$$

For load combination 2 the maximum allowable stresses are calculated to
$\sigma_a = Sf \cdot \sigma_y = 0,75 \cdot 355 = 266 \, N/mm^2$

For load combination 3 the maximum allowable stresses are calculated to
$\sigma_a = Sf \cdot \sigma_y = 0,85 \cdot 355 = 301 \, N/mm^2$

- The construction can be fabricated out of the material **42CrMo4** 100-160mm with the following specifications:

$\sigma_u = 800 \, N/mm^2$ and $\sigma_y = 550 \, N/mm^2$

$$\frac{\sigma_y}{\sigma_u} = \frac{550}{800} = 0,69 \leq 0,7$$

For load combination 2 the maximum allowable stresses are calculated to
$\sigma_a = Sf \cdot \sigma_y = 0,75 \cdot 550 = 412 \, N/mm^2$

- The construction can be fabricated out of the material **42CrMo4** 160-250mm with the following specifications:

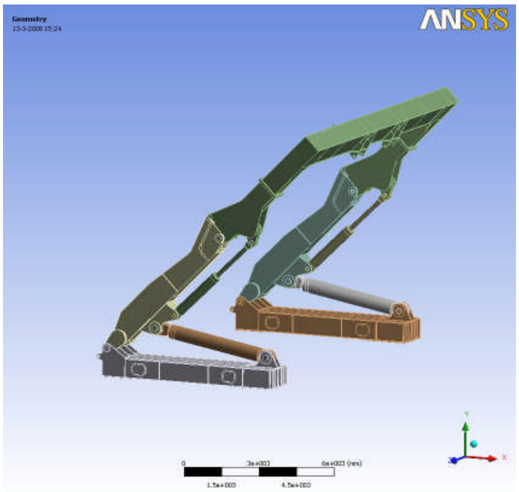
$\sigma_u = 750 \, N/mm^2$ and $\sigma_y = 500 \, N/mm^2$

$$\frac{\sigma_y}{\sigma_u} = \frac{500}{750} = 0,67 \leq 0,7$$

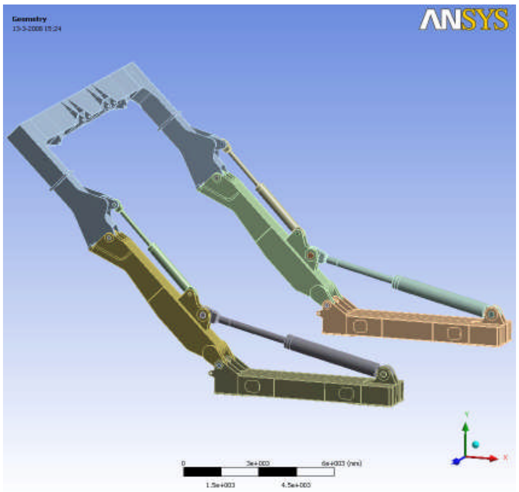
For load combination 2 the maximum allowable stresses are calculated to
$\sigma_a = Sf \cdot \sigma_y = 0,75 \cdot 500 = 375 \, N/mm^2$

3 Stress calculations

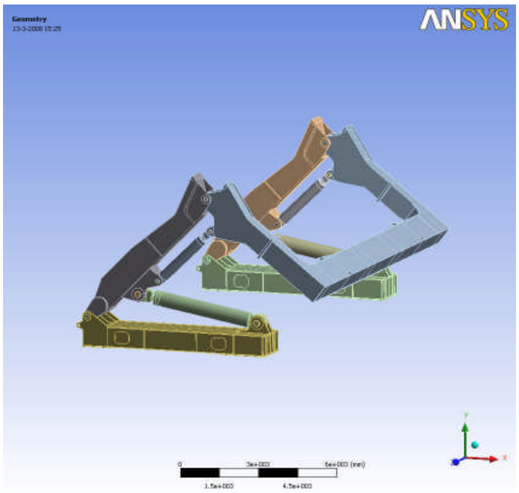
The stress calculations are made for 5 different load cases. Each load case is being checked for inadmissible stress levels. The design criteria can be found in appendix A.



Inboard lift case 1 and case 2



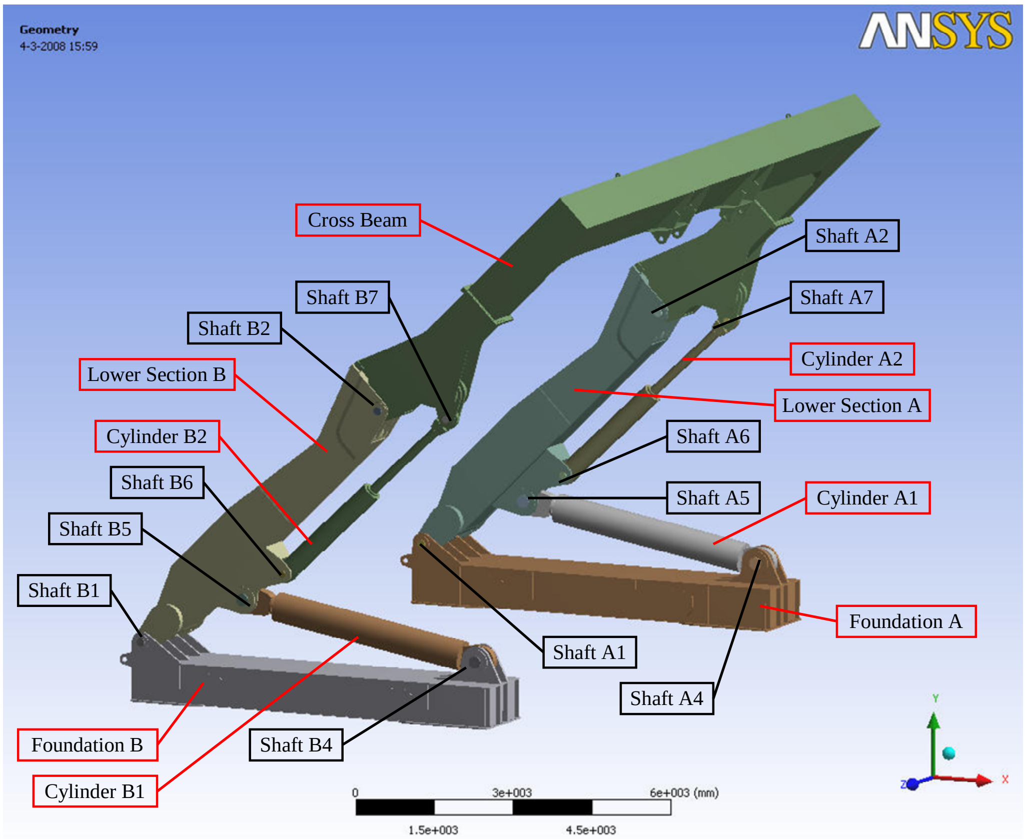
Outboard lift case 1 and case 2



Stowed

3.1 Inboard Lift

3.1.1 Geometry



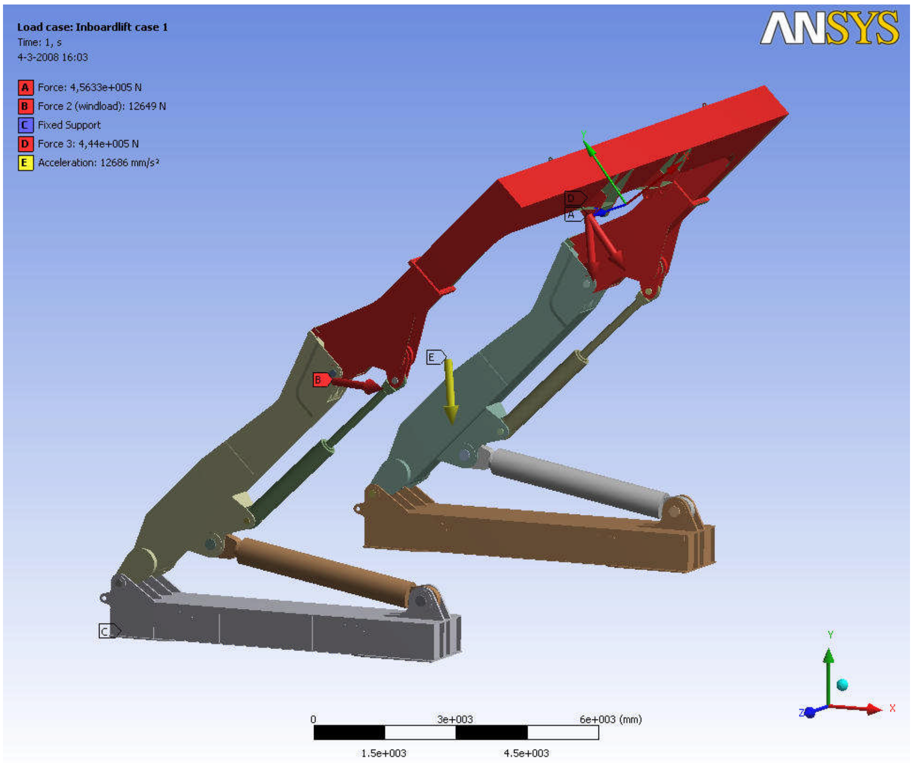
3.1.2 Connections

Object name	Type
Cross Beam To Lower Section A	No Separation
Cross Beam To Shaft A2	No Separation
Cross Beam To Cylinder A2	No Separation
Cross Beam To Shaft A2	No Separation
Cross Beam To Shaft A7	Bonded
Cross Beam To Lower section B	No Separation
Cross Beam To Shaft B2	No Separation
Cross Beam To Cylinder B2	No Separation
Cross Beam To Shaft B2	No Separation
Cross Beam To Shaft B7	Bonded
Foundation A To Lower Section A	No Separation
Foundation A To Shaft A1	Bonded
Foundation A To Cylinder A1	No Separation
Foundation A To Shaft A4	Bonded
Lower Section A To Shaft A1	No Separation
Lower Section A To Shaft A2	Bonded
Lower Section A To Cylinder A2	No Separation
Lower Section A To Cylinder A1	No Separation
Lower Section A To Shaft A5	Bonded
Lower Section A To Shaft A6	Bonded
Lower Section A To Shaft A2	Bonded

Object name	Type
Cylinder A2 To Shaft A6	No Separation
Cylinder A2 To Shaft A7	No Separation
Cylinder A1 To Shaft A5	No Separation
Cylinder A1 To Shaft A4	No Separation
Foundation B To Lower section B	No Separation
Foundation B To Shaft B1	Bonded
Foundation B To Cylinder B1	No Separation
Foundation B To Shaft B4	Bonded
Lower section B To Shaft B1	No Separation
Lower section B To Shaft B2	Bonded
Lower section B To Cylinder B2	No Separation
Lower section B To Cylinder B1	No Separation
Lower section B To Shaft B5	Bonded
Lower section B To Shaft B6	Bonded
Lower section B To Shaft B2	Bonded
Cylinder B2 To Shaft B6	No Separation
Cylinder B2 To Shaft B7	No Separation
Cylinder B1 To Shaft B5	No Separation
Cylinder B1 To Shaft B4	No Separation

3.1.3 Mesh

3.1.4 Loadcase: Inboardlift case 1



$Force$

$F_y = -423 \cdot 10^3 - 21 \cdot 10^3 = -444 \cdot 10^3\ N$

$(= designload + vertical\ vessel\ motion\ on\ SWL)$

$F_x = 22 \cdot 10^3 + 8 \cdot 10^3 + 46 \cdot 10^3 = 76 \cdot 10^3\ N$

$(= transverse\ offlead + transverse\ windload\ on\ load + transverse\ vessel\ motion\ on\ SWL)$

$F_z = 44 \cdot 10^3 + 4 \cdot 10^3 + 25 \cdot 10^3 = 73 \cdot 10^3\ N$

$(= longitudinal\ offlead + longitudinal\ windload\ on\ load + longitudinal\ vessel\ motion\ on\ SWL)$

$Force\ 2:\ Windload\ on\ structure$

$F_x = 12 \cdot 10^3\ N \quad (transverse\ windload\ on\ structure)$

$F_z = 4 \cdot 10^3\ N \quad (longitudinal\ windload\ on\ structure)$

$Force\ 3:\ From\ top\ sheave\ to\ deck\ level\ in\ angle\ 52°$

$F_{52°} = -444 \cdot 10^3\ N$

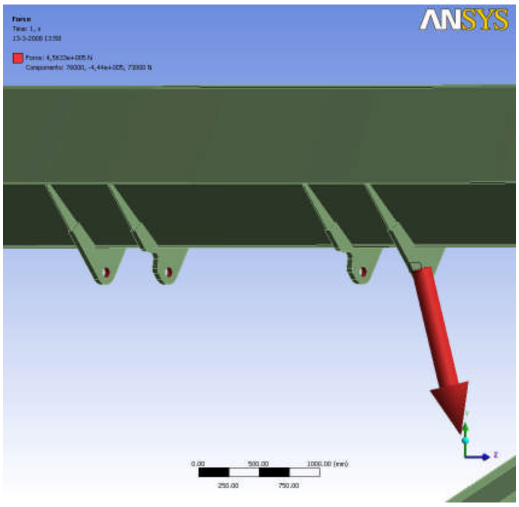
$(= F_y\ \ from\ top\ sheave\ to\ deck\ level\ in\ angle\ 52°)$

$Acceleration\ /\ vessel\ motions$

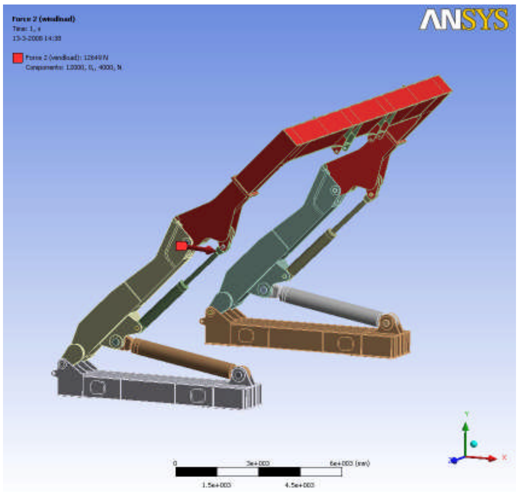
$a_y = -600 + 1{,}2 \cdot -10000 = -12600\ mm/s^2 \quad (vertical\ acceleration + 1{,}2 \cdot gravity)$

$a_x = 1300\ mm/s^2 \quad (transverse\ acceleration)$

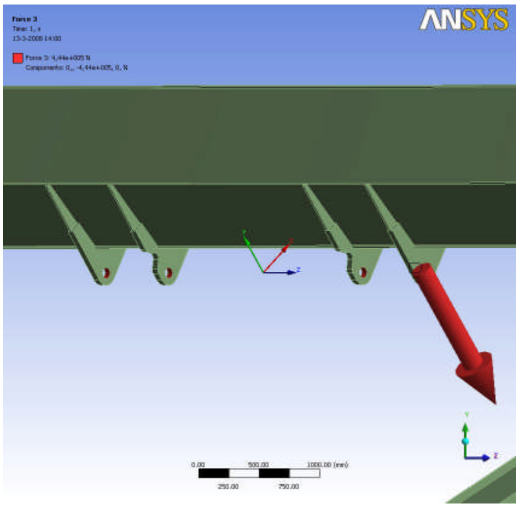
$a_z = 700\ mm/s^2 \quad (longitudinal\ acceleration)$



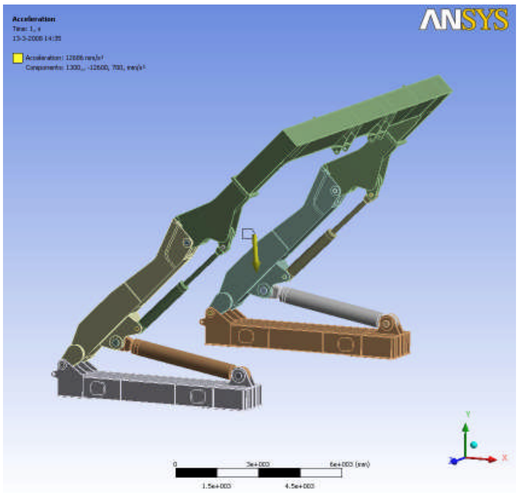
Force (areas marked red)



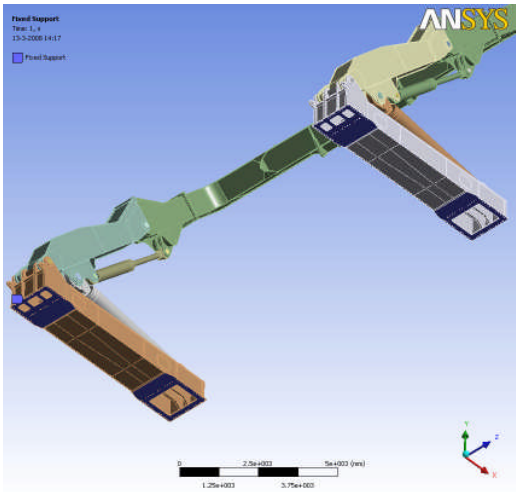
Force 2, wind load (areas marked red)



