Free offshore Seminar on ANSYS
Issues in Fatigue Analysis

Tuesday the 17th of November 2009

Esbjerg

Department of Civil Engineering, AAU
http://www.civil.aau.dk/

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Presentation

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Esbjerg Campus

Aalborg University

Goals

- Mission
  - To educate Finite Element Method
  - To ensure transfer of technology and knowledge between University and Industry
- Objectives
  - Bachelor level: Mechanical Engineering students should be able to use FEA in a product design and development environment
  - Bachelor level: Civil Engineering students should be able to use FEA in structural design
  - Master level: Civil and Mechanical Engineering students should be able to use FEA in a research and development environment

Program

- Issues in Fatigue Analysis – from an educational point of view
  - Education – Self paced learning and Project Oriented Problem Based Learning
    - FEA - Strong motivator in teaching structural behavior
  - Scope of Fatigue Analysis
  - Issues in Fatigue Analysis
- Issues in Deterministic Fatigue Analysis
- Examples – In danish

Education - FEM in Esbjerg

- 10 years ago – use of FE in graduate projects 50%:
  - Supervison and training share in the study curriculum
  - 0% CAE Inventor Professional
  - 100% ANSYS Classic
  - 0% ANSYS Workbench
- 5 years ago – use of FE in graduate projects 70%:
  - Supervison and training share in the study curriculum
  - 10% CAE Inventor Professional
  - 90% ANSYS Classic
  - 0% ANSYS Workbench
- 3 years ago – use of FE in graduate projects 90%:
  - Supervison and training share in the study curriculum
  - 20% CAE Inventor Professional
  - 70% ANSYS Classic
  - 10% ANSYS Workbench
- Currently – use of FE in graduate projects 100%:
  - Supervison and training share in the study curriculum
  - 20% CAE Inventor Professional
  - 50% ANSYS Classic
  - 30% ANSYS Workbench

Education

- Bachelor level
  - Fatigue in Machine elements – infinite life (only for mechanical engineering students)
  - Fatigue in Steel structures - introductory (welded) – finite life (for both civil and mechanical engineering students)
  - Fatigue in Steel structures (welded) – finite life (only for mechanical engineering students)
- Master level
  - Fatigue in Steel structures (welded) – finite life (for both civil and mechanical engineering students)
  - Linear Elastic Fracture Mechanics (for both civil and mechanical engineering students)

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Scope of Fatigue Analysis

- Considering a minimum of 8 directions, 10 waves per direction and 10 periods per wave and reminding that there must be 18 steps for each wave, this means that the fatigue stresses will require 14400 load cases, in order to determine 800 stress ranges
- In the case of a jacket structure it is usually checked for fatigue at 8 points around the circumference of the joint connection, times 2, because each member has 2 ends and times 2 again because there is stress concentration on both the chord side and the brace side of the connection.
- If the jacket has 1000 members, this means that 32000 fatigue checks must be performed, dealing with the 1440 stress values that were determined above, leading to 80 stress ranges.
- This means that 80 x 32000 = 2.56 million damage calculations must be performed for the entire structure (80 for each point).

- In education minimum is one.

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Issues in fatigue analysis

- Design approach
  - Infinite life design
  - Safe life design
  - Fail-safe design
- Identification of critical regions
- Modeling issues
  - Idealization
  - Mesh
  - Geometrical Detail
  - Stress Concentrations
  - Fatigue Modification Factors
  - Material Data (S-N data, toughness, surface roughness…)

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Issues in fatigue analysis …

- Load data
  - Dynamical behavior (large deformation, flexible multi-bodies, …)
  - Number of cycles
  - Stress range in each load cycle
  - Mean stress in each load cycle
  - Multi-axial Stress Correction
- Fatigue analysis approach
  - Deterministic Fatigue Analysis – Time domain
  - Spectral Fatigue Analysis – Frequency domain
  - Strain life LCF
  - Stress life HCF
  - LEFM

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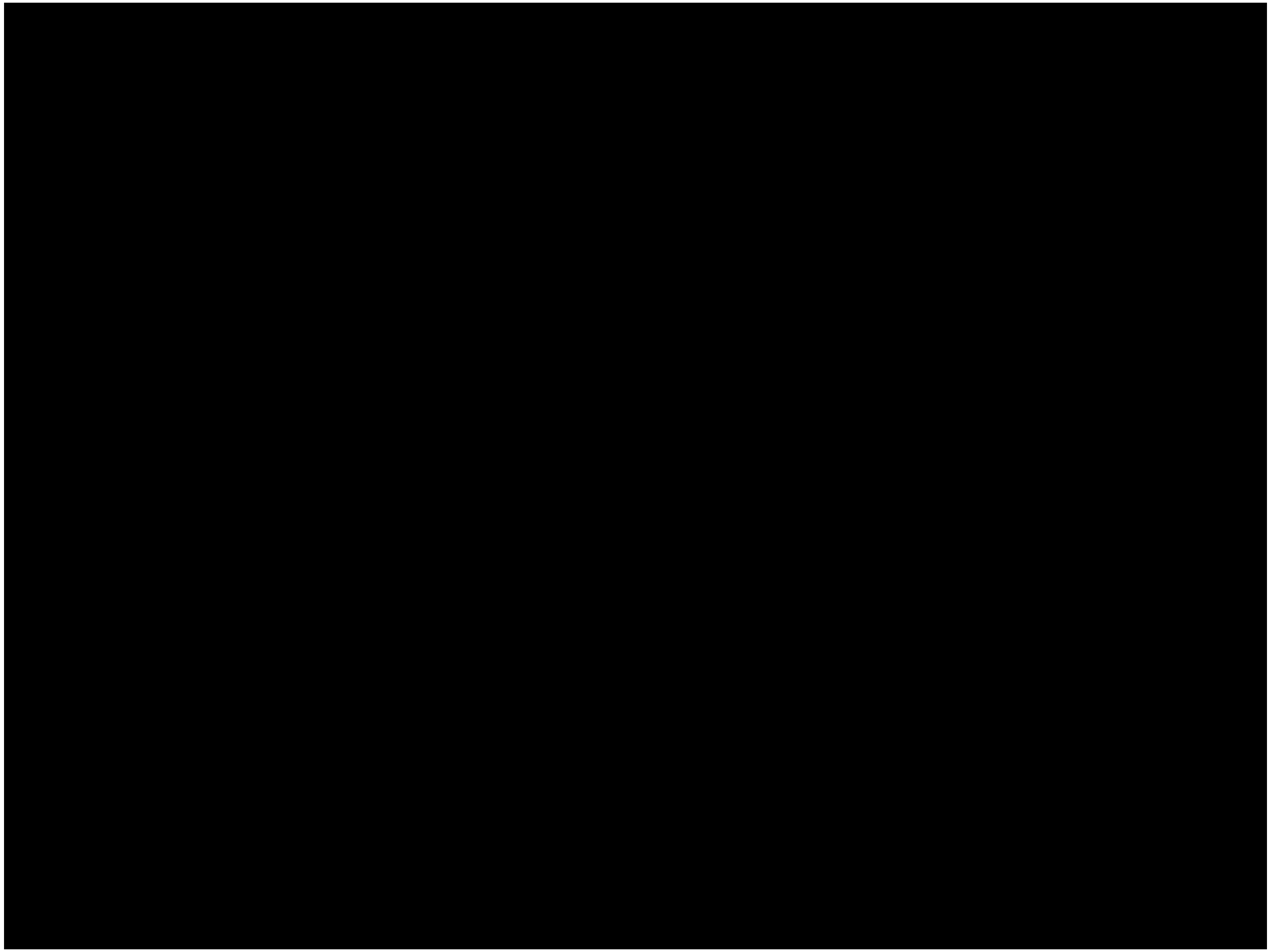
Issues in fatigue analysis



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Issues in Deterministic Fatigue Analysis

1. Identify all phenomena which contribute to fatigue
2. Translate phenomena into loads on structural members
3. Translate member loads into local stresses
4. Choose appropriate S-N curve
5. Carry out Damage calculation using Miner's Rule
6. Compare with design life accounting for Factors of Safety

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Examples

- Example – Bachelor
- Example – Master
- Current work

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Example - Bachelor

- Static models to identify loading conditions employing a varity of elementtypes in ANSYS Classic
- Static models in 3D solid in ANSYS Workbench to identify stress concentrations
- Dynamic models to compute eigenfrequency
- Establish dynamical models to generate a load history
- Hot-spot stress by, e.g. DNV or Eurocode
- Fatigue analysis by ANSYS/Workbench