Force 3 (areas marked red) from top sheave to deck level in angle 52°



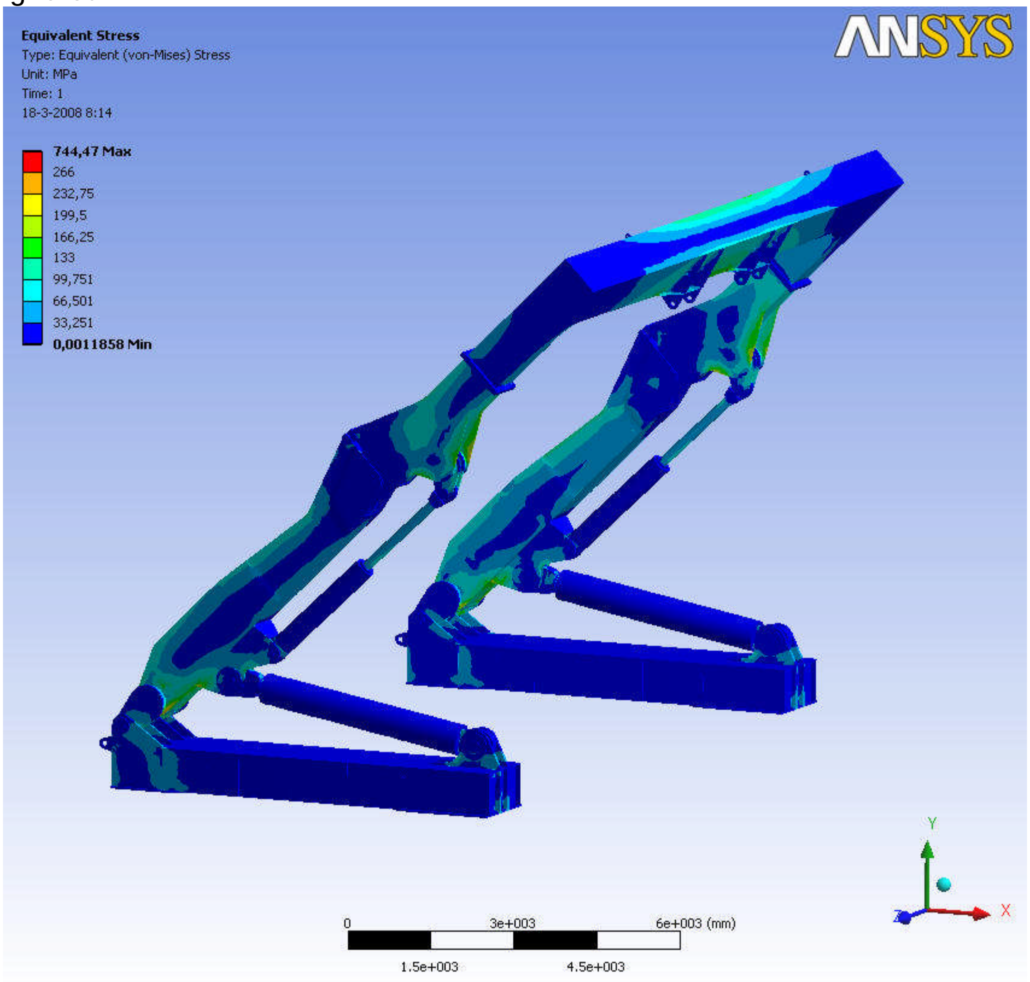
Acceleration (all bodies)



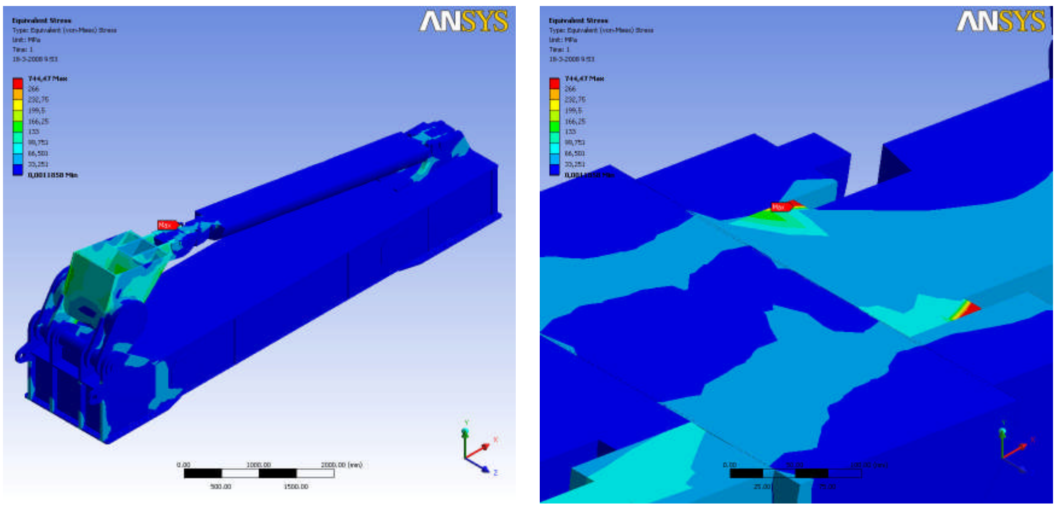
Fixed Support (areas marked blue)

3.1.5 Solution: Inboard lift case 1

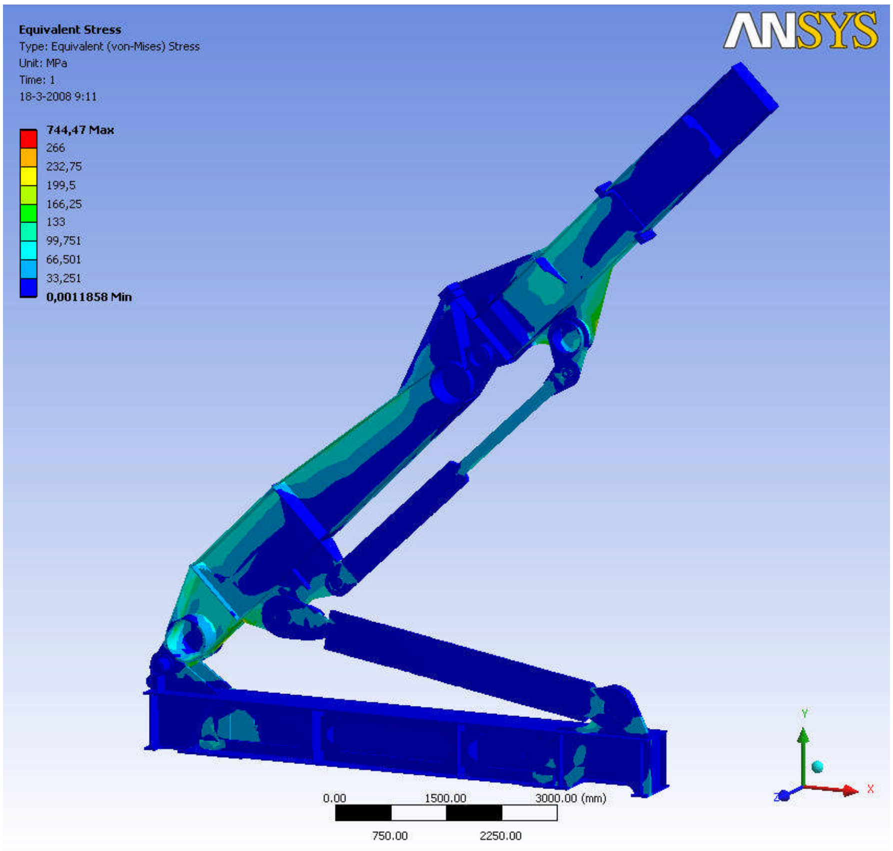
Stress levels are shown in the figures below. For this load case a maximum allowable stress is 266 N/mm^2 (see §2.2). Inadmissible stress levels are marked in the color red. A maximum peak stress of 744,47 N/mm^2 is found, but this is probably a result of singularity in the model. Therefore this peak stress can be ignored.



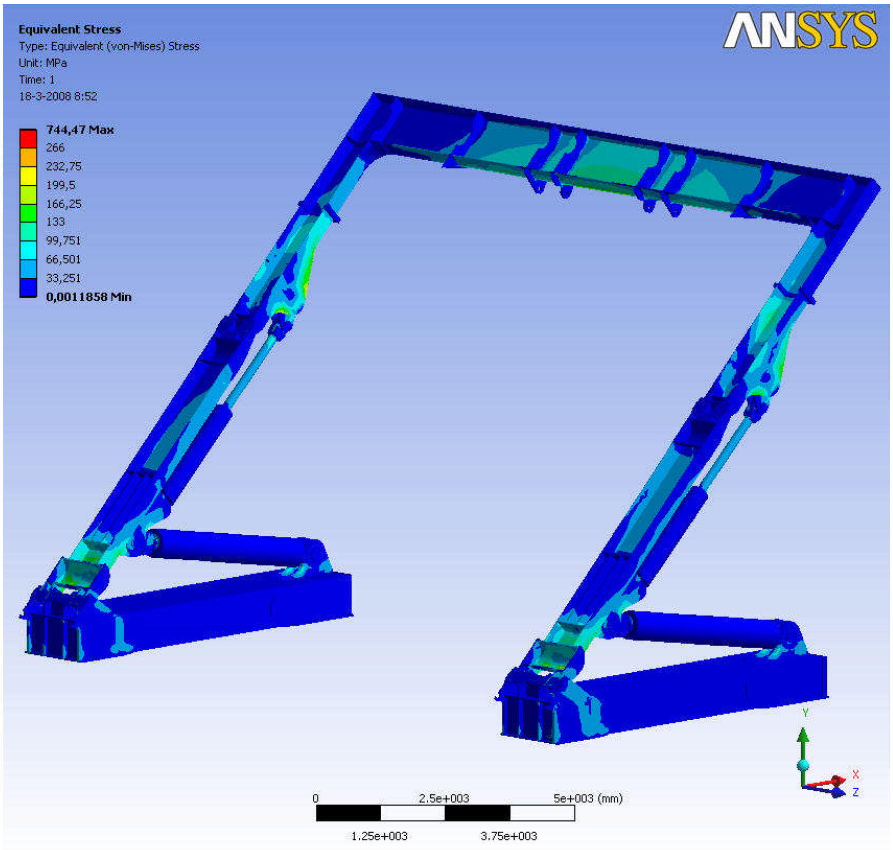
Equivalent stress levels (total overview)



Location peak stress

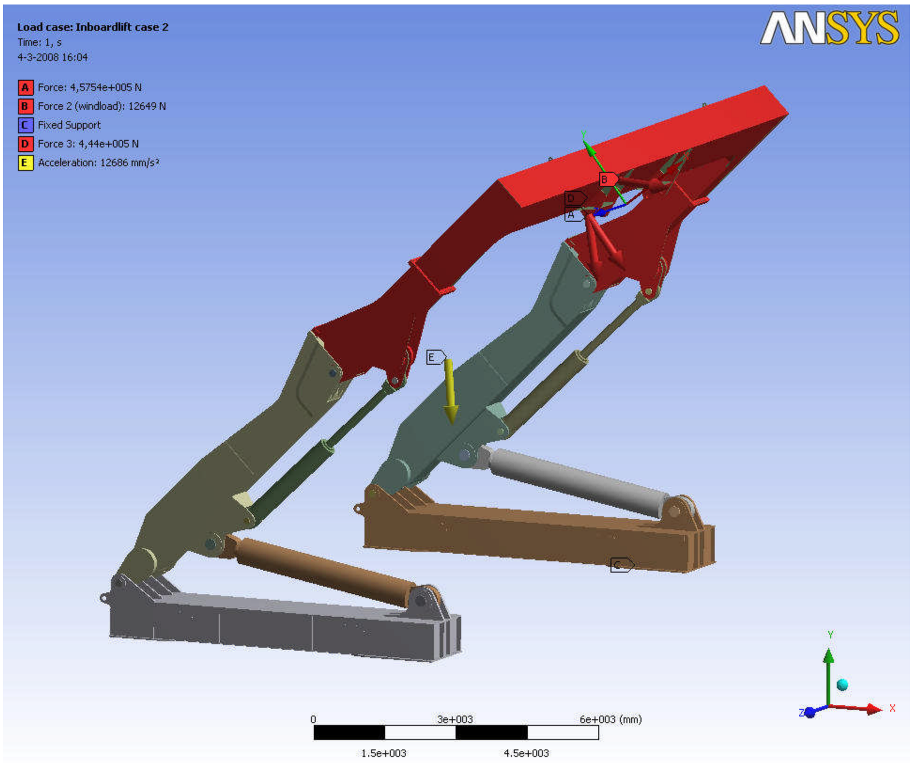


Equivalent stress levels (section view 1)



Equivalent stress levels (section view 2)

3.1.6 Loadcase: Inboardlift case 2



Force

$F_y = -423 \cdot 10^3 - 21 \cdot 10^3 = -444 \cdot 10^3\,N$

$(= designload + vertical\ vessel\ motion\ on\ SWL)$

$F_x = 44 \cdot 10^3 + 8 \cdot 10^3 + 46 \cdot 10^3 = 98 \cdot 10^3\,N$

$(= transverse\ offlead + transverse\ windload\ on\ load + transverse\ vessel\ motion\ on\ SWL)$

$F_z = 22 \cdot 10^3 + 4 \cdot 10^3 + 25 \cdot 10^3 = 51 \cdot 10^3\,N$

$(= longitudinal\ offlead + longitudinal\ windload\ on\ load + longitudinal\ vessel\ motion\ on\ SWL)$

Force 2: Windload on structure

$F_x = 12 \cdot 10^3\,N \quad (transverse\ windload\ on\ structure)$

$F_z = 4 \cdot 10^3\,N \quad (longitudinal\ windload\ on\ structure)$

Force 3: From top sheave to deck level in angle 52°

$F_{52^\circ} = -444 \cdot 10^3\,N F_{52^\circ} = -444 \cdot 10^3\,N$

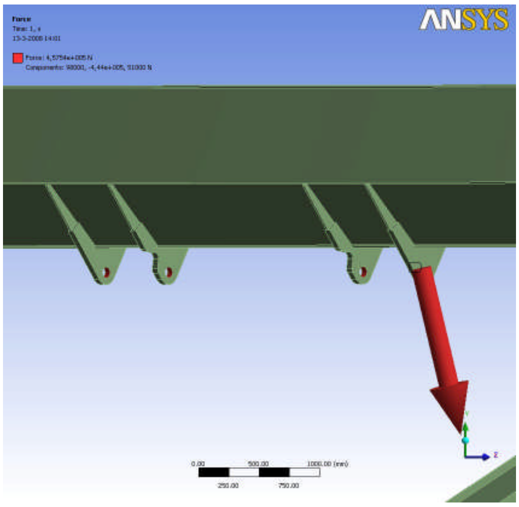
$(= F_y\ from\ top\ sheave\ to\ deck\ level\ in\ angle\ 52^\circ)$

Acceleration / vessel motions

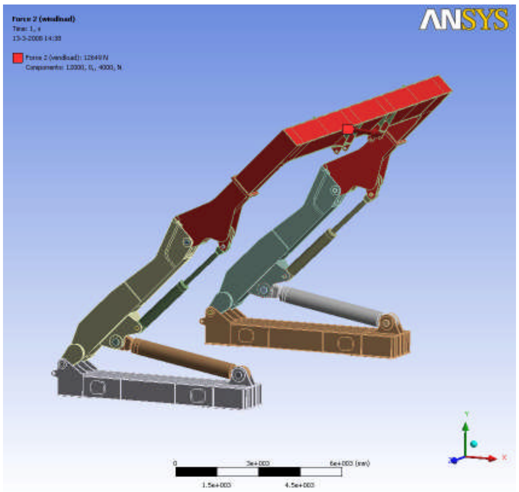
$a_y = -600 + 1{,}2 \cdot -10000 = -12600\ mm/s^2 \quad (vertical\ acceleration + 1{,}2 \cdot gravity)$

$a_x = 1300\ mm/s^2 \quad (transverse\ acceleration)$

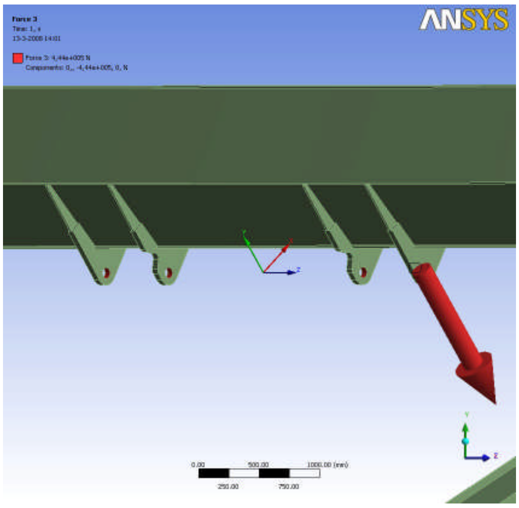
$a_z = 700\ mm/s^2 \quad (longitudinal\ acceleration)$



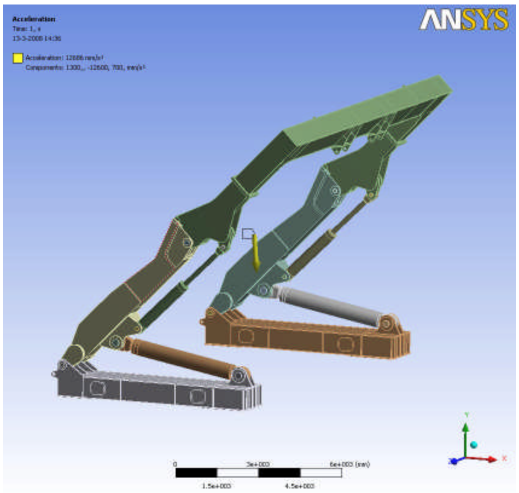
Force (areas marked red)



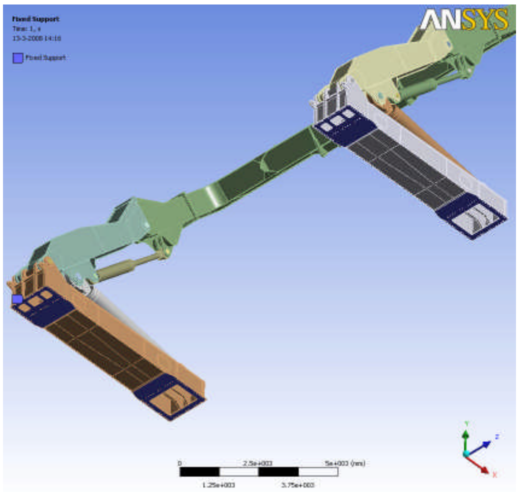
Force 2, wind load (areas marked red)



Force 3 (areas marked red) from top sheave to deck level in angle 52°



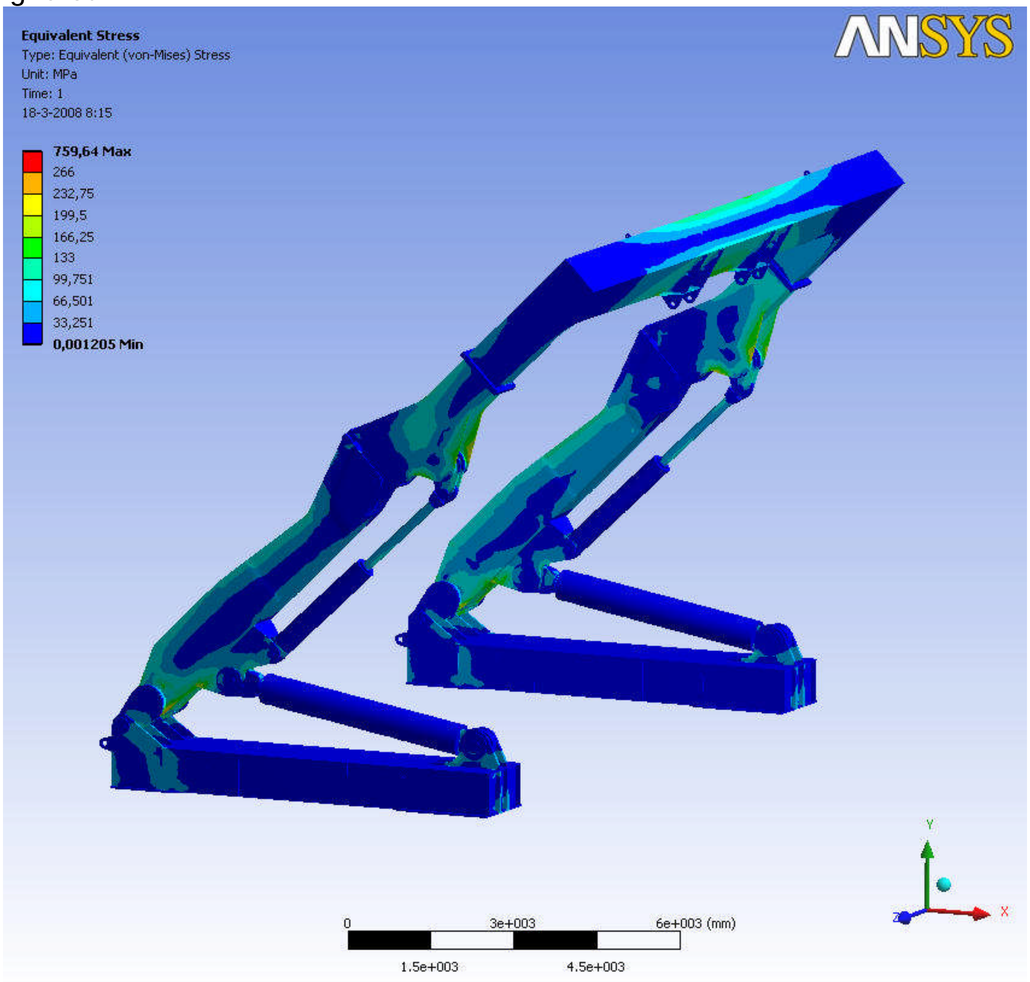
Acceleration (all bodies)



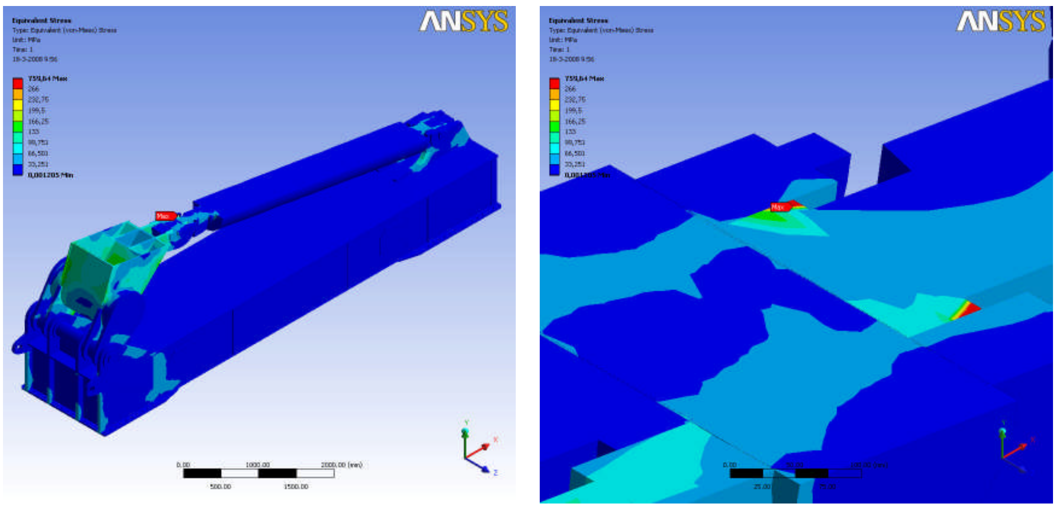
Fixed Support (areas marked blue)

3.1.7 Solution: Inboardlift case 2

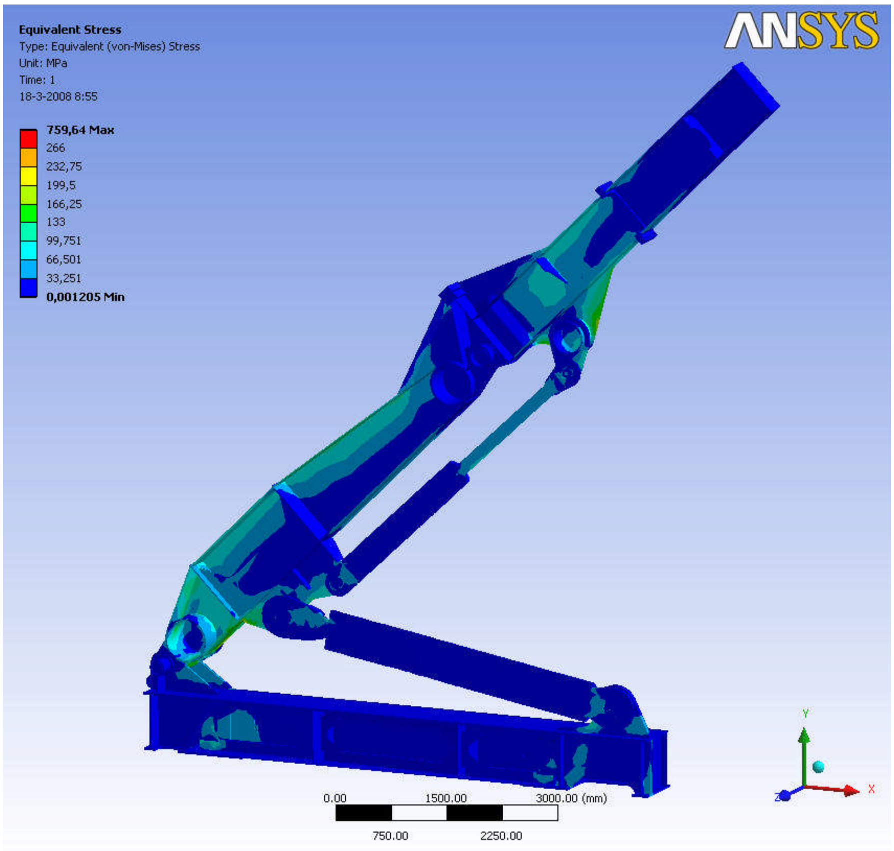
Stress levels are shown in the figures below. For this load case a maximum allowable stress is 266 N/mm^2 (see §2.2). Inadmissible stress levels are marked in the color red. A maximum peak stress of 759,64 N/mm^2 is found, but this is probably a result of singularity in the model. Therefore this peak stress can be ignored.



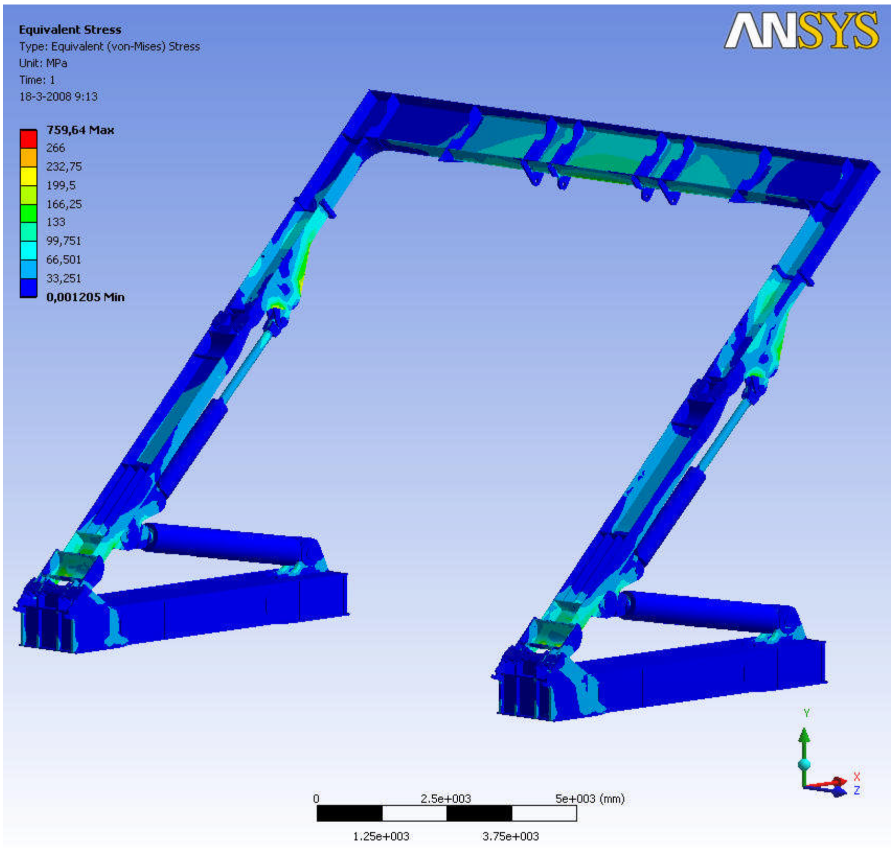
Equivalent stress levels (total overview)



Location peak stress



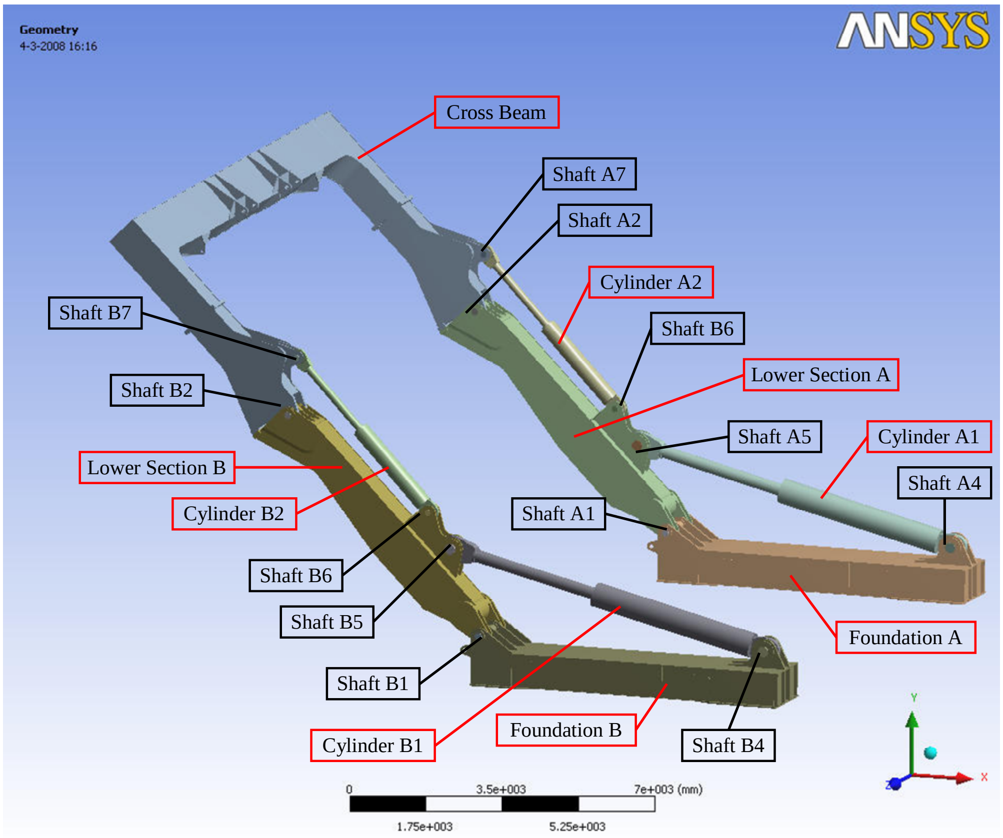
Equivalent stress levels (section view 1)



Equivalent stress levels (section view 2)

3.2 Outboard Lift

3.2.1 Geometry

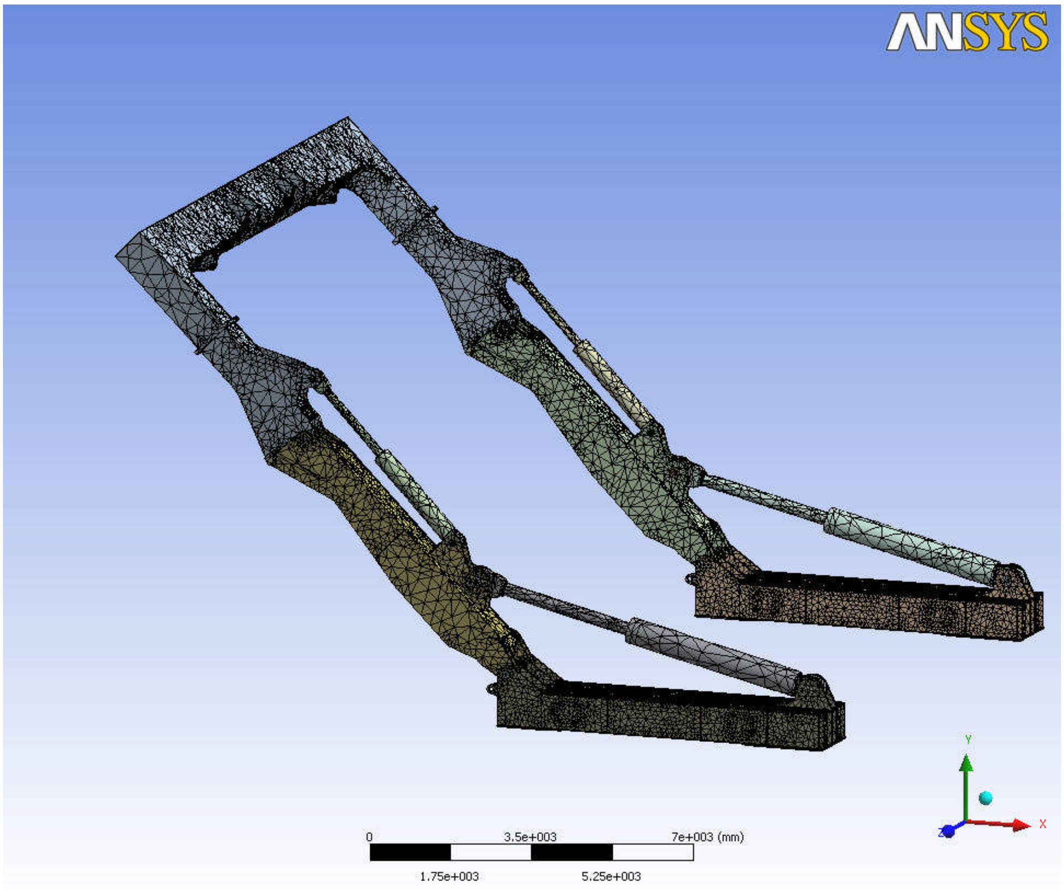


3.2.2 Connections

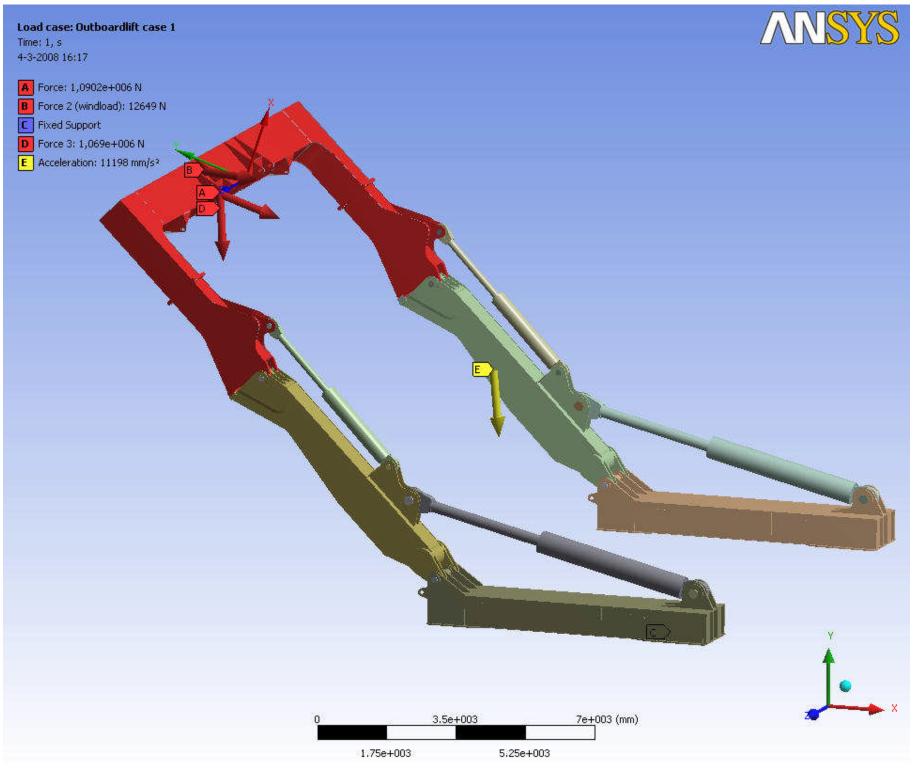
Object name	Type
Cross Beam To Lower Section A	No Separation
Cross Beam To Shaft A2	No Separation
Cross Beam To Cylinder A2	No Separation
Cross Beam To Shaft A2	No Separation
Cross Beam To Shaft A7	Bonded
Cross Beam To Lower section B	No Separation
Cross Beam To Shaft B2	No Separation
Cross Beam To Cylinder B2	No Separation
Cross Beam To Shaft B2	No Separation
Cross Beam To Shaft B7	Bonded
Foundation A To Lower Section A	No Separation
Foundation A To Shaft A1	Bonded
Foundation A To Cylinder A1	No Separation
Foundation A To Shaft A4	Bonded
Lower Section A To Shaft A1	No Separation
Lower Section A To Shaft A2	Bonded
Lower Section A To Cylinder A2	No Separation
Lower Section A To Cylinder A1	No Separation
Lower Section A To Shaft A5	Bonded
Lower Section A To Shaft A6	Bonded
Lower Section A To Shaft A2	Bonded