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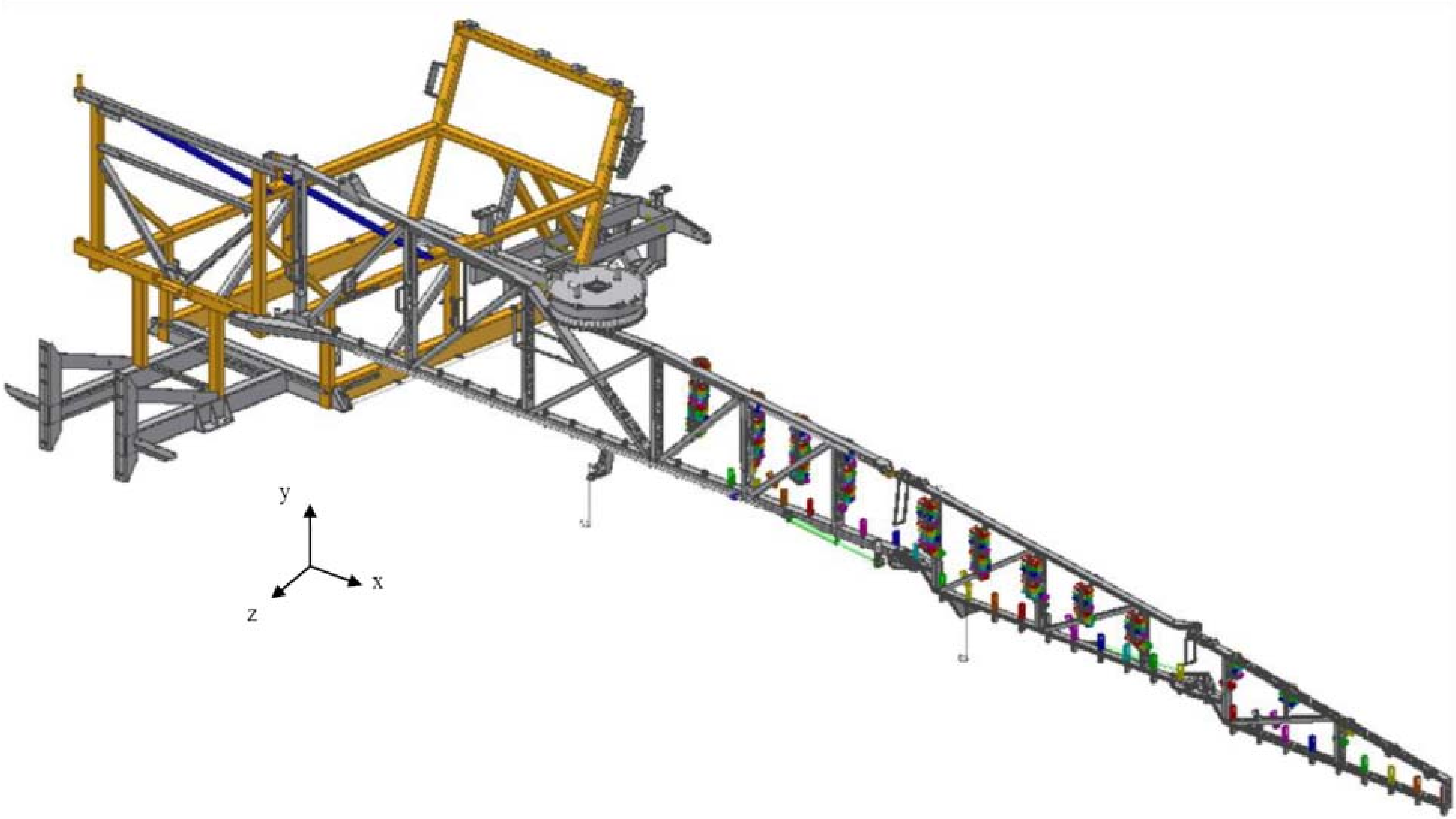
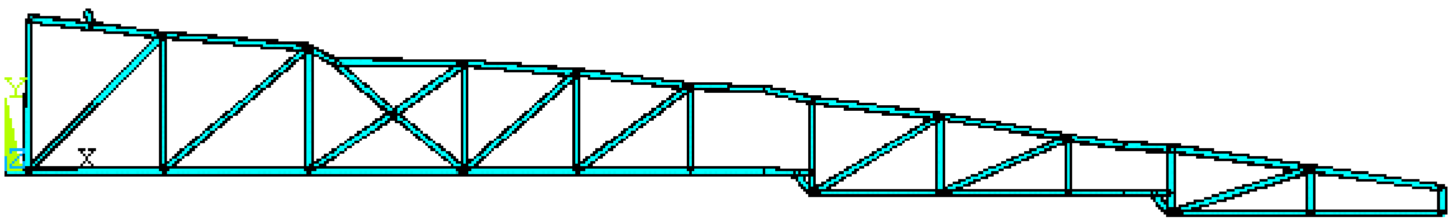
Example - Bachelor



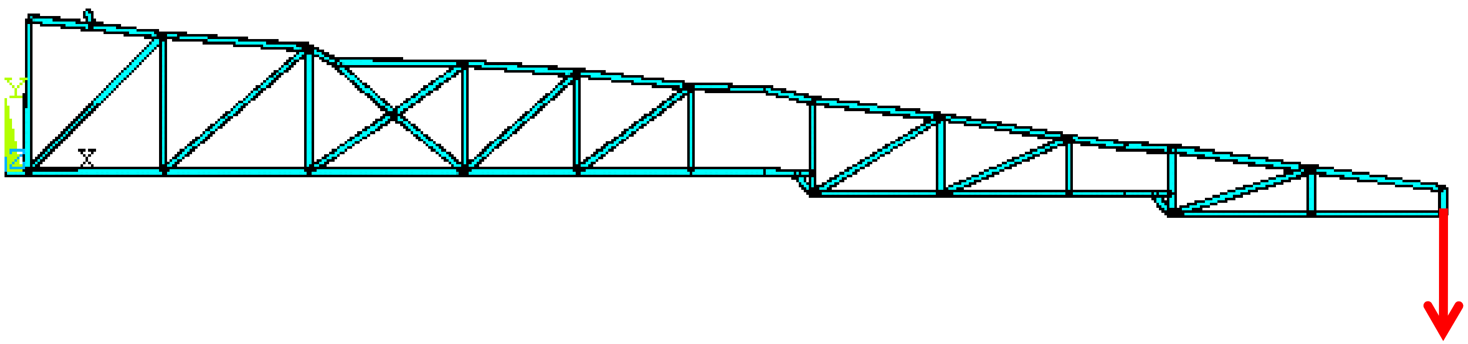
Lasttilfælde

- Lasttilfælde 1
  - Egenvægt af vingekonstruktion
  - Slanger med gylle



Lasttilfælde

- Lasttilfælde 2
  - Egenvægt af vingekonstruktion
  - Slanger med gylle
  - 1200 N i 3. sektion



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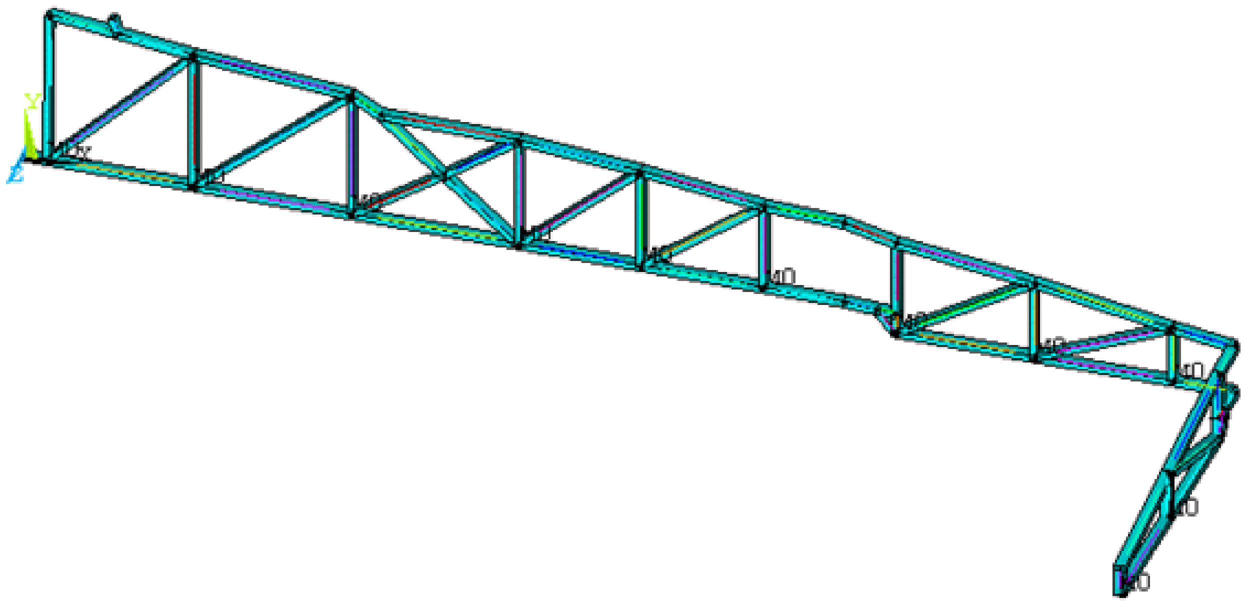
Lasttilfælde

- Lasttilfælde 3
  - Egenvægt af vingekonstruktion
  - Slanger med gylle
  - 3. sektion knækket i 90°