Object name	Type
Cylinder A2 To Shaft A6	No Separation
Cylinder A2 To Shaft A7	No Separation
Cylinder A1 To Shaft A5	No Separation
Cylinder A1 To Shaft A4	No Separation
Foundation B To Lower section B	No Separation
Foundation B To Shaft B1	Bonded
Foundation B To Cylinder B1	No Separation
Foundation B To Shaft B4	Bonded
Lower section B To Shaft B1	No Separation
Lower section B To Shaft B2	Bonded
Lower section B To Cylinder B2	No Separation
Lower section B To Cylinder B1	No Separation
Lower section B To Shaft B5	Bonded
Lower section B To Shaft B6	Bonded
Lower section B To Shaft B2	Bonded
Cylinder B2 To Shaft B6	No Separation
Cylinder B2 To Shaft B7	No Separation
Cylinder B1 To Shaft B5	No Separation
Cylinder B1 To Shaft B4	No Separation

3.2.3 Mesh



3.2.4 Loadcase: Outboardlift case 1



$Force$

$F_y = -1048 \cdot 10^3 - 21 \cdot 10^3 = -1069 \cdot 10^3\, N$

$(= designload + vertical\ vessel\ motion\ on\ SWL)$

$F_x = 73 \cdot 10^3 + 8 \cdot 10^3 + 46 \cdot 10^3 = 123 \cdot 10^3\, N$

$(= transverse\ offlead + transverse\ windload\ on\ load + transverse\ vessel\ motion\ on\ SWL)$

$F_z = 146 \cdot 10^3 + 4 \cdot 10^3 + 25 \cdot 10^3 = 175 \cdot 10^3\, N$

$(= longitudinal\ offlead + longitudinal\ windload\ on\ load + longitudinal\ vessel\ motion\ on\ SWL)$

$Force\ 2: Windload\ on\ structure$

$F_x = 12 \cdot 10^3\, N \quad (transverse\ windload\ on\ structure)$

$F_z = 4 \cdot 10^3\, N \quad (longitudinal\ windload\ on\ structure)$

$F_{18,5°} = -1069 \cdot 10^3\, N$

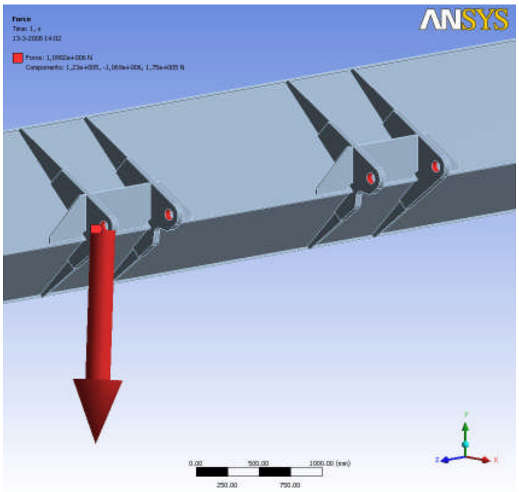
$(= F_y\ \ from\ top\ sheave\ to\ deck\ level\ in\ angle\ 18{,}5°)$

$Acceleration\ /\ vessel\ motions$

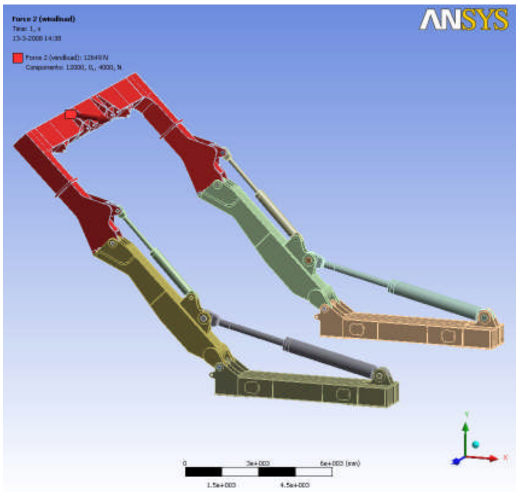
$a_y = -600 + 1{,}05 \cdot -10000 = -11100\ mm/s^2 \quad (vertical\ acceleration + 1{,}05 \cdot gravity)$

$a_x = 1300\ mm/s^2 \quad (transverse\ acceleration)$

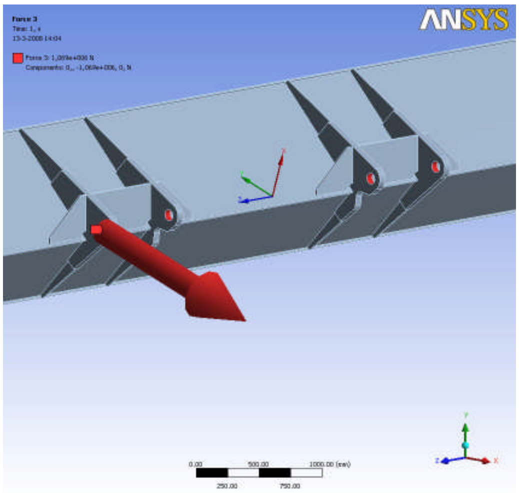
$a_z = 700\ mm/s^2 \quad (longitudinal\ acceleration)$



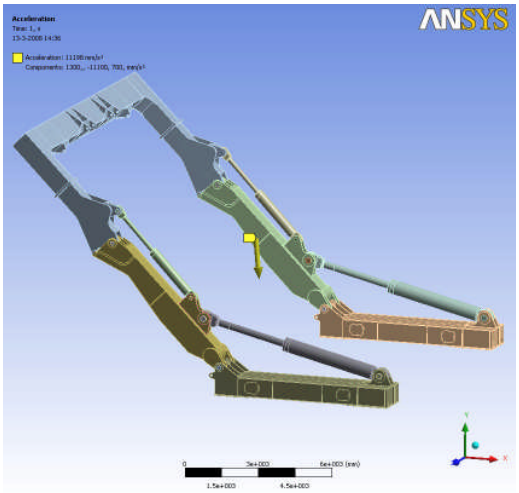
Force (areas marked red)



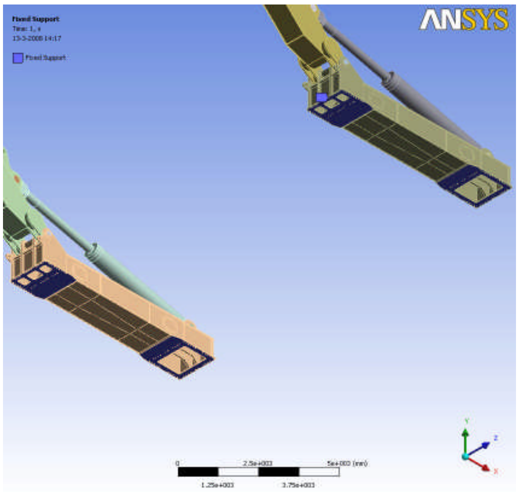
Force 2, wind load (areas marked red)



Force 3 (areas marked red) from top sheave to deck level in angle 52°



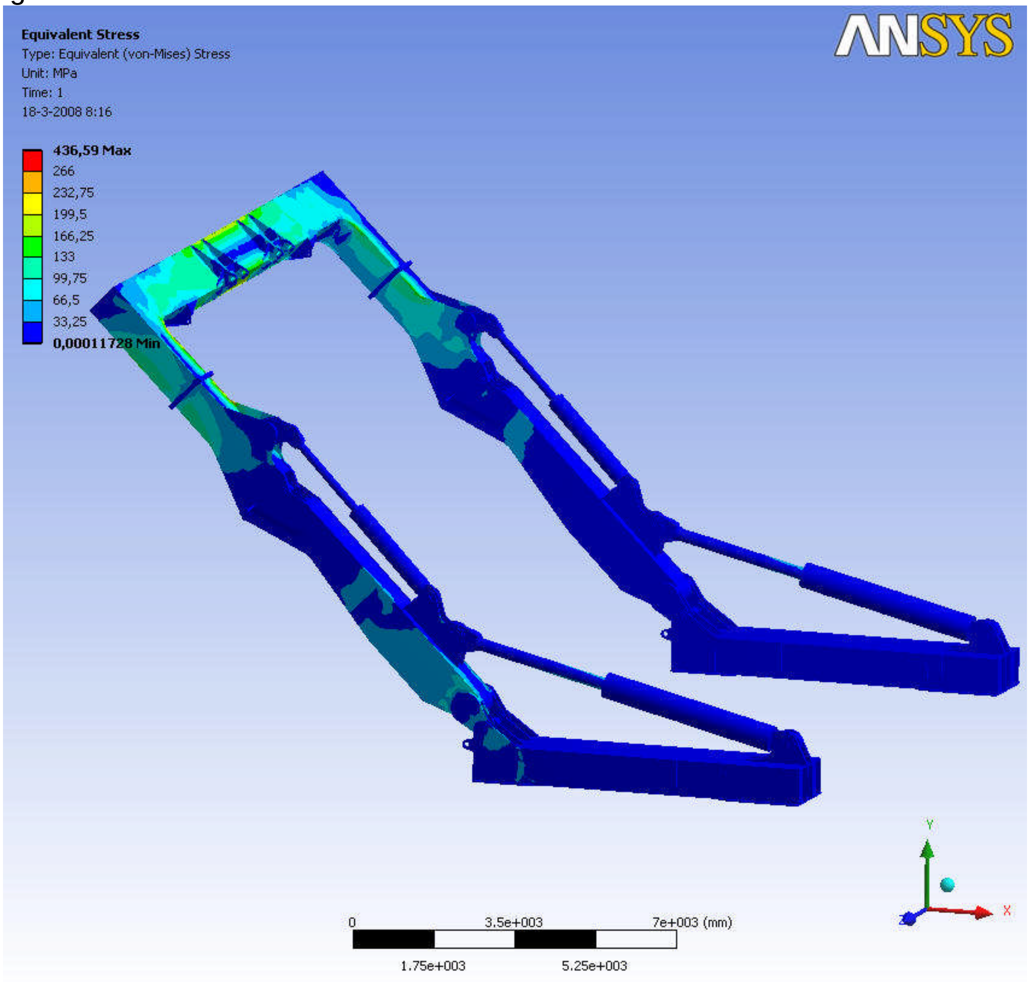
Acceleration (all bodies)



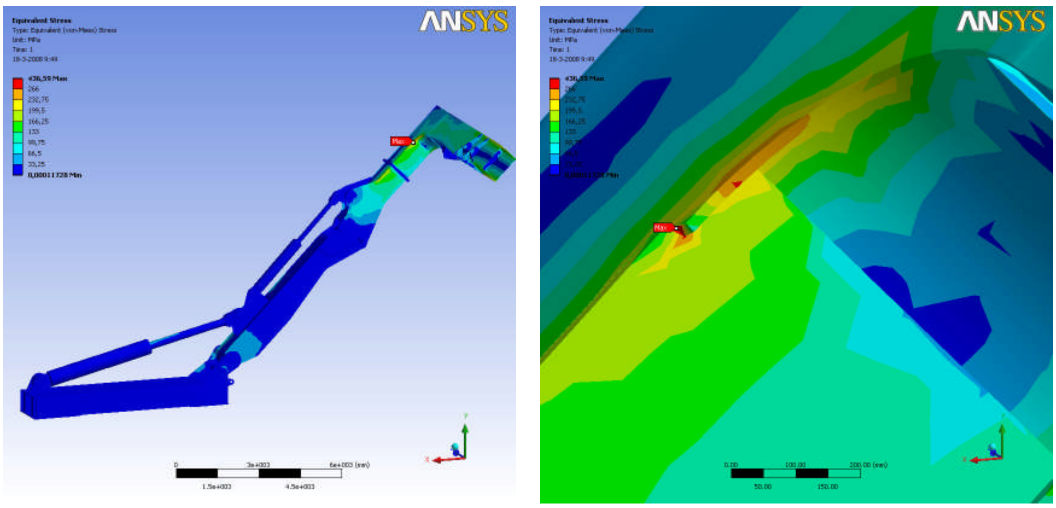
Fixed Support (areas marked blue)

3.2.5 Solution: Outboardlift case 1

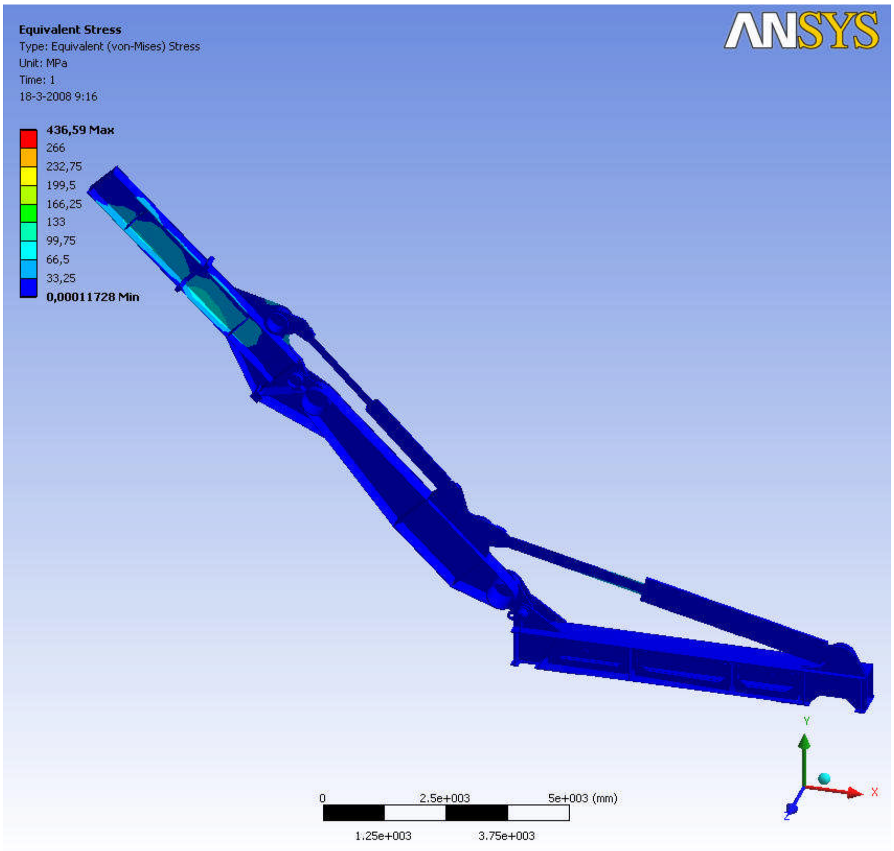
Stress levels are shown in the figures below. For this load case a maximum allowable stress is 266 N/mm^2 (see §2.2). Inadmissible stress levels are marked in the color red. A maximum peak stress of 436,59 N/mm^2 is found, but this is probably a result of singularity in the model. Therefore this peak stress can be ignored.



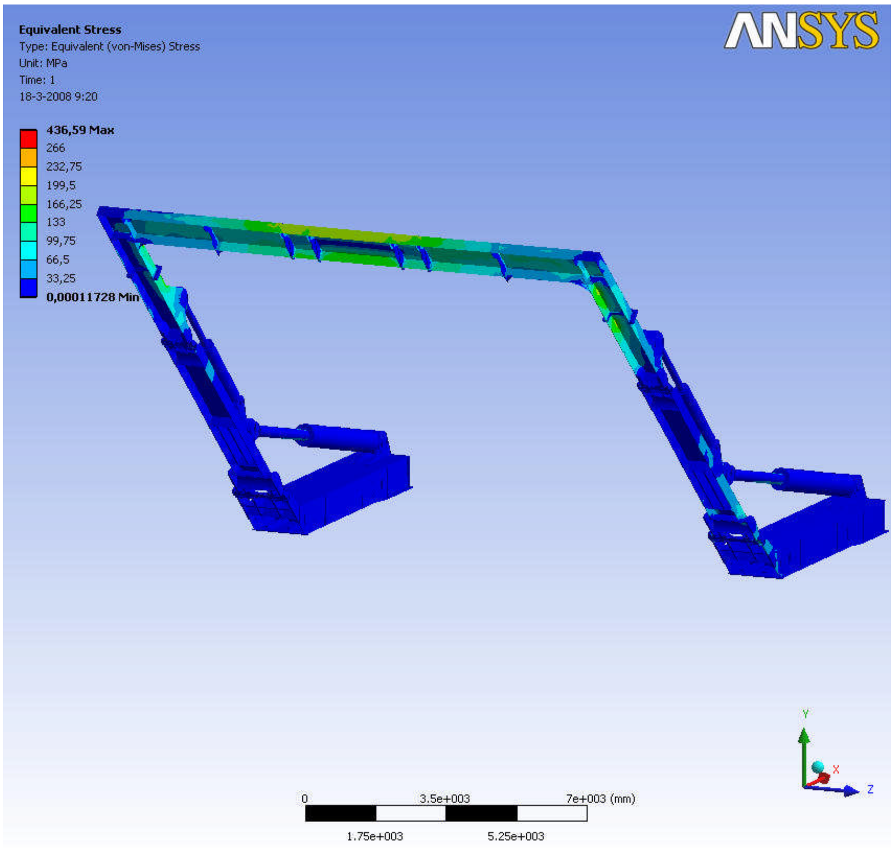
Equivalent stress levels (total overview)



Location peak stress

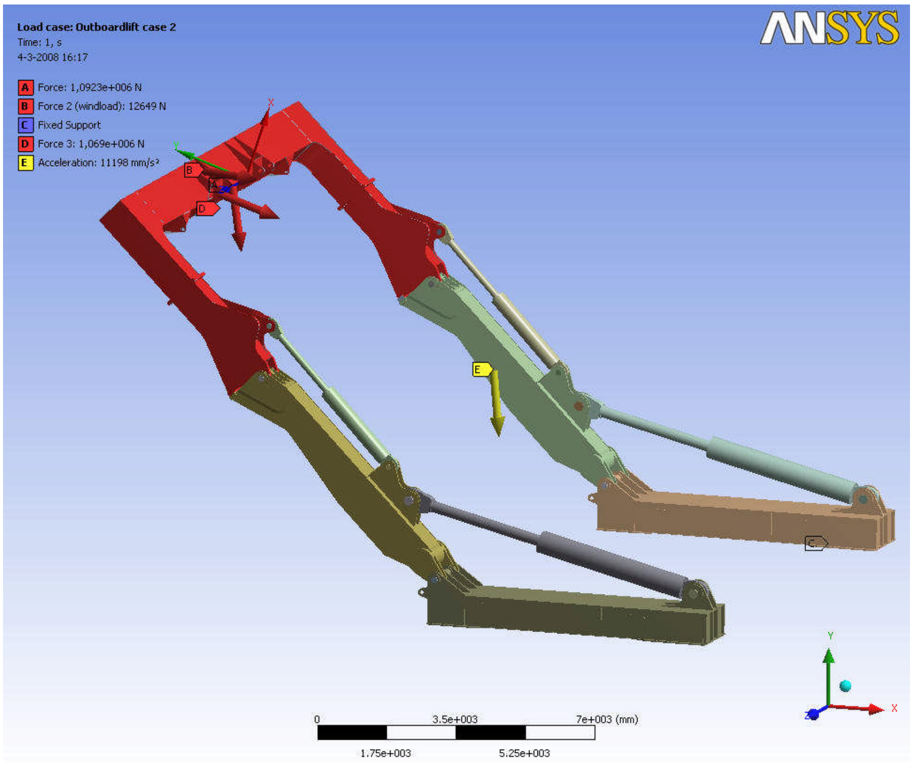


Equivalent stress levels (section view 1)



Equivalent stress levels (section view 2)

3.2.6 Loadcase: Outboardlift case 2



Force

$F_y = -1048 \cdot 10^3 - 21 \cdot 10^3 = -1069 \cdot 10^3\, N$

$(= designload + vertical\ vessel\ motion\ on\ SWL)$

$F_x = 146 \cdot 10^3 + 8 \cdot 10^3 + 46 \cdot 10^3 = 200 \cdot 10^3\, N$

$(= transverse\ offlead + transverse\ windload\ on\ load + transverse\ vessel\ motion\ on\ SWL)$

$F_z = 73 \cdot 10^3 + 4 \cdot 10^3 + 25 \cdot 10^3 = 102 \cdot 10^3\, N$

$(= longitudinal\ offlead + longitudinal\ windload\ on\ load + longitudinal\ vessel\ motion\ on\ SWL)$

Force 2: Windload on structure

$F_x = 12 \cdot 10^3\, N \quad (transverse\ windload\ on\ structure)$

$F_z = 4 \cdot 10^3\, N \quad (longitudinal\ windload\ on\ structure)$

$F_{18,5°} = -1069 \cdot 10^3\, N$

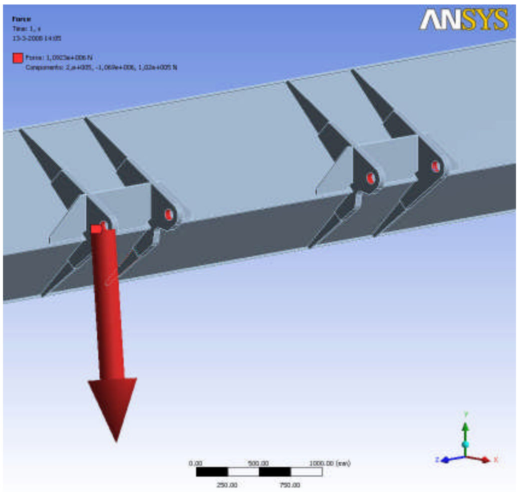
$(= F_y\ \ from\ top\ sheave\ to\ deck\ level\ in\ angle\ 18{,}5°)$

Acceleration / vessel motions

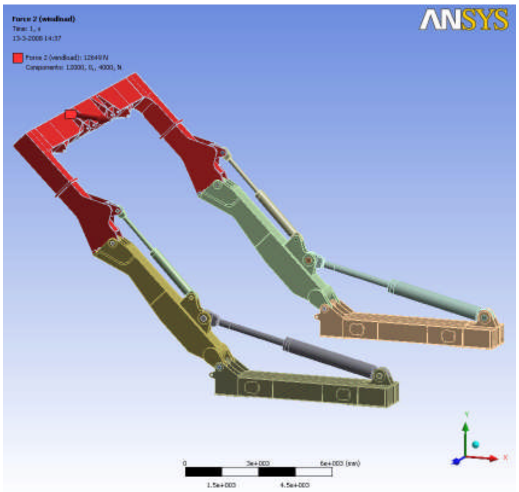
$a_y = -600 + 1{,}05 \cdot -10000 = -11100\ mm/s^2 \quad (vertical\ acceleration + 1{,}05 \cdot gravity)$

$a_x = 1300\ mm/s^2 \quad (transverse\ acceleration)$

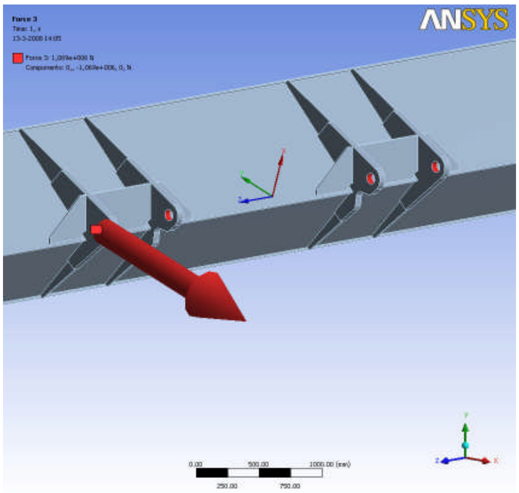
$a_z = 700\ mm/s^2 \quad (longitudinal\ acceleration)$



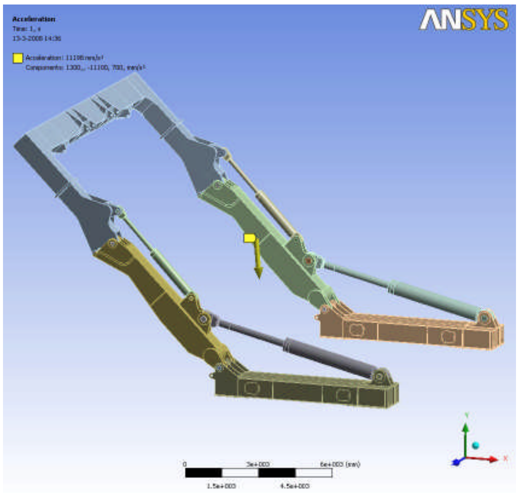
Force (areas marked red)



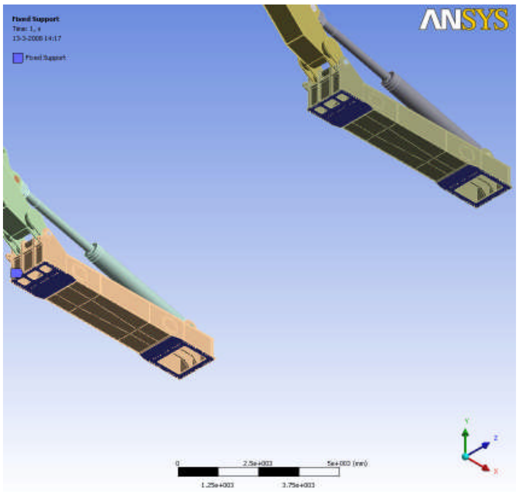
Force 2, wind load (areas marked red)



Force 3 (areas marked red) from top sheave to deck level in angle 52°



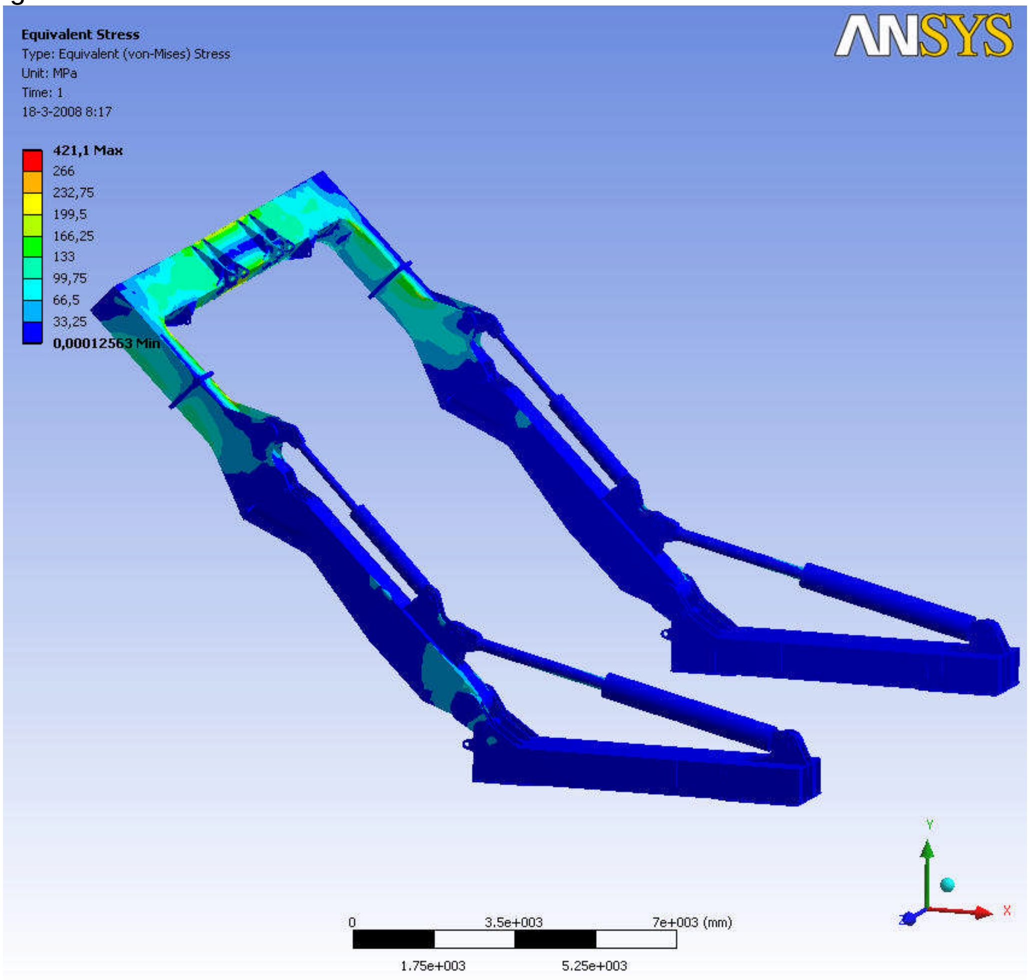
Acceleration (all bodies)



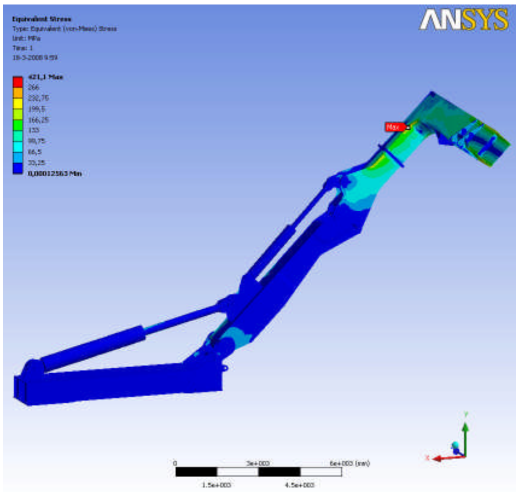
Fixed Support (areas marked blue)

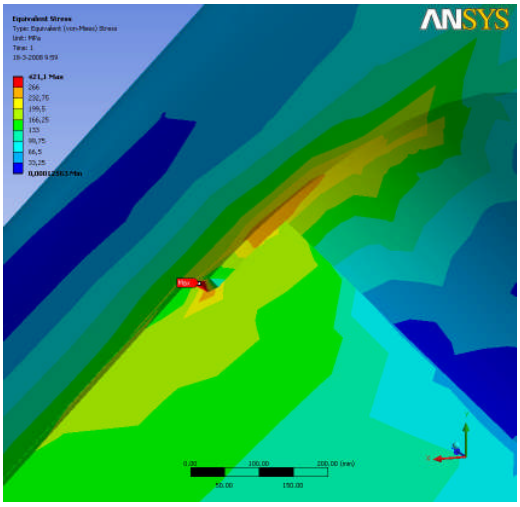
3.2.7 Solution: Outboardlift case 2

Stress levels are shown in the figures below. For this load case a maximum allowable stress is 266 N/mm^2 (see §2.2). Inadmissible stress levels are marked in the color red. A maximum peak stress of 421,1 N/mm^2 is found, but this is probably a result of singularity in the model. Therefore this peak stress can be ignored.

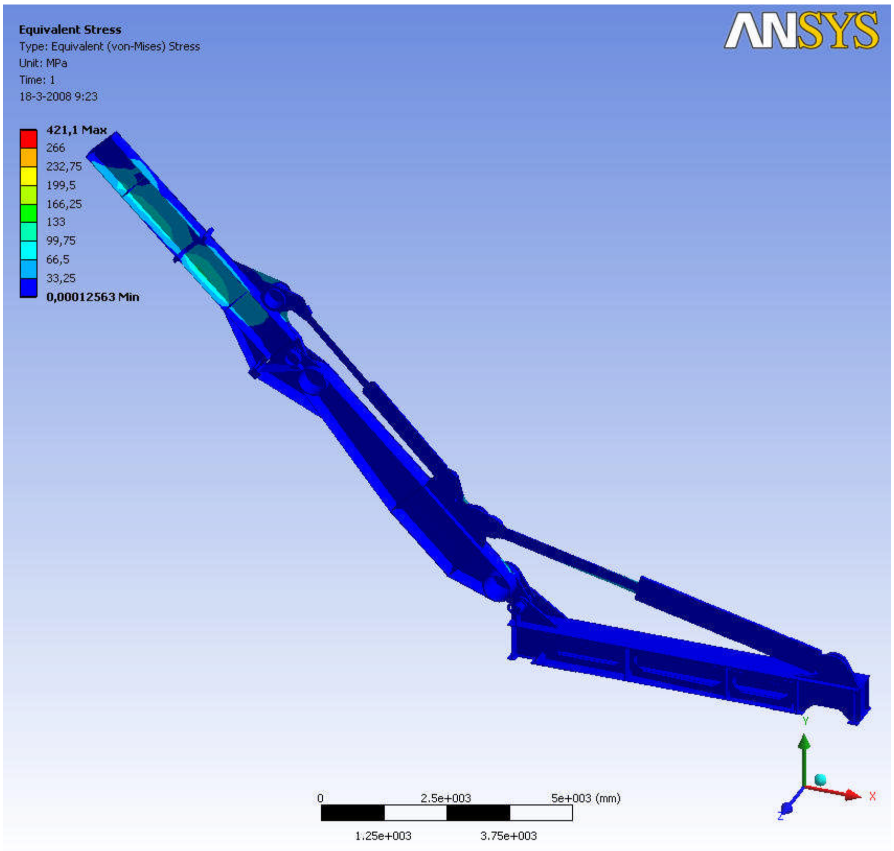


Equivalent stress levels (total overview)