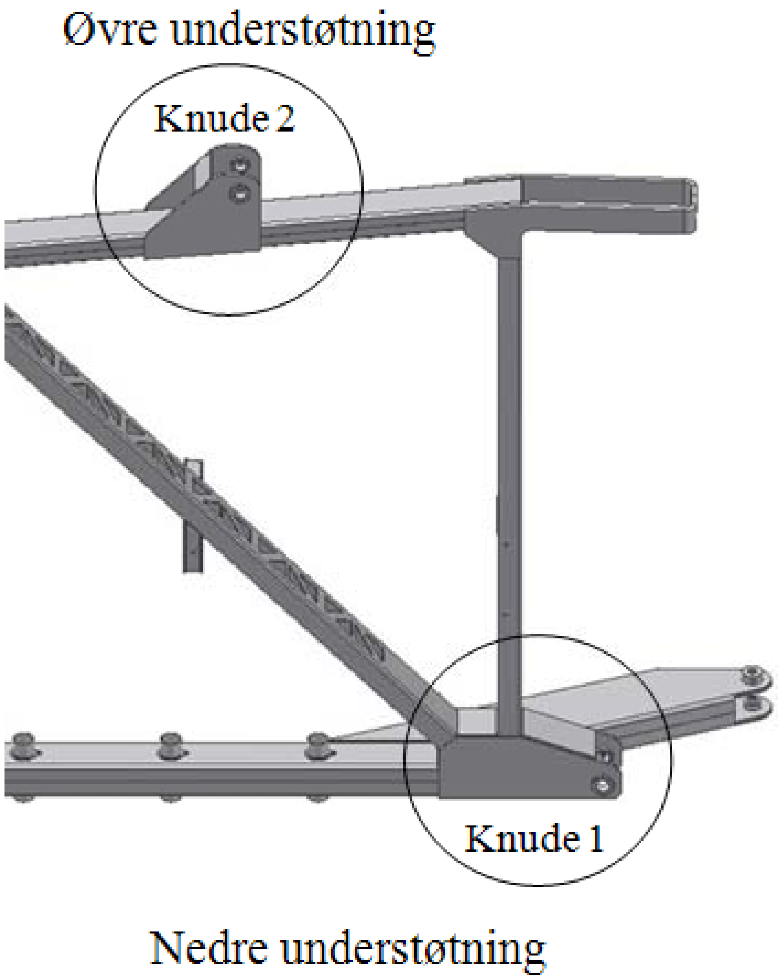


Bjælkemodel af vinge

- Randbetingelser

$$\boldsymbol{K}_{Global} \cdot \vec{v}_{Global} = \vec{r}_{Global}$$

$$\boldsymbol{K}_{Global} = Global\ stivhedsmatric\ \left[\frac{N}{m}\ el.\ \frac{Nm}{rad}\right]$$
$$\vec{v}_{Global} = Global\ flytningsvektor\ [m\ el. rad]$$
$$\vec{r}_{Global} = Global\ knudekraftvektor\ [N\ el. Nm]$$



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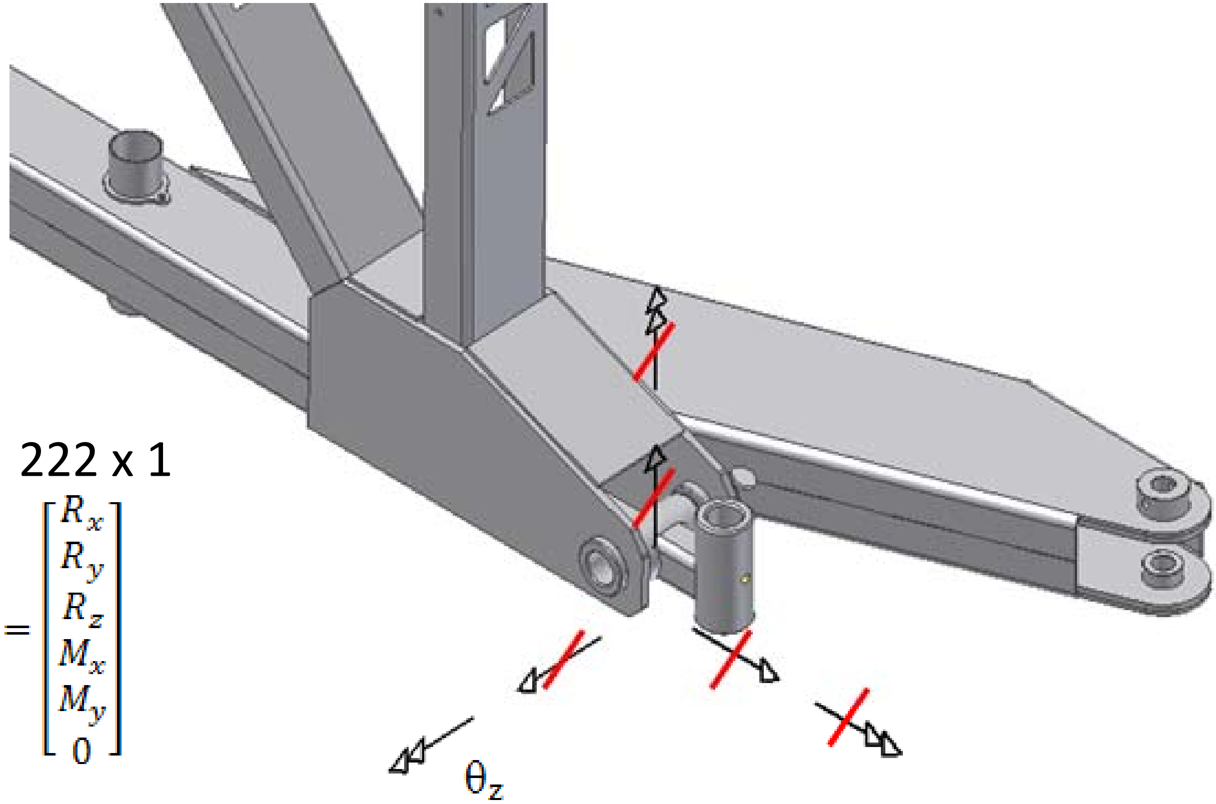
Bjælkemodel af vinge

222 x 222   222 x 1   222 x 1

$$\begin{bmatrix} & & \\ & \boldsymbol{K} & \\ & & \end{bmatrix} \cdot \begin{bmatrix} u_x = 0 \\ u_y = 0 \\ u_z = 0 \\ \theta_x = 0 \\ \theta_y = 0 \\ \theta_z \end{bmatrix} = \begin{bmatrix} R_x \\ R_y \\ R_z \\ M_x \\ M_y \\ 0 \end{bmatrix}$$



$$\boldsymbol{K}_{Global} \cdot \vec{v}_{Global} = \vec{r}_{Global}$$

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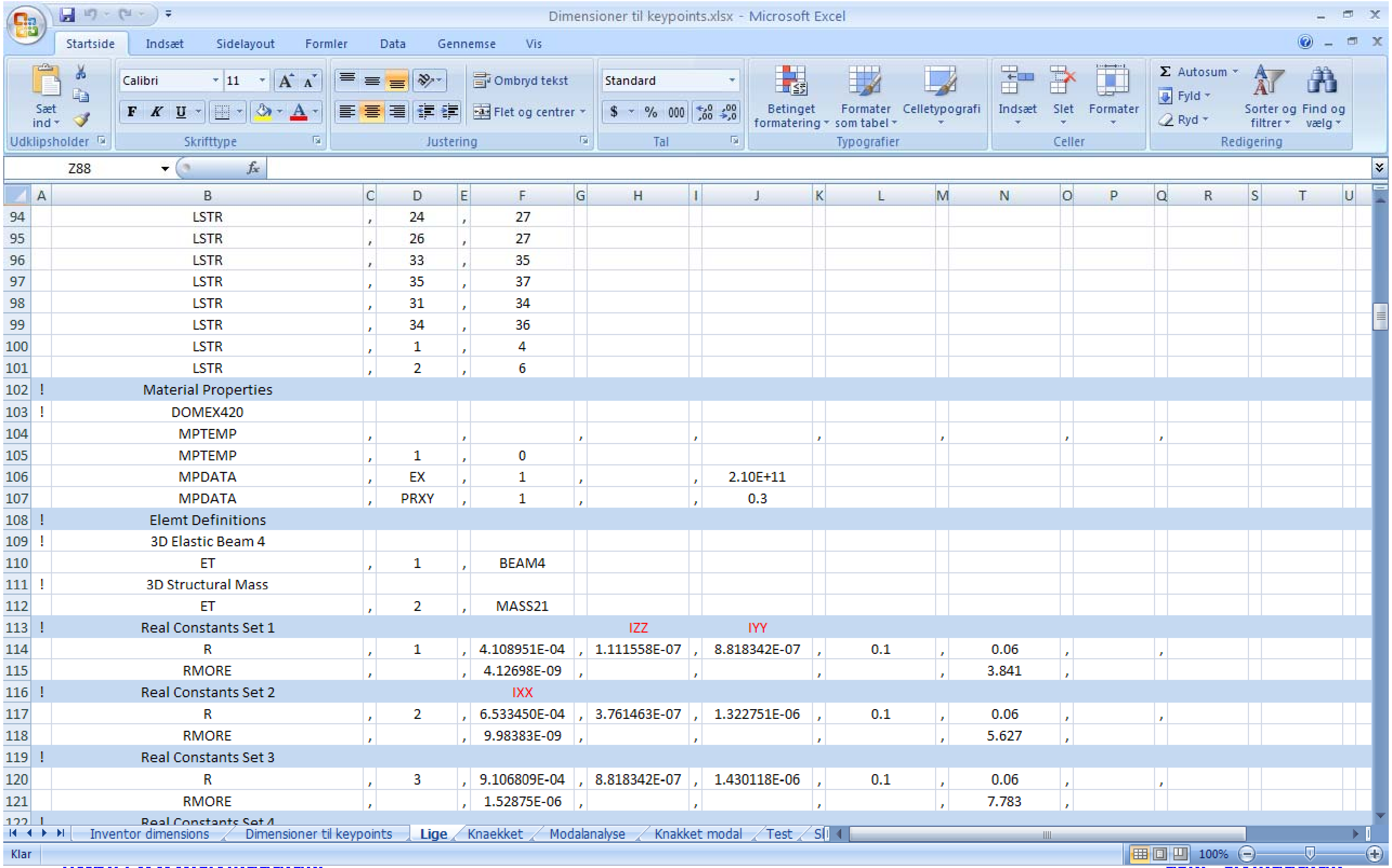
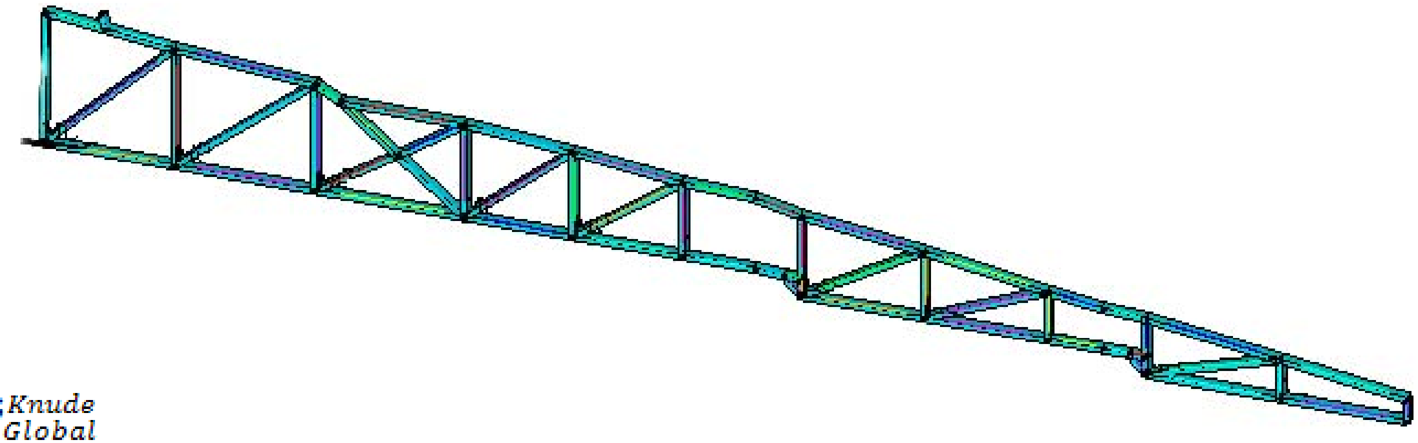
Opbygning af bjælkemodel



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
94		LSTR	,	24	,	27											
95		LSTR	,	26	,	27											
96		LSTR	,	33	,	35											
97		LSTR	,	35	,	37											
98		LSTR	,	31	,	34											
99		LSTR	,	34	,	36											
100		LSTR	,	1	,	4											
101		LSTR	,	2	,	6											
102	!	Material Properties															
103	!	DOMEX420															
104		MPTEMP	,		,		,		,		,		,		,		,
105		MPTEMP	,	1	,	0											
106		MPDATA	,	EX	,	1	,		,	2.10E+11							
107		MPDATA	,	PRXY	,	1	,		,	0.3							
108	!	Elemt Definitions															
109	!	3D Elastic Beam 4															
110		ET	,	1	,	BEAM4											
111	!	3D Structural Mass															
112		ET	,	2	,	MASS21											
113	!	Real Constants Set 1						IZZ		IYY							
114		R	,	1	,	4.108951E-04	,	1.111558E-07	,	8.818342E-07	,	0.1	,	0.06	,		,
115		RMORE	,		,	4.12698E-09	,		,		,		,	3.841	,		
116	!	Real Constants Set 2				IXX											
117		R	,	2	,	6.533450E-04	,	3.761463E-07	,	1.322751E-06	,	0.1	,	0.06	,		,
118		RMORE	,		,	9.98383E-09	,		,		,		,	5.627	,		
119	!	Real Constants Set 3															
120		R	,	3	,	9.106809E-04	,	8.818342E-07	,	1.430118E-06	,	0.1	,	0.06	,		,
121		RMORE	,		,	1.52875E-06	,		,		,		,	7.783	,		
122	!	Real Constants Set 4															

Bjælkemodel af vinge



$$\vec{v}_{Lokal}^{Knude} = \boldsymbol{T} \cdot \vec{v}_{Global}^{Knude}$$

$$\boldsymbol{k}_{Lokal} \cdot \vec{v}_{Lokal} = \vec{r}_{Lokal}$$

$$\boldsymbol{k}_{Lokal} = Lokal\ stivhedsmatric\ [\frac{N}{m}\ el.\ \frac{Nm}{"rad"}]$$
$$\vec{v}_{Lokal} = Lokal\ flytningsvektor\ [m\ el. "rad"]$$
$$\vec{r}_{Lokal} = Lokal\ knudekraftvektor\ [N\ el. Nm]$$

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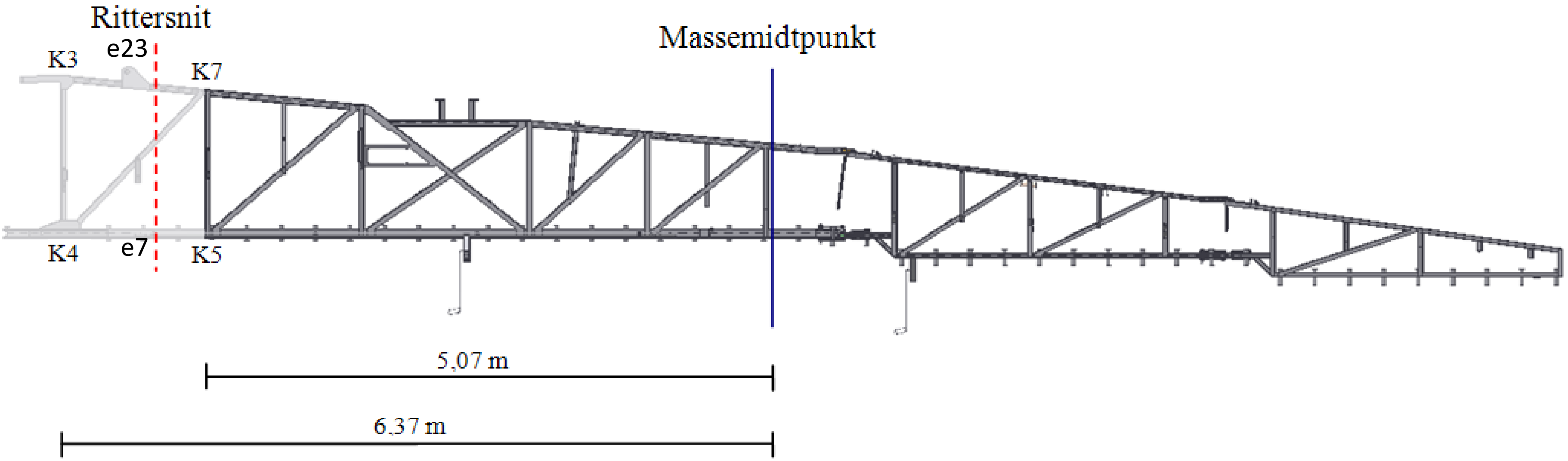
Validering

- Rittersnit



	Lasttilfælde 1			Lasttilfælde 2		
Normalkraft	**Rittersnit**	**Ansys Classic**	**Afvigelse**	**Rittersnit**	**Ansys Classic**	**Afvigelse**
N7	-27,6 kN	-25,2 kN	**9,5 %**	-38,9 kN	-36,6 kN	**6,3 %**
N23	27,4 kN	26,4 kN	**3,8 %**	37,6 kN	36,6 kN	**2,7 %**