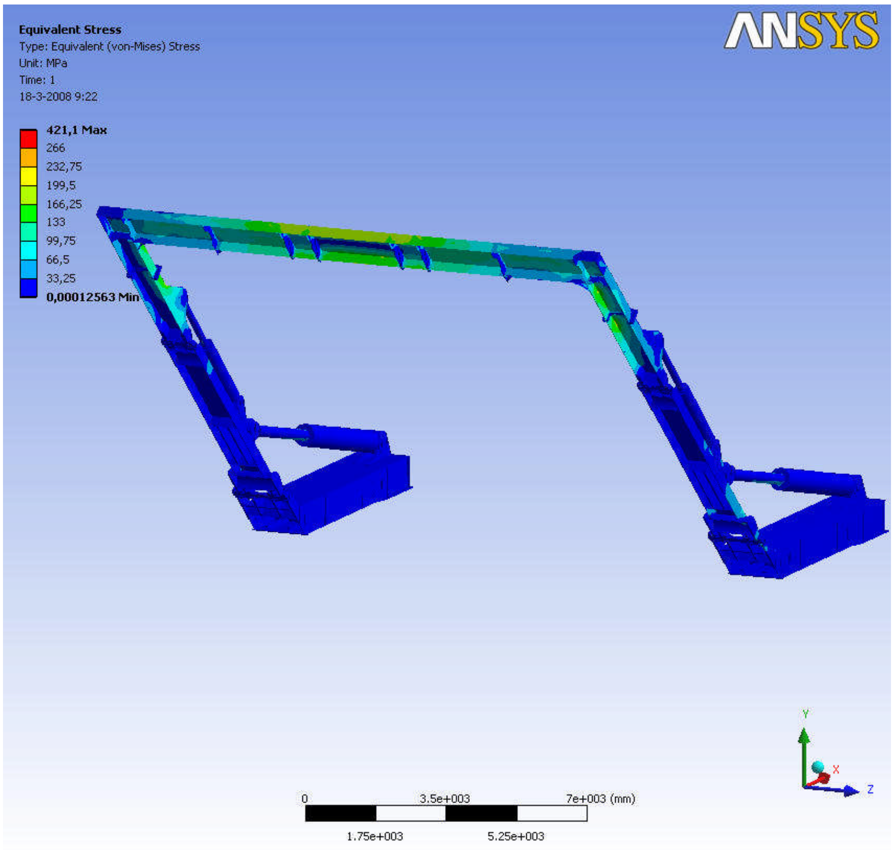




Location peak stress



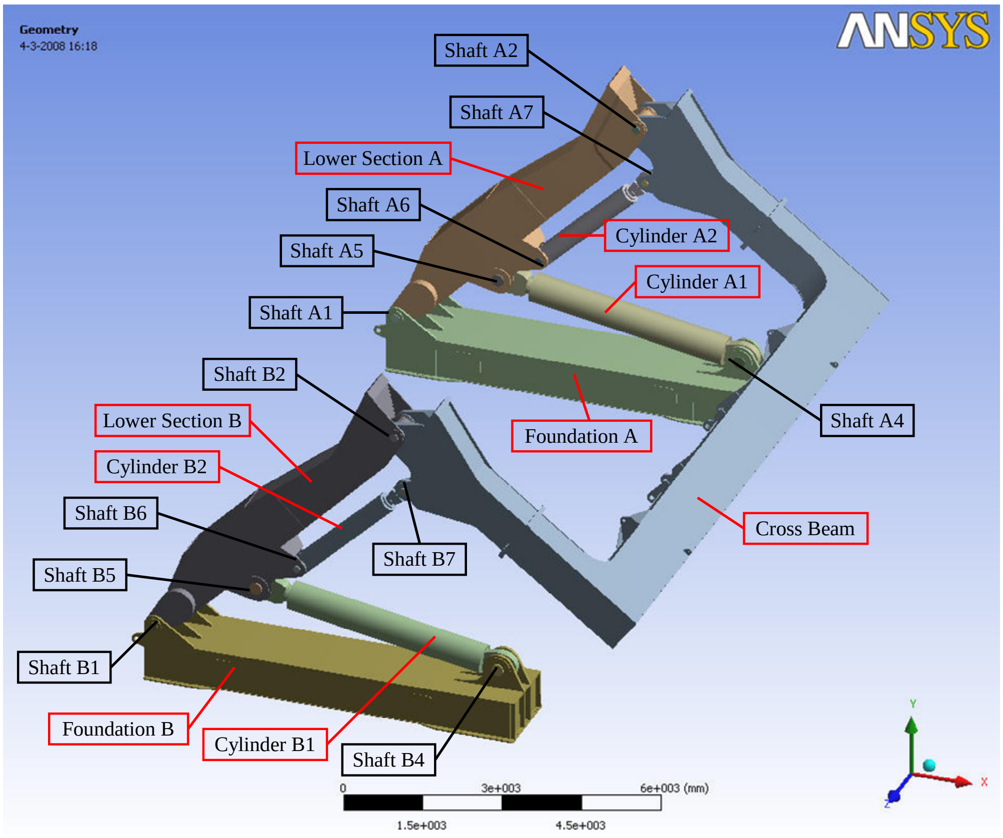
Equivalent stress levels (section view 1)



Equivalent stress levels (section view 2)

3.3 Stowed

3.3.1 Geometry

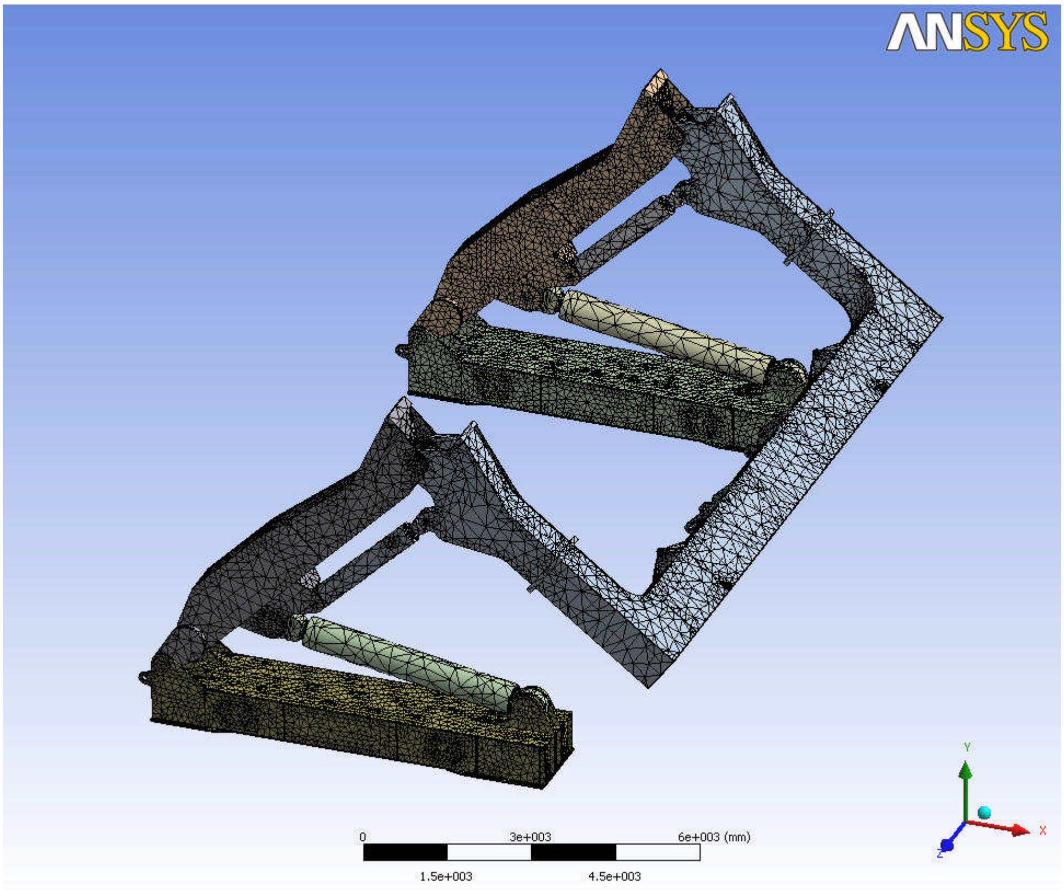


3.3.2 Connections

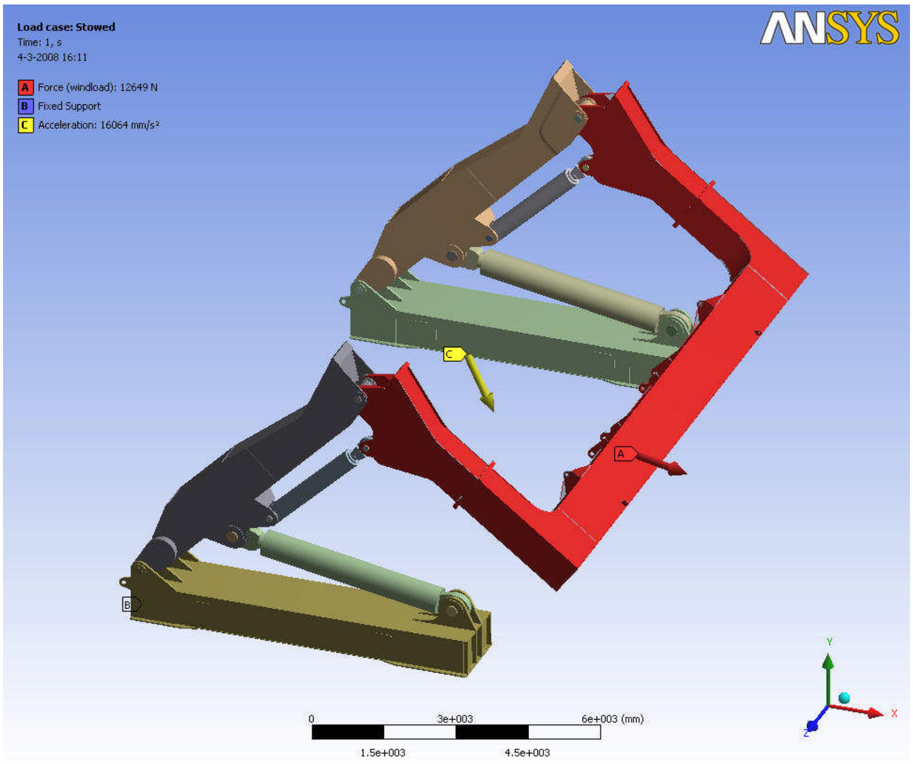
Object name	Type
Cross Beam To Lower Section A	No Separation
Cross Beam To Shaft A2	No Separation
Cross Beam To Cylinder A2	No Separation
Cross Beam To Shaft A2	No Separation
Cross Beam To Shaft A7	Bonded
Cross Beam To Lower section B	No Separation
Cross Beam To Shaft B2	No Separation
Cross Beam To Cylinder B2	No Separation
Cross Beam To Shaft B2	No Separation
Cross Beam To Shaft B7	Bonded
Foundation A To Lower Section A	No Separation
Foundation A To Shaft A1	Bonded
Foundation A To Cylinder A1	No Separation
Foundation A To Shaft A4	Bonded
Lower Section A To Shaft A1	No Separation
Lower Section A To Shaft A2	Bonded
Lower Section A To Cylinder A2	No Separation
Lower Section A To Cylinder A1	No Separation
Lower Section A To Shaft A5	Bonded
Lower Section A To Shaft A6	Bonded
Lower Section A To Shaft A2	Bonded

Object name	Type
Cylinder A2 To Shaft A6	No Separation
Cylinder A2 To Shaft A7	No Separation
Cylinder A1 To Shaft A5	No Separation
Cylinder A1 To Shaft A4	No Separation
Foundation B To Lower section B	No Separation
Foundation B To Shaft B1	Bonded
Foundation B To Cylinder B1	No Separation
Foundation B To Shaft B4	Bonded
Lower section B To Shaft B1	No Separation
Lower section B To Shaft B2	Bonded
Lower section B To Cylinder B2	No Separation
Lower section B To Cylinder B1	No Separation
Lower section B To Shaft B5	Bonded
Lower section B To Shaft B6	Bonded
Lower section B To Shaft B2	Bonded
Cylinder B2 To Shaft B6	No Separation
Cylinder B2 To Shaft B7	No Separation
Cylinder B1 To Shaft B5	No Separation
Cylinder B1 To Shaft B4	No Separation

3.3.3 Mesh



3.3.4 Loadcase: Stowed



Acceleration

$$a_y = -3400 + 1{,}05 \cdot -10000 = -13900\ mm/s^2 \quad (vertical\ acceleration + 1{,}05 \cdot gravity)$$

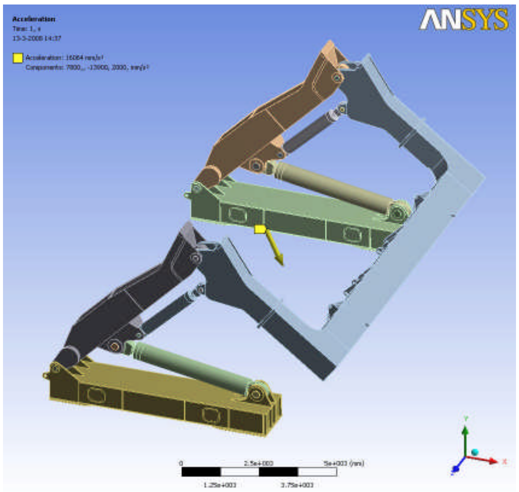
$$a_x = 7800\ mm/s^2 \quad (transverse\ acceleration)$$

$$a_z = 2000\ mm/s^2 \quad (longitudinal\ acceleration)$$

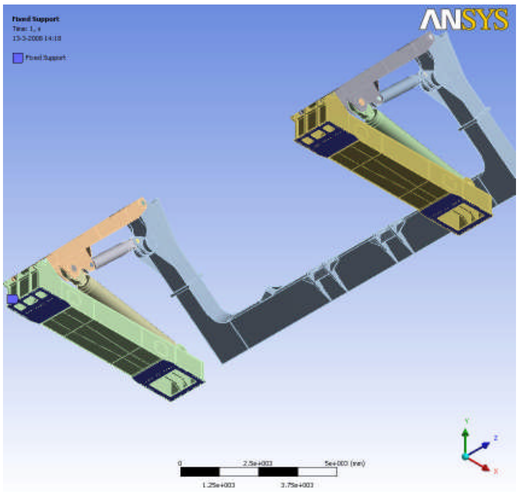
Force: Windload on structure

$$F_x = 81 \cdot 10^3\ N \quad (transverse\ acceleration)$$

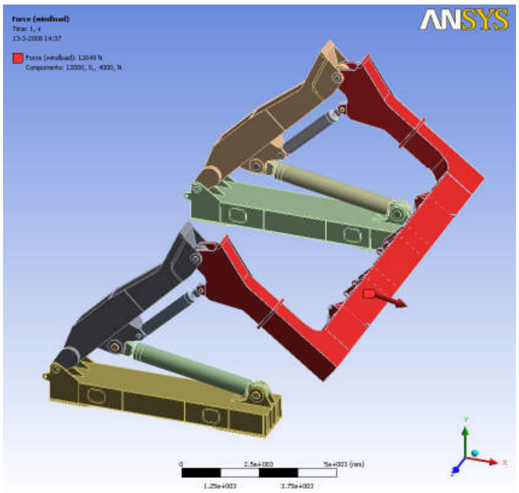
$$F_z = 42 \cdot 10^3\ N \quad (longitudinal\ acceleration)$$



Acceleration (all bodies)



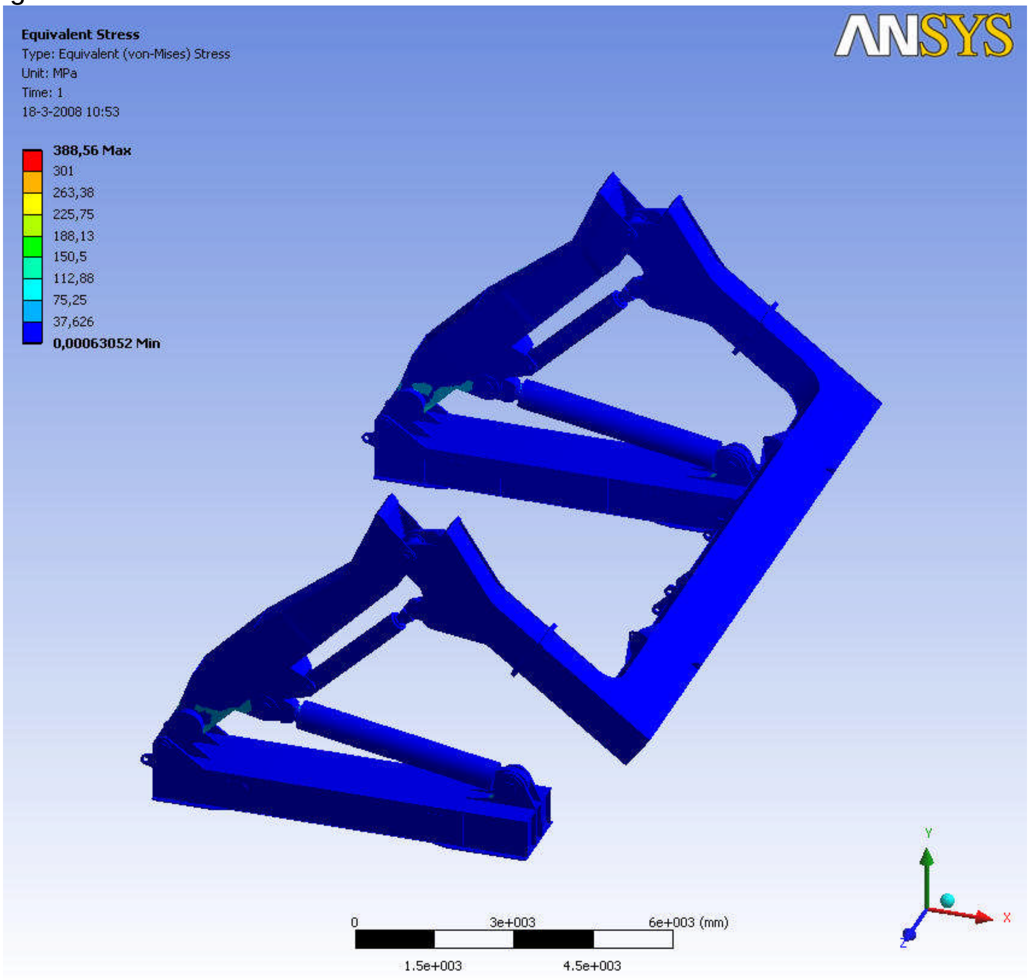
Fixed Support (areas marked blue)