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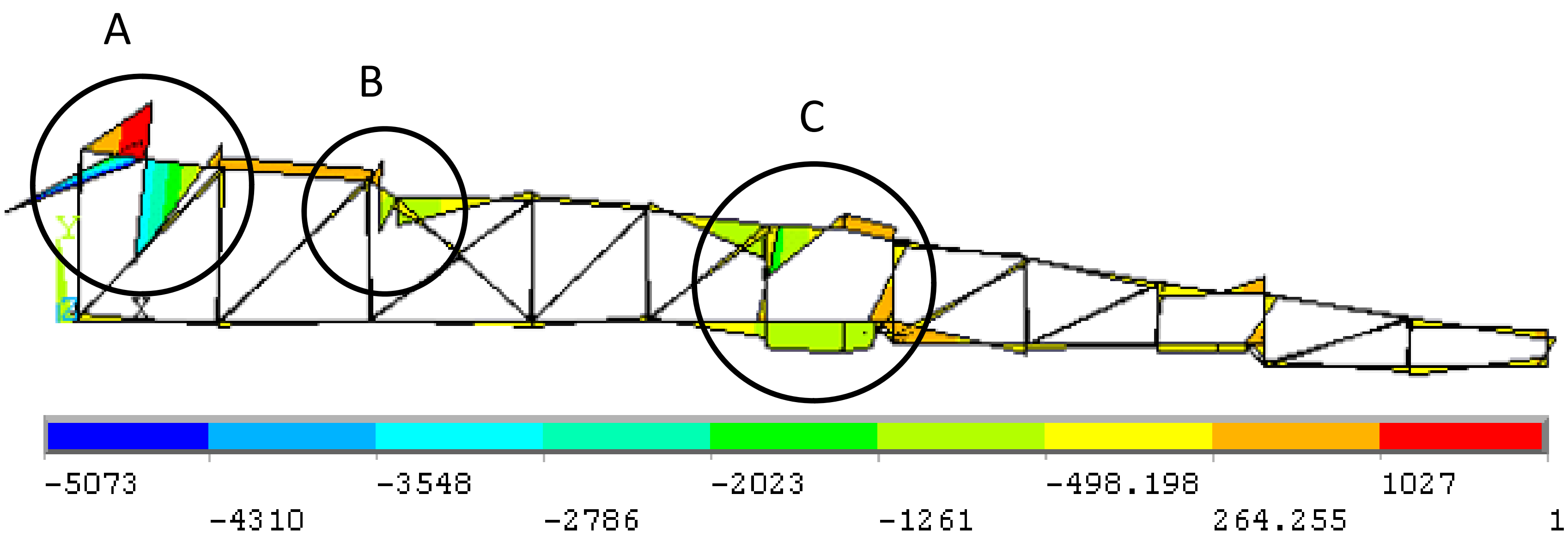
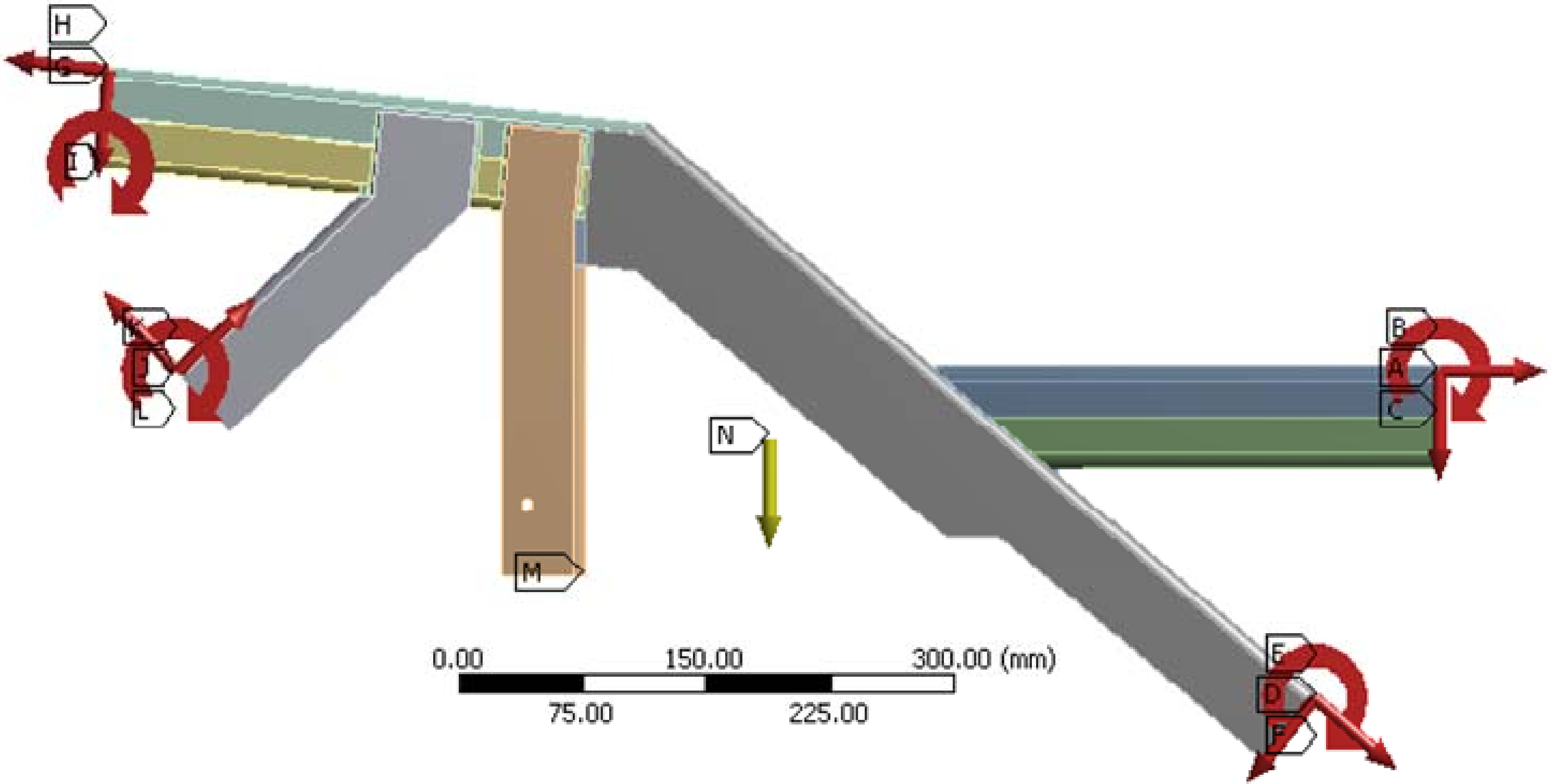
Resultater fra bjælkemodellen

- Lasttilfælde 2
  - Udbøjningen er 67,4 mm
  - Normalkræfter
  - Bøjningsmomenter om z-aksen



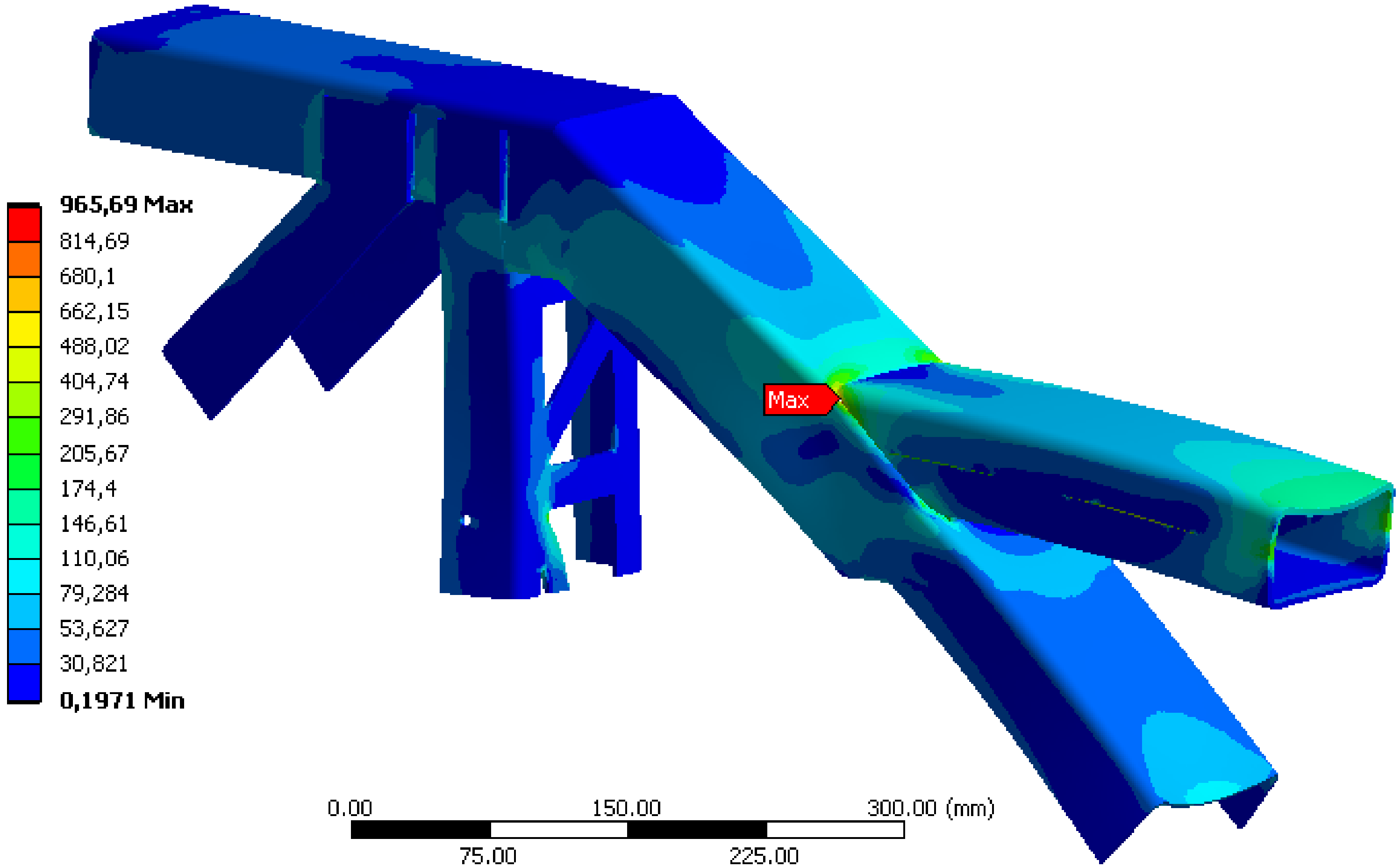
Analyse af knudesamling

- Kontrol af valgt knudesamling



Analyse af knudesamling

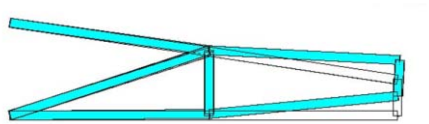
- Konvergensstudie af lasttilfælde 2
  - Refinement = 1, Meshrelevance = 85

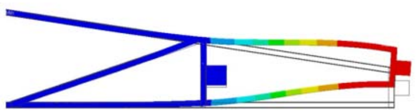


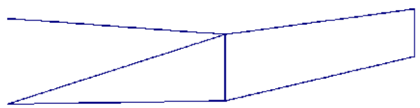
Validering

- Sammenligning af egenfrekvenser

Modeshape	Bjælkemodel	Solidmodel Inventor		Analytisk beregning	
	F [Hz]	F [Hz]	Afvigelse. [%]	F [Hz]	Afvigelse. [%]
1	21,6	22,5	+5,1	19,8	-8,3
2	64,2	68,9	+7,3	55,4	-13,7







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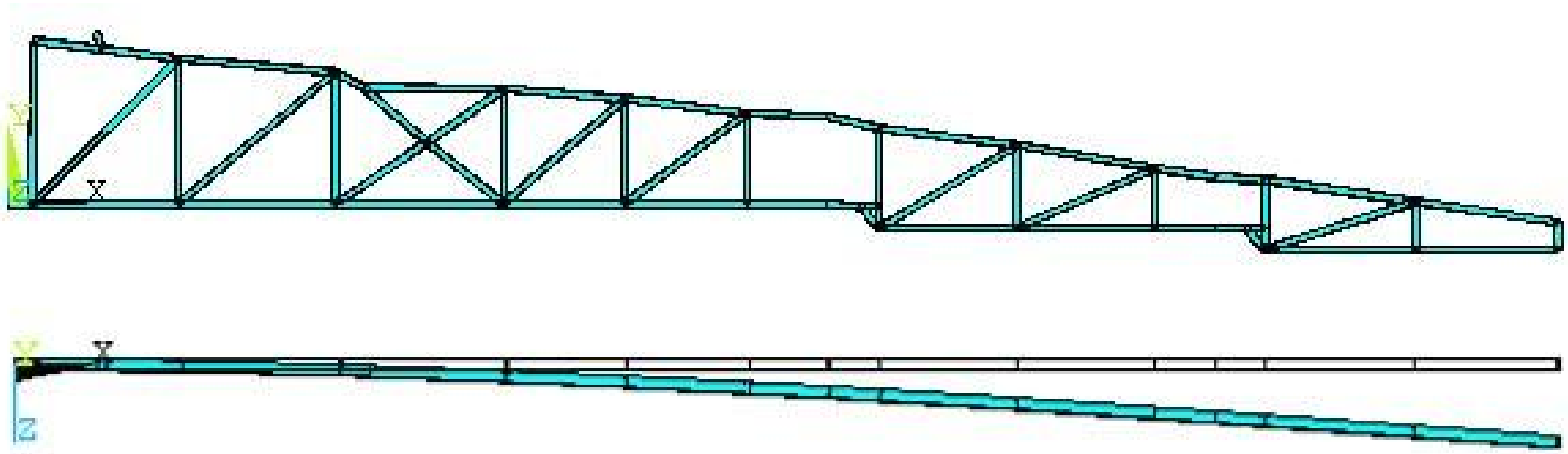
Modeshapes

- $F_{konstruktion,1} = 0,37\text{ Hz} < 3,33\text{ Hz}$



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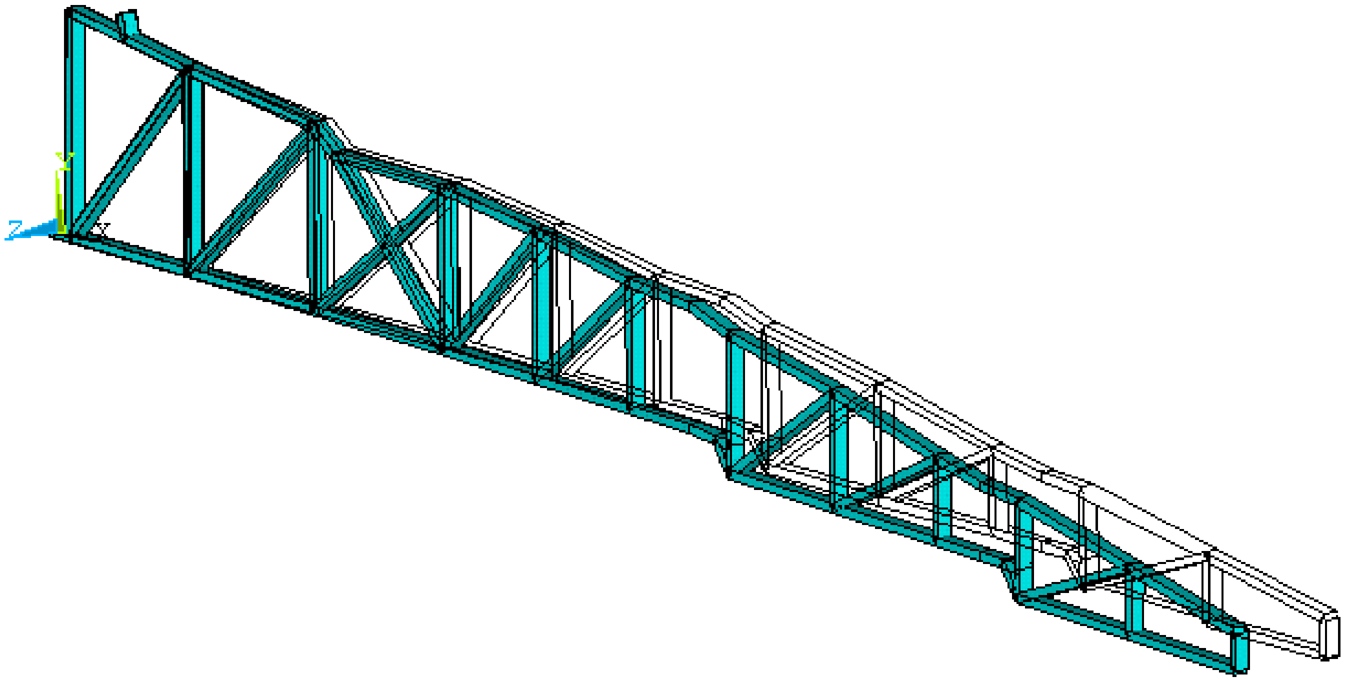
Modeshapes

- 2 laveste egenfrekvenser
  - $F_{konstruktion,1,2} < 3,33$ Hz



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Påvirkninger under kørsel

- Beregning af acceleration

$$\ddot{x}_p(t_{maks}) = \ddot{x}_p(0{,}23\ s) = 3{,}22\frac{m}{s^2}$$

$$\ddot{x}_{p,maks} =^{+}_{-} 3{,}22\frac{m}{s^2}$$

- Påvirkninger på konstruktionen

$$a_{maks} = 9{,}82\frac{m}{s^2} + 3{,}22\frac{m}{s^2} = 13{,}04\frac{m}{s^2}$$

$$a_{min} = 9{,}82\frac{m}{s^2} - 3{,}22\frac{m}{s^2} = 6{,}60\frac{m}{s^2}$$

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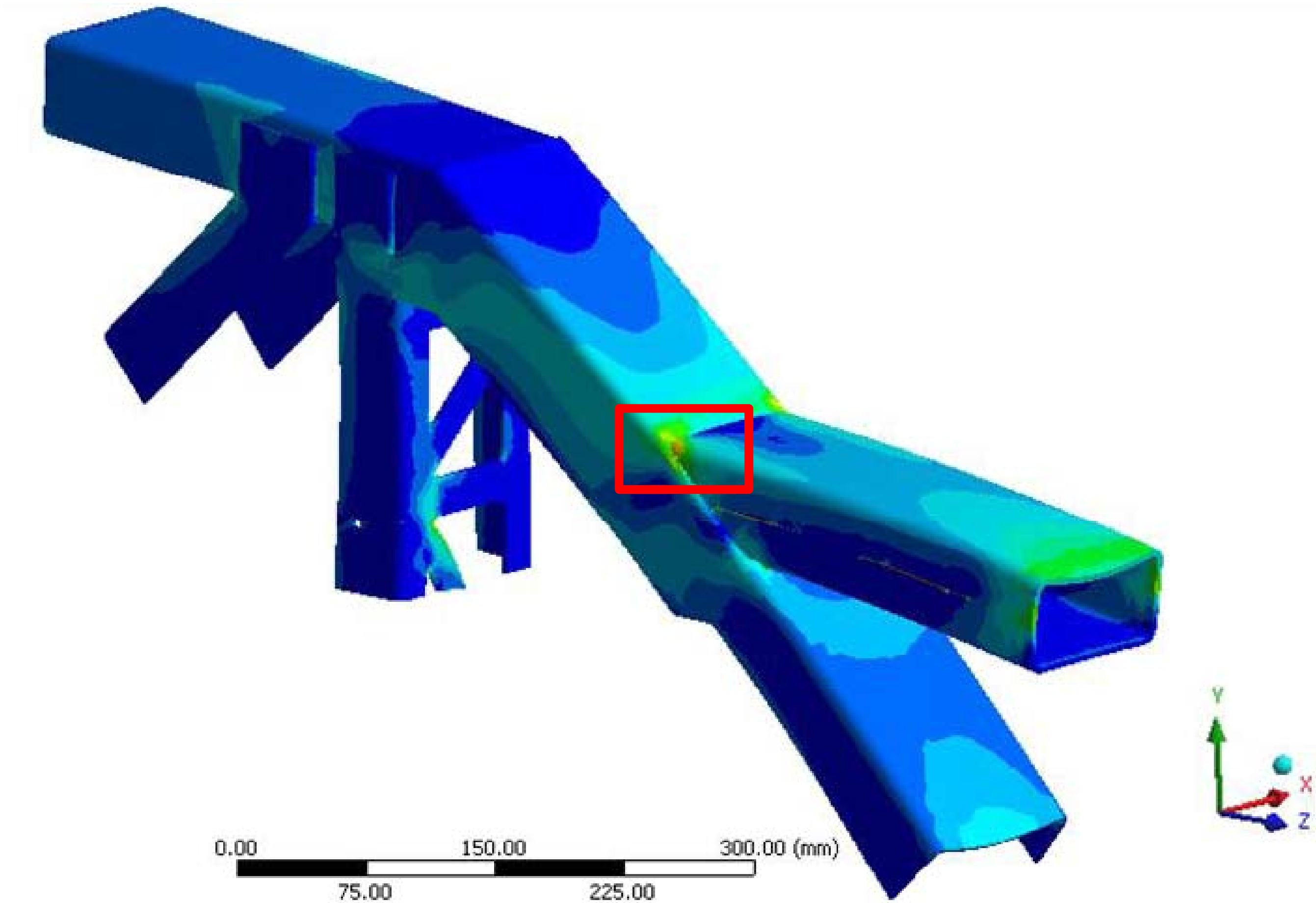
Udmattelse efter DS 412