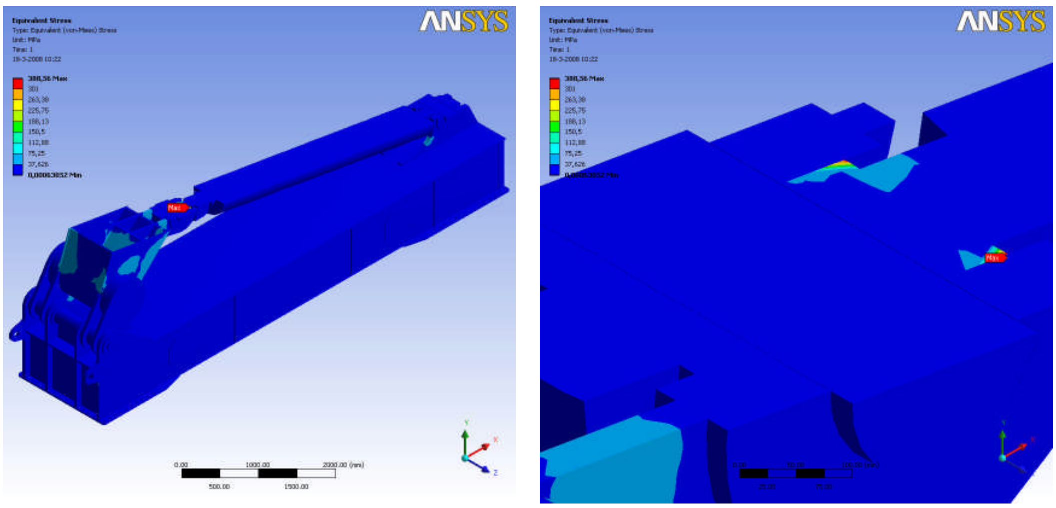
Force, wind load (areas marked red)

3.3.5 Solution: Stowed

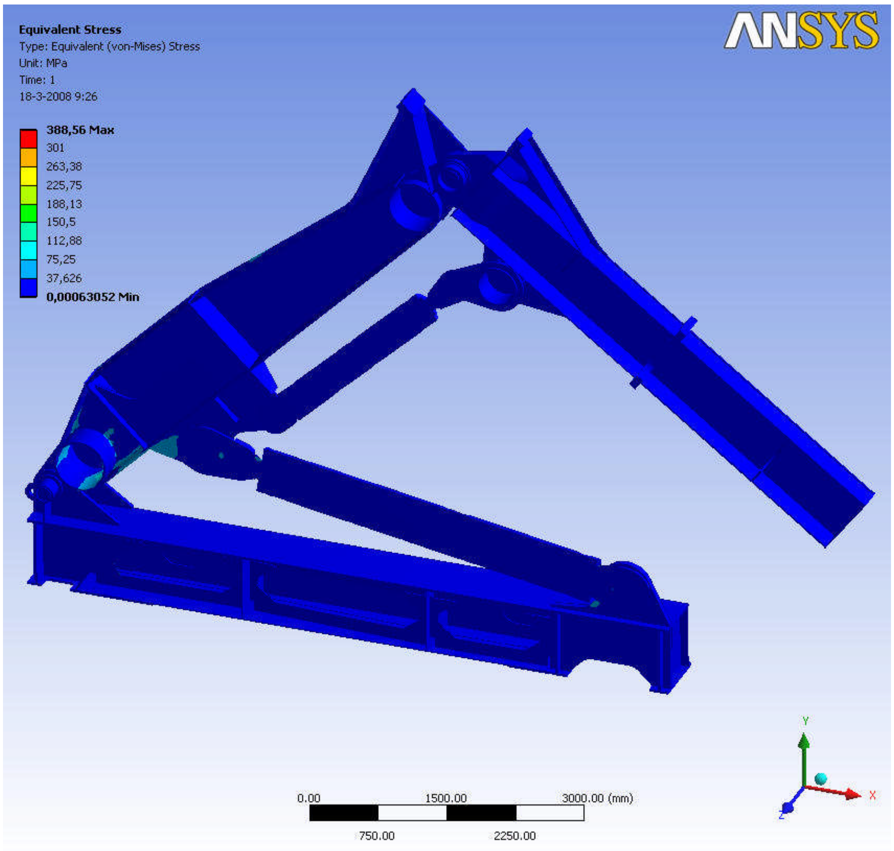
Stress levels are shown in the figures below. For this load case a maximum allowable stress is 301 N/mm^2 (see §2.2). Inadmissible stress levels are marked in the color red. A maximum peak stress of 388,56 N/mm^2 is found, but this is probably a result of singularity in the model. Therefore this peak stress can be ignored.



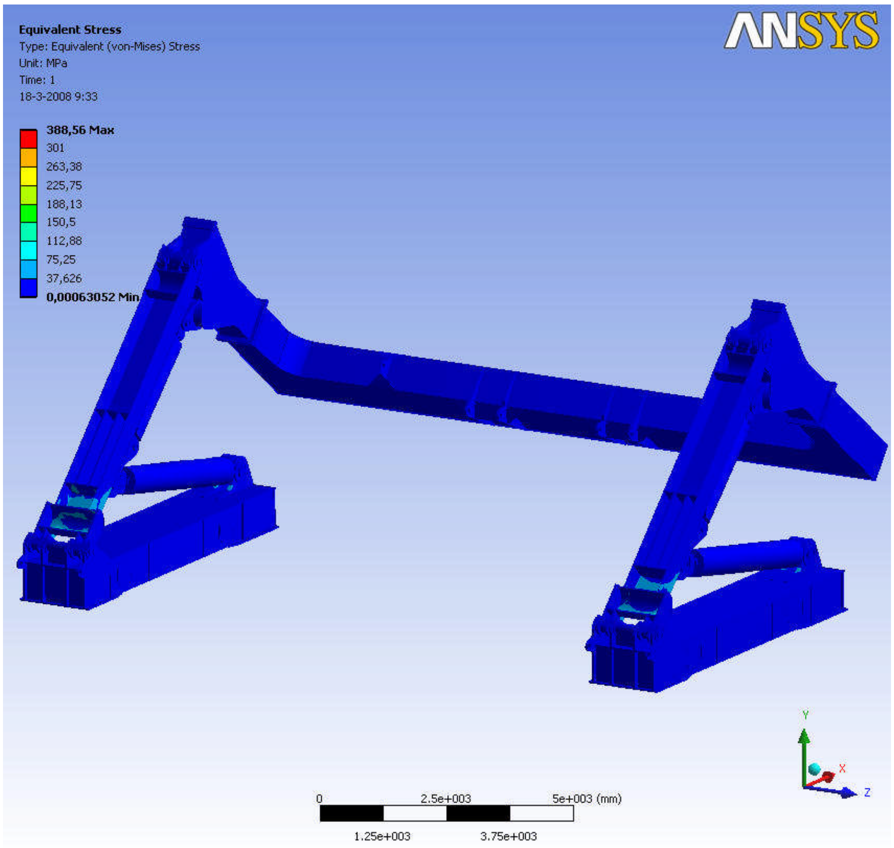
Equivalent stress levels (total overview)



Location peak stress

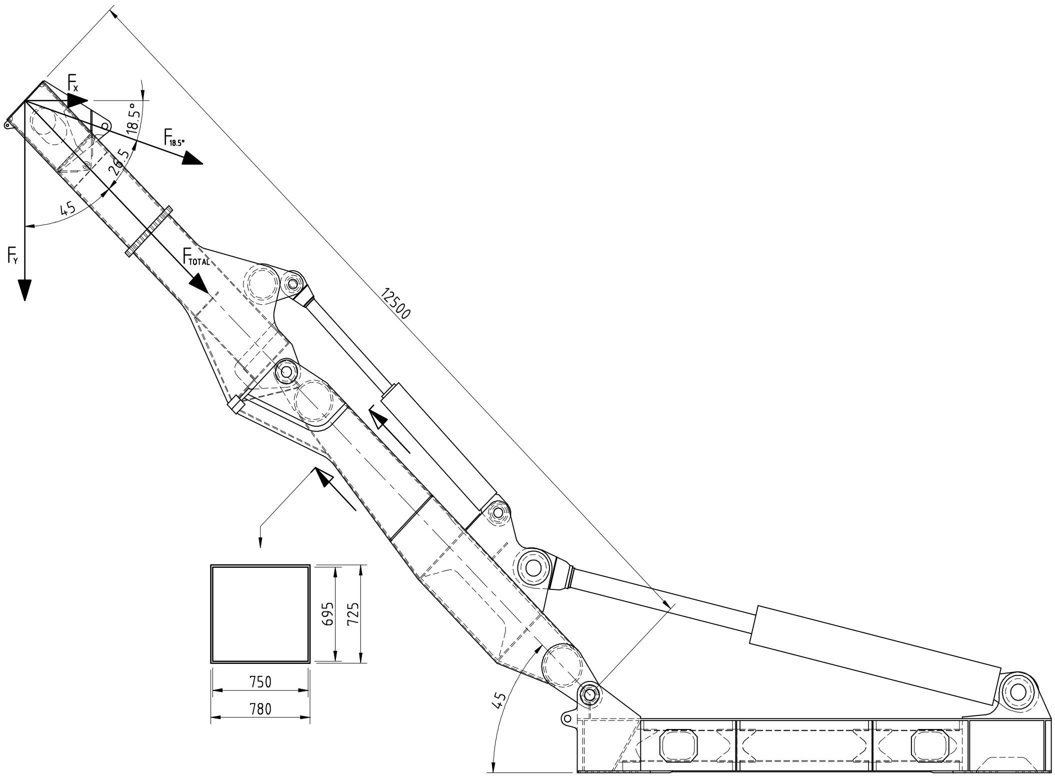


Equivalent stress levels (section view 1)



Equivalent stress levels (section view 2)

3.4 Buckling analysis



$$F_{TOTAL} = F_X \cdot \cos 45° + F_Y \cdot \cos 45° + F_{18,5} \cdot \cos 26{,}5°$$

$$F_{TOTAL} = 200 \cdot 10^3 \cdot \cos 45° + 1069 \cdot 10^3 \cdot \cos 45° + 1069 \cdot 10^3 \cdot \cos 26{,}5°$$

$$F_{TOTAL} = 1854\ kN$$

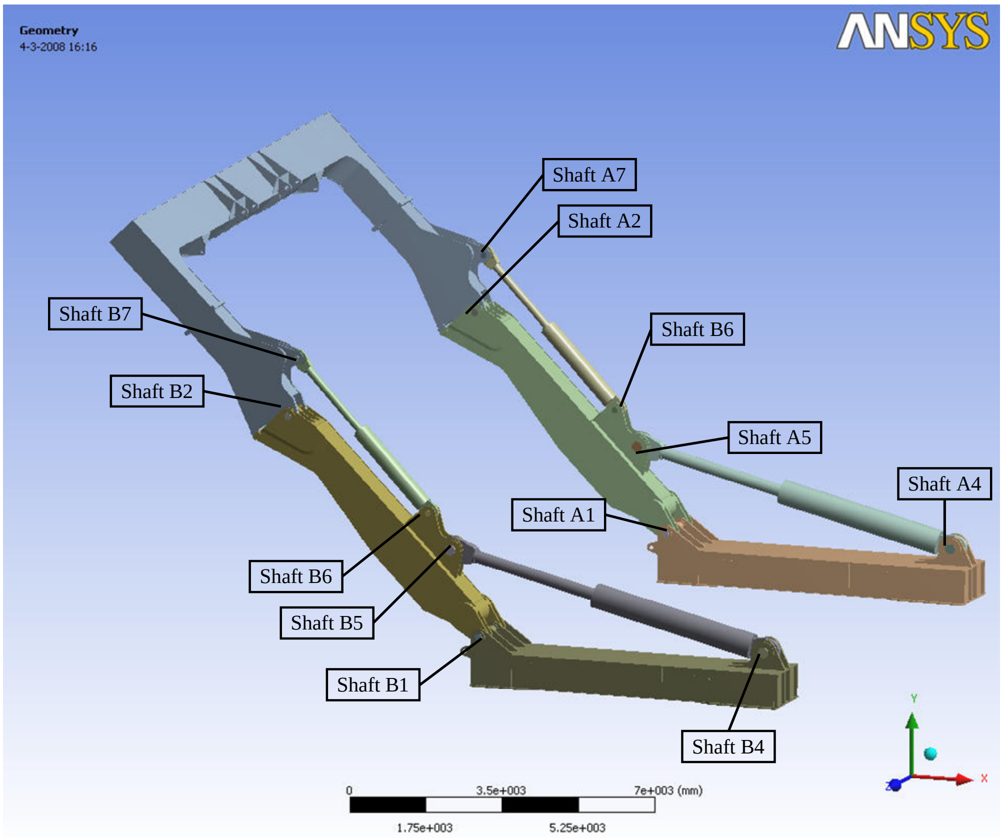
$$I = \frac{BH^3 - bh^3}{12} = \frac{780 \cdot 725^3 - 750 \cdot 695^3}{12} = 3788679688\ mm^4$$

$$E = 2{,}10 \cdot 10^5\ N/mm^2$$

$$F_{BUCKLING} = \frac{\pi^2 \cdot E \cdot I}{L^2} = \frac{\pi^2 \cdot 2{,}10 \cdot 10^5 \cdot 3788679688}{12500^2} = 50255882{,}5\ N$$

$$Bucklingfactor = \frac{F_{TOTAL}}{F_{BUCKLING}} = \frac{1854 \cdot 10^3}{50255882{,}5} = 0{,}04$$

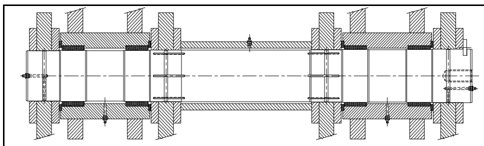
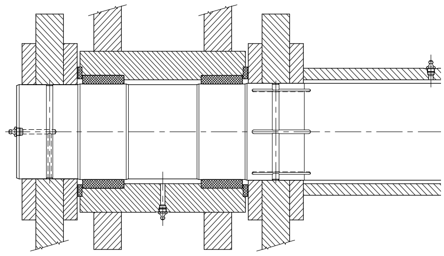
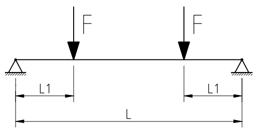
3.5 Shaft calculations



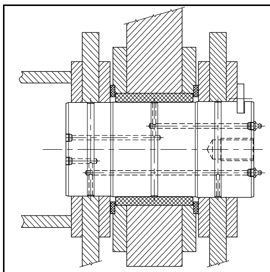
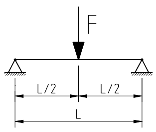
Maximum force reactions:

Shaft	Inboard case 1 [N]	Inboard case 2 [N]	Outboard case 1 [N]	Outboard case 2 [N]	Stowed [N]
1	2,6028E+06	2,6572E+06	6,4786E+05	4,7587E+05	1,1273E+06
2	6,4581E+05	6,6864E+05	9,1678E+05	8,8993E+05	1,1275E+05
4	2,7709E+06	2,8312E+06	2,1506E+05	3,9174E+05	1,3643E+06
5	2,7470E+06	2,8064E+06	2,4821E+05	4,2820E+05	1,2593E+06
6	1,2999E+06	1,3227E+06	2,8892E+05	4,0495E+05	2,0215E+05
7	1,4361E+06	1,4607E+06	2,9548E+05	3,9899E+05	572,57

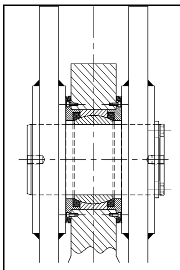
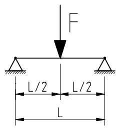
3.5.1 Shaft 1

   	$D = ø160\ mm$ $L = 400\ mm$ $L1 = 100\ mm$ $Wb = \frac{\pi \cdot D^3}{32} = 402124\ mm^3$ $A = \frac{1}{4} \cdot \pi \cdot D^2 = 20106\ mm^2$ $F = 664300\ N$ $Mb = F \cdot L1 = 66430000\ Nmm$
$\sigma = \frac{Mb}{Wb} = 165\ N/mm^2$ $\tau = \frac{F}{A} = 33\ N/mm^2$ $\sigma_i = \sqrt{\sigma^2 + 3 \cdot \tau^2} = 175\ N/mm^2$	$mat.\ 42CrMo4\ \left(\sigma_y = 550\ N/mm^2\right)$ $\sigma_a = 368{,}5\ N/mm^2$ $\sigma_i > \sigma_a \rightarrow O.K.$

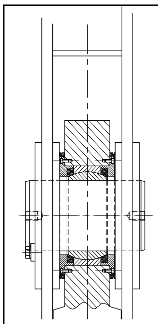
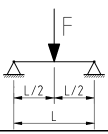
3.5.2 Shaft 2

  	$D = ø160\ mm$ $L = 230\ mm$ $Wb = \frac{\pi \cdot D^3}{32} = 402124\ mm^3$ $A = \frac{1}{4} \cdot \pi \cdot D^2 = 20106\ mm^2$ $F = 916780\ N$ $Mb = \frac{F \cdot L}{4} = 52714850\ Nmm$
$\sigma = \frac{Mb}{Wb} = 131\ N/mm^2$ $\tau = \frac{F}{A} = 46\ N/mm^2$ $\sigma_i = \sqrt{\sigma^2 + 3 \cdot \tau^2} = 153\ N/mm^2$	$mat.\ 42CrMo4\ \left(\sigma_y = 550\ N/mm^2\right)$ $\sigma_a = 368{,}5\ N/mm^2$ $\sigma_i > \sigma_a \rightarrow O.K.$

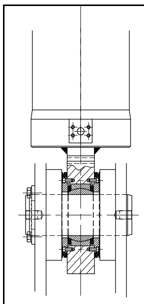
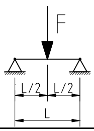
3.5.3 Shaft 4

  	$D = \varnothing 240\ mm$ $L = 325\ mm$ $Wb = \frac{\pi \cdot D^3}{32} = 1357168\ mm^3$ $A = \frac{1}{4} \cdot \pi \cdot D^2 = 45239\ mm^2$ $F = 2831200\ N$ $Mb = \frac{F \cdot L}{4} = 230035000\ Nmm$
$\sigma = \frac{Mb}{Wb} = 170\ N/mm^2$ $\tau = \frac{F}{A} = 63\ N/mm^2$ $\sigma_i = \sqrt{\sigma^2 + 3 \cdot \tau^2} = 201\ N/mm^2$	$mat.\ 42CrMo4\ (\sigma_y = 500\ N/mm^2)$ $\sigma_a = 335\ N/mm^2$ $\sigma_i > \sigma_a \rightarrow O.K.$