- Knudesamling [K10] mellem e25 og e6



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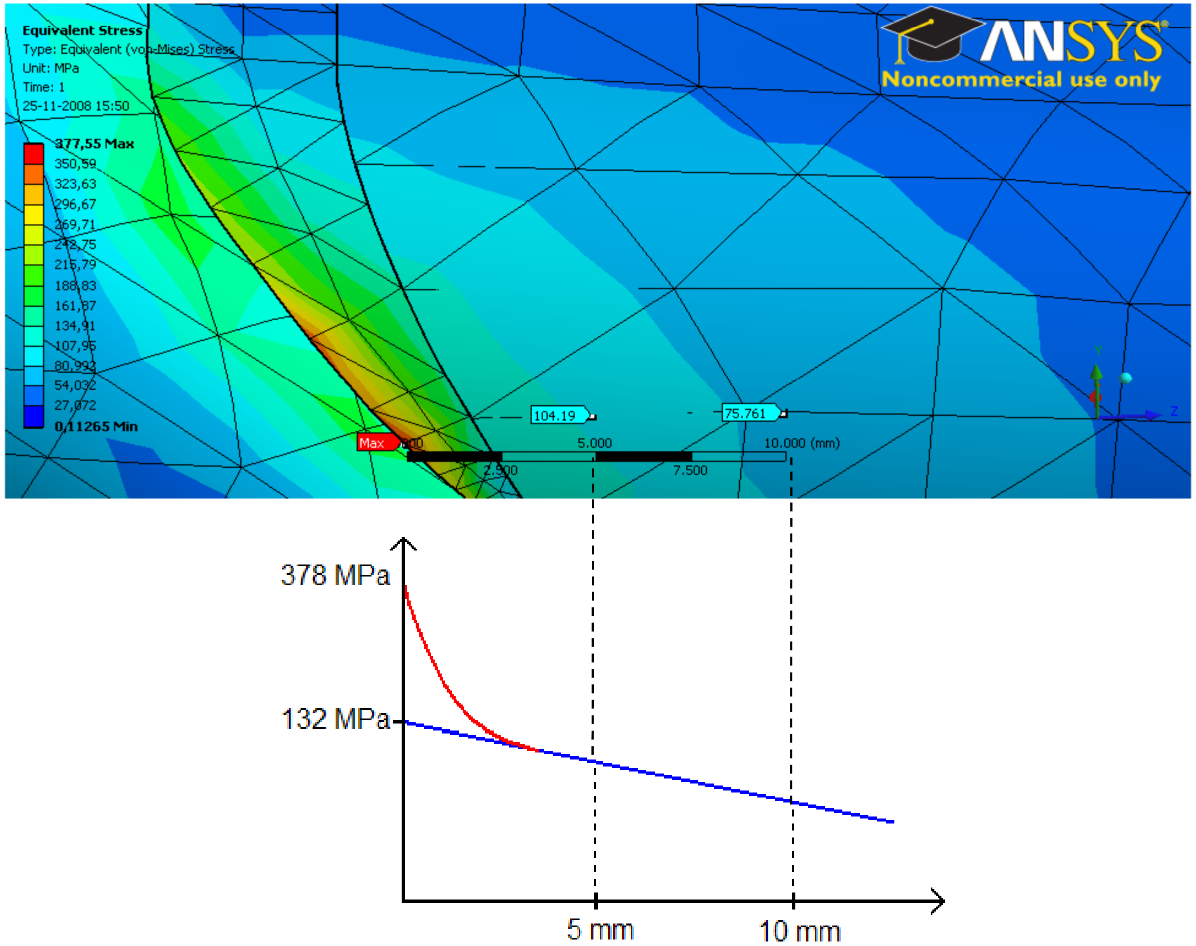
Udmattelse efter DS 412

- Hot spot analyse ved en acceleration på $6{,}60\ \frac{m}{s^2}$



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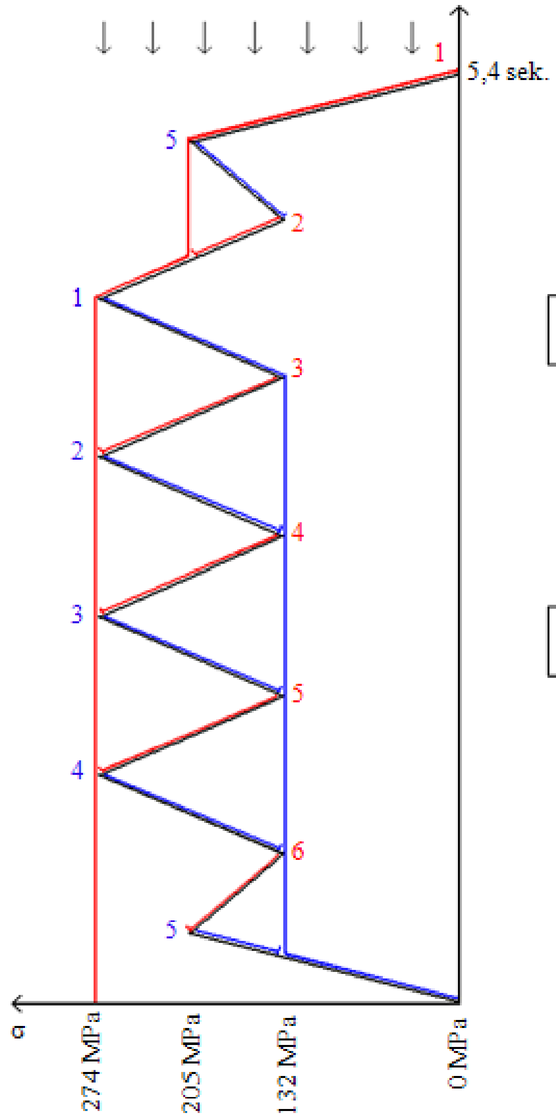
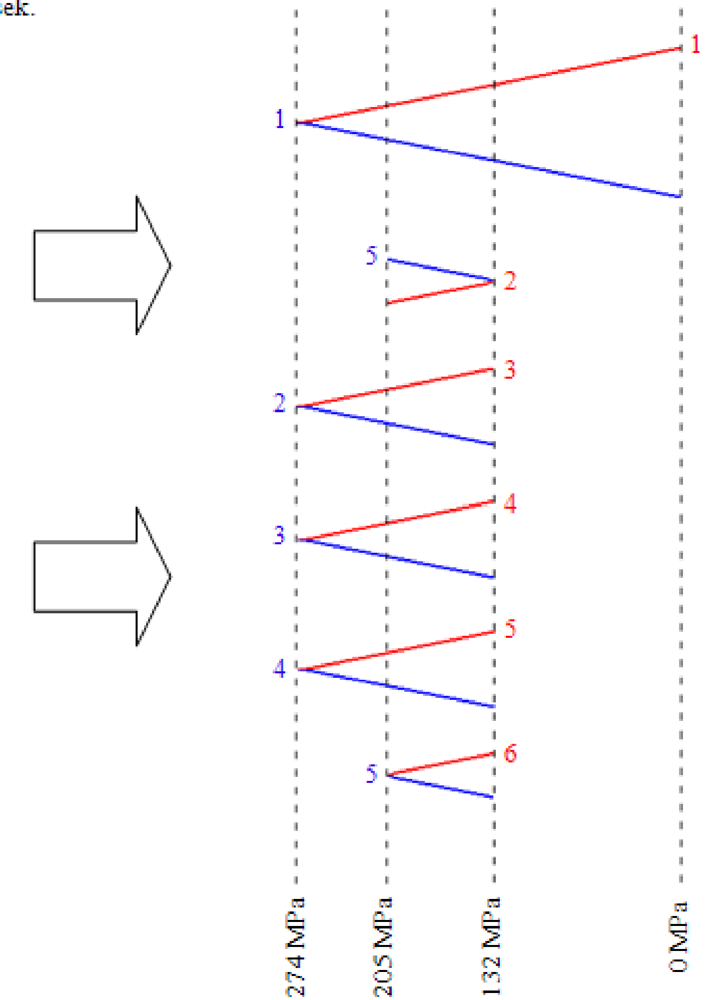
Udmattelse efter DS 412





1 x 274 MPa
3 x 142 MPa
2 x 73 MPa

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Levetidsberegning efter DS 412