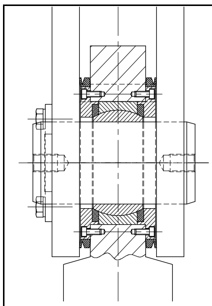
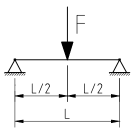
3.5.4 Shaft 5

  	$D = \varnothing 240\ mm$ $L = 300\ mm$ $Wb = \frac{\pi \cdot D^3}{32} = 1357168\ mm^3$ $A = \frac{1}{4} \cdot \pi \cdot D^2 = 45239\ mm^2$ $F = 2806400\ N$ $Mb = \frac{F \cdot L}{4} = 210480000\ Nmm$
$\sigma = \frac{Mb}{Wb} = 155\ N/mm^2$ $\tau = \frac{F}{A} = 62\ N/mm^2$ $\sigma_i = \sqrt{\sigma^2 + 3 \cdot \tau^2} = 189\ N/mm^2$	$mat.\ 42CrMo4\ (\sigma_y = 500\ N/mm^2)$ $\sigma_a = 335\ N/mm^2$ $\sigma_i > \sigma_a \rightarrow O.K.$

3.5.5 Shaft 6

  	$D = \varnothing 140\ mm$ $L = 240\ mm$ $Wb = \frac{\pi \cdot D^3}{32} = 269392\ mm^3$ $A = \frac{1}{4} \cdot \pi \cdot D^2 = 15394\ mm^2$ $F = 1322700\ N$ $Mb = \frac{F \cdot L}{4} = 79362000\ Nmm$
$\sigma = \frac{Mb}{Wb} = 295\ N/mm^2$ $\tau = \frac{F}{A} = 86\ N/mm^2$ $\sigma_i = \sqrt{\sigma^2 + 3 \cdot \tau^2} = 330\ N/mm^2$	$mat.\ 42CrMo4\ (\sigma_y = 550\ N/mm^2)$ $\sigma_a = 368{,}5\ N/mm^2$ $\sigma_i > \sigma_a \rightarrow O.K.$

3.5.6 Shaft 7

  	$D = \varnothing 140\ mm$ $L = 190\ mm$ $Wb = \frac{\pi \cdot D^3}{32} = 269392\ mm^3$ $A = \frac{1}{4} \cdot \pi \cdot D^2 = 15394\ mm^2$ $F = 1460700\ N$ $Mb = \frac{F \cdot L}{4} = 69383250\ Nmm$
$\sigma = \frac{Mb}{Wb} = 258\ N/mm^2$ $\tau = \frac{F}{A} = 95\ N/mm^2$ $\sigma_i = \sqrt{\sigma^2 + 3 \cdot \tau^2} = 306\ N/mm^2$	$mat.\ 42CrMo4\ (\sigma_y = 550\ N/mm^2)$ $\sigma_a = 368{,}5\ N/mm^2$ $\sigma_i > \sigma_a \rightarrow O.K.$

4 Conclusion

An A-frame has been designed for a SWL 35 ton. This report describes the stress calculations which are made to check for inadmissible stress levels. The stress calculations for the construction has been made with the finite element analysis method. The shafts are checked with manual stress calculations.

The construction has been made of S355 with a yield stress 355 N/mm^2. The shafts are made off 42CrMo4 with a yield stress 550 N/mm^2 (100-160mm) and 500 N/mm^2 (160-250mm). The calculations show no inadmissible stress levels in all construction parts.

Appendix A

Design criteria

Design loads

The A-Frame design loads used in this report are provided by the manufacturer and have been adjusted to the new situation. This means forces due to accelerations are adjusted to the new location of the A-Frame on the vessel and wind loads are adjusted to the dimensions of the new load.

Three load cases are distinguished:

- Inboard Lift;
- Outboard Lift;
- Stowed / Survival.

Inboard Lift

For inboard lift it is assumed that the A-Frame is used as a shipboard crane, since the lifting is performed solely on the offshore installation itself. The duty factor and the hoisting factor are obtained as follows:

Ref. [1] section 3.2.3.1: Duty factor: $F_d = 1.05$;
Ref. [1] section 3.2.5.2: Hoisting factor: $F_h = 1 + C_l\, V_h$;
$C_l = 0.6$ for this type of cranes;
$V_h = 0.16$ m/s;
$F_h = 1 + 0.6 \times 0.16 = 1.1$, but not to be taken less than 1.15.

Load:

Part	Sub-part	Weight [ton]	Combined Load factor	Design load [ton]
Load	SWL	35	1.2 *(1.05 x 1.15)*	42.3

This load acts from the A-Frame downwards and also in the direction of the Upper Deck Sheave. The latter direction has an angle of 51.9° with respect to the deck for the inboard lift load case. This combination results in a vertical and a transverse load on the A-Frame as can be seen in the following table:

Load [ton]	Vertical [ton]	Transverse load [ton]
2 x 42.3 (downwards and sideways)	75.5	26.1

Self-weight A-Frame (Live-load):

Part	Sub-part	Weight [ton]	Combined Load factor	Design load [ton]
A-Frame	Crossbeam	10	1.2	12
	Upper-legs	2 x 4.1	1.2	2 x 4.9
	Lower-legs	2 x 8.2	1.2	2 x 9.8
	Upper Cylinders	2 x 3	1.2	2 x 3.6
	Lower Cylinders	2 x 5	1.2	2 x 6
	Hoisting equip.	5	1.2	6
			Total:	67.1

Self-weight A-Frame (Dead-load):

Part	Sub-part	Weight [ton]	Combined Load factor	Design load [ton]
A-Frame	Leg Foundation	2 x 10	1.05	2 x 10.5
			Total:	21.0

Forces as a result of offlead angles (sea state 2-3):

Load [ton]	Alpha	Beta	Transverse load [ton]	Longitudinal load [ton]
42, Case 1	3		2.2 *(42.3 x sin(3))*	
42, Case 2	6		4.4	
42, Case 2		3		2.2
42, Case 1		6		4.4

The wind load (V = 20 m/s) is obtained as follows:

Ref. [1] section 3.2.12.4: Wind load: $F_w = A\ p\ C_f$;
Wind pressure: $p = 0.613\ V^2 = 0.613 \times 20^2 = 245$ [N/m^2];
Force coefficient C_f : obtained from ref [1].

The total effective areas of the concerned structures are obtained as follows:

Part	Area in transverse direction [m^2]	Area in longitudinal direction [m^2]
A-Frame – Upper-legs	2 x 2	2
A-Frame – Lower-legs	2 x 6.5	7
A-Frame – Crossbeam	14	2
Total:	31	11
Load – Spreader	7	7
Load - Mattress	12	2
Total:	19	9

Wind load (V=20 m/s):

Location	Direction	Area [m^2]	Pressure [N/m^2]	C_f	Force [ton]
On structure	Transverse	31	245	1.55	1.2
	Longitudinal	11	245	1.55	0.4
On Load	Transverse	19	245	1.7	0.8
	Longitudinal	9	245	1.7	0.4

Forces as a result of vessel motions:

Conservative maximum accelerations in x-,y- and z-direction are used, based on the 3 hour maximum wave height for sea-state 5-6, with heading control.

Part	Direction	Weight [ton]	Acceleration [m/s^2] SS 5-6 with heading control	Force [ton] SS 5-6 with heading control
Crossbeam	Vertical	10	0.6	0.6
Upper-legs		2 x 4.1	0.6	2 x 0.25
Lower-legs		2 x 8.2	0.6	2 x 0.5
Leg Foundation		2 x 10	0.6	2 x 0.6
Upper Cylinders		2 x 3	0.6	2 x 0.18
Lower Cylinders		2 x 5	0.6	2 x 0.3
Hoisting equip.		5	0.6	0.3
			Total:	4.5
Crossbeam	Transverse	10	1.3	1.3
Upper-legs		2 x 4.1	1.3	2 x 0.5
Lower-legs		2 x 8.2	1.3	2 x 1.1
Leg Foundation		2 x 10	1.3	2 x 1.3
Upper Cylinders		2 x 3	1.3	2 x 0.4
Lower Cylinders		2 x 5	1.3	2 x 0.7
Hoisting equip.		5	1.3	0.7
			Total:	9.8
Crossbeam	Longitudinal	10	0.7	0.7
Upper-legs		2 x 4.1	0.7	2 x 0.3
Lower-legs		2 x 8.2	0.7	2 x 0.6
Leg Foundation		2 x 10	0.7	2 x 0.7
Upper Cylinders		2 x 3	0.7	2 x 0.2
Lower Cylinders		2 x 5	0.7	2 x 0.4
Hoisting equip.		5	0.7	0.4
			Total:	5.3

SWL	Vertical	35	0.6	2.1
	Transverse	35	1.3	4.6
	Longitudinal	35	0.7	2.5

Total Forces on A-Frame:

Load case	Direction	Force [ton]
	Vertical	-170.3
Load case 1	Transverse	44.6
Load case 1	Longitudinal	46.8
Load case 2	Transverse	13.0
Load case 2	Longitudinal	10.7

Total forces on components:

Component	Direction	Force [ton]	Remark
Upper Deck Sheave	Vertical	-8	Based on 42.3[t] cable tension and cable angles
	Transverse	-35	Based on 42.3[t] cable tension and cable angles
Heave Compensator	-	-	Outboard lift is governing
Traction Winch	-	-	Outboard lift is governing
Snatch-Block	-	-	Outboard lift is governing
Storage Winch	-	-	Outboard lift is governing

Outboard Lift

For outboard lift it is assumed that the A-Frame is an offshore crane. The A-Frame itself is no longer considered to be a live-load, since the A-Frame is in rest during an outboard lift. Although a Heave Compensator is present and used during an outboard lift, a conservative approach with respect to the hoisting factor is chosen and hence the positive effect on the hoisting factor was not taken into account in these design calculations. The duty factor and the hoisting factor are obtained as follows:

Ref. [1] section 3.3.2.1: Duty factor: F_d = 1.2 (1.05 for Dead-load);

Ref. [1] section 3.3.3.2: Hoisting factor: $F_h = 0.83 + F_w \sqrt{\frac{K}{L_l}}$;

F_w = 21.7 (Sea-state 5-6);

$\sqrt{\frac{K}{L_l}} = 0.057$;

$F_h = 0.83 + 21.7 \times 0.057 = 2.07$.

Load:

Part	Sub-part	Weight [ton]	Combined Load factor	Design load [ton]
Load	SWL	35	2.48 *(1.2 x 2.07)*	86.8
	Wire (1500m)	15	1.2	18
			Total:	104.8

These loads act from the A-Frame downwards and also in the direction of the Upper Deck Sheave. The latter direction has an angle of 18.5° with respect to the deck for the outboard lift load case. This combination results in a vertical and a transverse load on the A-Frame as can be seen in the following table:

Load [ton]	Vertical [ton]	Transverse load [ton]
2 x 104.8 (downwards and sideways)	138.1	99.4

Self-weight A-Frame (Dead-load):

Part	Sub-part	Weight [ton]	Combined Load factor	Design load [ton]
A-Frame	Crossbeam	10	1.05	10.5
	Upper-legs	2 x 4.1	1.05	2 x 4.3
	Lower-legs	2 x 8.2	1.05	2 x 8.6
	Leg Foundation	2 x 10	1.05	2 x 10.5
	Upper Cylinders	2 x 3	1.05	2 x 3.2
	Lower Cylinders	2 x 5	1.05	2 x 5.3
	Hoisting equip.	5	1.05	5.3
			Total:	79.4

Forces as a result of offlead angles (sea state 5-6):

Load [ton]	Alpha	Beta	Transverse load [ton]	Longitudinal load [ton]
105, Case 1	4		7.3 *(104.8 x sin(4))*	
105, Case 2	8		14.6	
105, Case 2		4		7.3
105, Case 1		8		14.6

Wind load (V=20 m/s):

Location	Direction	Area [m^2]	Pressure [N/m^2]	C_f	Force [ton]
On structure	Transverse	31	245	1.55	1.2
	Longitudinal	11	245	1.55	0.4
On Load	Transverse	19	245	1.7	0.8
	Longitudinal	9	245	1.7	0.4

Forces as a result of vessel motions:
Conservative maximum accelerations in x-,y- and z-direction are used, based on the 3 hour maximum wave height for sea-state 5-6, with heading control.

Part	Direction	Weight [ton]	Acceleration [m/s^2] SS 5-6	Force [ton] SS 5-6
Crossbeam	Vertical	10	0.6	0.6
Upper-legs		2 x 4.1	0.6	2 x 0.25
Lower-legs		2 x 8.2	0.6	2 x 0.5
Leg Foundation		2 x 10	0.6	2 x 0.6
Upper Cylinders		2 x 3	0.6	2 x 0.18
Lower Cylinders		2 x 5	0.6	2 x 0.3
Hoisting equip.		5	0.6	0.3
			Total:	4.5
Crossbeam	Transverse	10	1.3	1.3
Upper-legs		2 x 4.1	1.3	2 x 0.5
Lower-legs		2 x 8.2	1.3	2 x 1.1
Leg Foundation		2 x 10	1.3	2 x 1.3
Upper Cylinders		2 x 3	1.3	2 x 0.4
Lower Cylinders		2 x 5	1.3	2 x 0.7
Hoisting equip.		5	1.3	0.7
			Total:	9.8

Crossbeam	Longitudinal	10	0.7	0.7
Upper-legs		2 x 4.1	0.7	2 x 0.3
Lower-legs		2 x 8.2	0.7	2 x 0.6
Leg Foundation		2 x 10	0.7	2 x 0.7
Upper Cylinders		2 x 3	0.7	2 x 0.2
Lower Cylinders		2 x 5	0.7	2 x 0.4
Hoisting equip.		5	0.7	0.4
			Total:	5.3
SWL	Vertical	35	0.6	2.1
	Transverse	35	1.3	4.6
	Longitudinal	35	0.7	2.5

Total Forces on A-Frame:

Load case	Direction	Force [ton]
	Vertical	-224.1
Load case 1	Transverse	123.1
Load case 1	Longitudinal	130.3
Load case 2	Transverse	23.1
Load case 2	Longitudinal	15.8

Forces on components:

Component	Direction	Description	Force [ton]
Upper Deck Sheave	Transverse	Based on 104.8t cable tension and cable angles	-134
	Vertical	Based on 104.8t cable tension and cable angles	-65
Heave Compensator	Longitudinal	Based on 104.8t cable tension and cable angles	104
	Transverse	Based on 104.8t cable tension and cable angles	30
	Vertical	Based on 104.8t cable tension and cable angles	88
	Vertical	Self-weight	-14
Traction Winch	Longitudinal	Based on 104.8t cable tension and cable angles	-105
	Vertical	Self-weight	-35
Snatch-Block	Longitudinal	Based on 2 x 6.3t cable tension and cable angles	-12.6
	Transverse	Based on 2 x 6.3t cable tension and cable angles	-12.6
	Vertical	Self-weight	-1
Storage Winch	Transverse	Based on 20t cable tension and cable angles	20
	Vertical	Self-weight	-60

Stowed / Survival

Self-weight A-Frame (Dead-load):

Part	Sub-part	Weight [ton]	Duty Factor	Design load [ton]
A-Frame	Crossbeam	10	1.05	10.5
	Upper-legs	2 x 4.1	1.05	2 x 4.3
	Lower-legs	2 x 8.2	1.05	2 x 8.6
	Leg Foundation	2 x 10	1.05	2 x 10.5
	Upper Cylinders	2 x 3	1.05	2 x 3.2
	Lower Cylinders	2 x 5	1.05	2 x 5.3
	Hoisting equip.	5	1.05	5.3
			Total:	79.4

Wind load (V = 63 m/s):

Location	Direction	Area [m^2]	Pressure [N/m^2]	C_f	Force [ton]
On structure	Transverse	21.4	2433	1.55	8.1
	Longitudinal	11.0	2433	1.55	4.1

Forces as a result of vessel motions:

Conservative maximum accelerations in x-,y- and z-direction are used based on the 3 hour maximum wave height for sea-state 9-13, with heading control.

Part	**Force**	**Weight [ton]**	**Acceleration [m/s^2]**	**Force [ton]**
Crossbeam	Vertical	10	3.4	3.4
Upper-legs		2 x 4.1	3.4	2 x 1.4
Lower-legs		2 x 8.2	3.4	2 x 2.8
Leg Foundation		2 x 10	3.4	2 x 3.4
Upper Cylinders		2 x 3	3.4	2 x 1.0
Lower Cylinders		2 x 5	3.4	2 x 1.7
Hoisting equip.		5	3.4	1.7
			Total:	25.7
Crossbeam	Transverse	10	7.8	7.8
Upper-legs		2 x 4.1	7.8	2 x 3.2
Lower-legs		2 x 8.2	7.8	2 x 6.4
Leg Foundation		2 x 10	7.8	2 x 7.8
Upper Cylinders		2 x 3	7.8	2 x 2.3
Lower Cylinders		2 x 5	7.8	2 x 3.9
Hoisting equip.		5	7.8	3.9
			Total:	59.0
Crossbeam	Longitudinal	10	2.0	2
Upper-legs		2 x 4.1	2.0	2 x 0.8
Lower-legs		2 x 8.2	2.0	2 x 1.6
Leg Foundation		2 x 10	2.0	2 x 2.0
Upper Cylinders		2 x 3	2.0	2 x 0.6
Lower Cylinders		2 x 5	2.0	2 x 1.0
Hoisting equip.		5	2.0	1
			Total:	15.1

Total Forces on A-Frame:

Direction	**Force [ton]**
Vertical	-105.1
Transverse	67.0
Longitudinal	19.3