Spændingsvidde	Antal påvirkninger		Påvirkninger før brud	Delskader
σ_{fat}	Cyklus	n_5	n_{fat}	n_5/n_{fat}
274 MPa	1	73720	137330	0,5368
142 MPa	322	23737840	986628	24,0596
73 MPa	2	147440	7261893	0,0203
			I alt	24,6167

- Beregning af fatale antal påvirkninger [n_{fat}]

$$\log(n_{fat}) = log(a) - m \cdot log(\sigma_{fat})$$

$$n_{fat} = 137330$$

- Beregning af delskade

$$\frac{n_5}{n_{fat\,1}} = \frac{73720}{137330} = 0{,}536$$

- Beregning af levetid

$$Levetid\ i\ \text{år} = 5\ \text{år} \cdot \frac{1}{24{,}61} = 0{,}2\ \text{år} \sim 240\ timer$$

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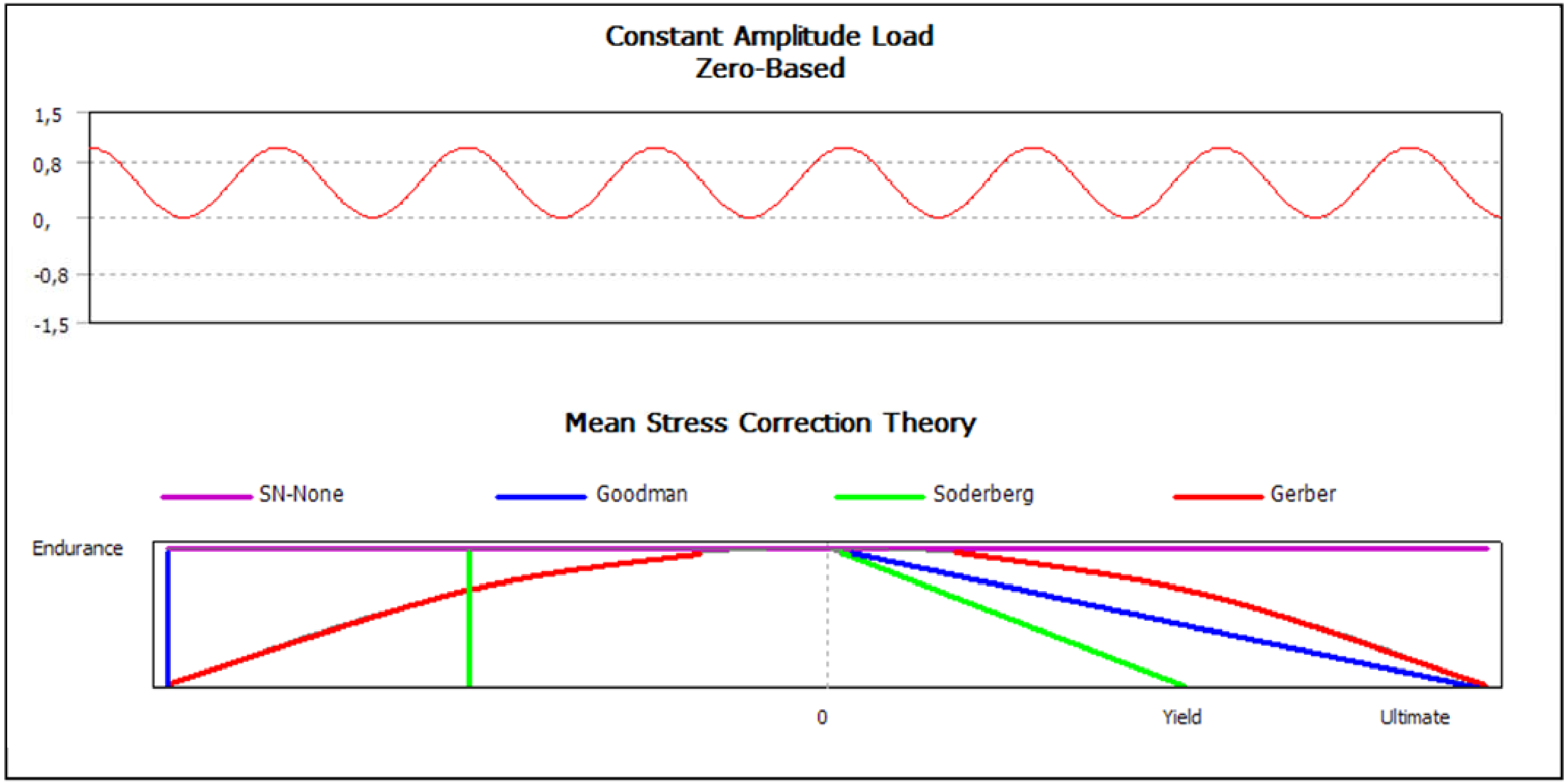
Levetidsberegning i Workbench

- Dynamisk kraftpåvirkning

Normalkraft ved 13,09 $\frac{m}{s^2}$	Normalkraft ved 6,55 $\frac{m}{s^2}$	Dynamisk normalkraft
17152 N	8586 N	8566 N



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Sammenligning af levetid

- Levetid vha. Ansys Workbench
  - 347 timer
- Levetid efter DS 412
  - 240 timer

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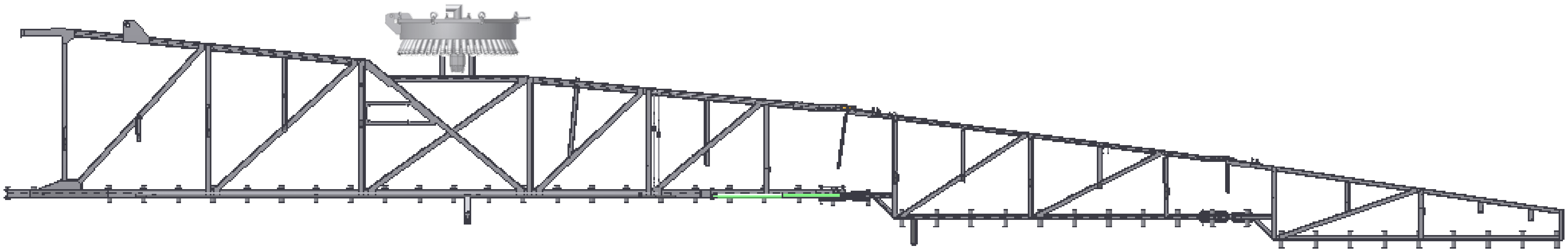
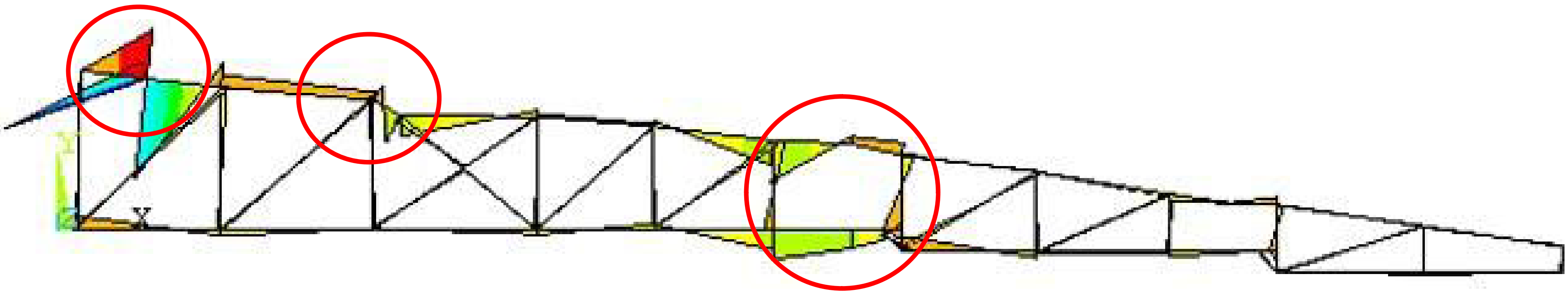
Optimering





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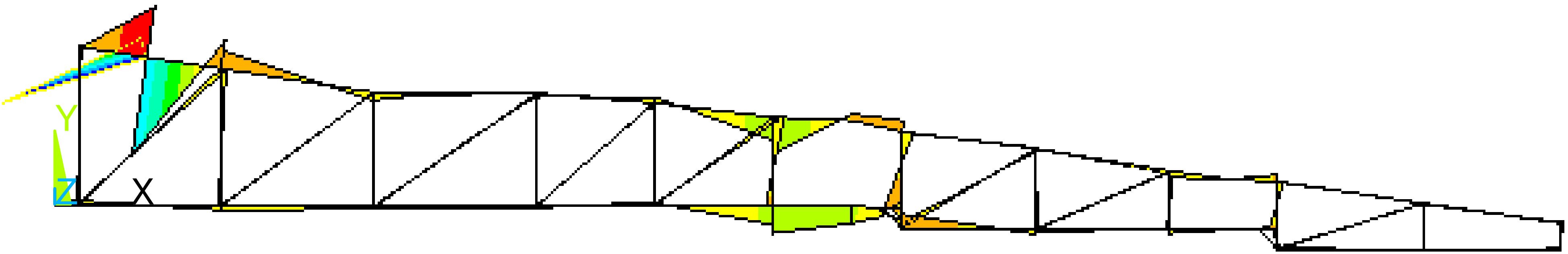
Optimering

- Resultater af den redesignede knude
  - Uændrede normalkræfter
  - Reducerede forskydningskræfter
  - Reducerede bøjningsmomenter med 50 %



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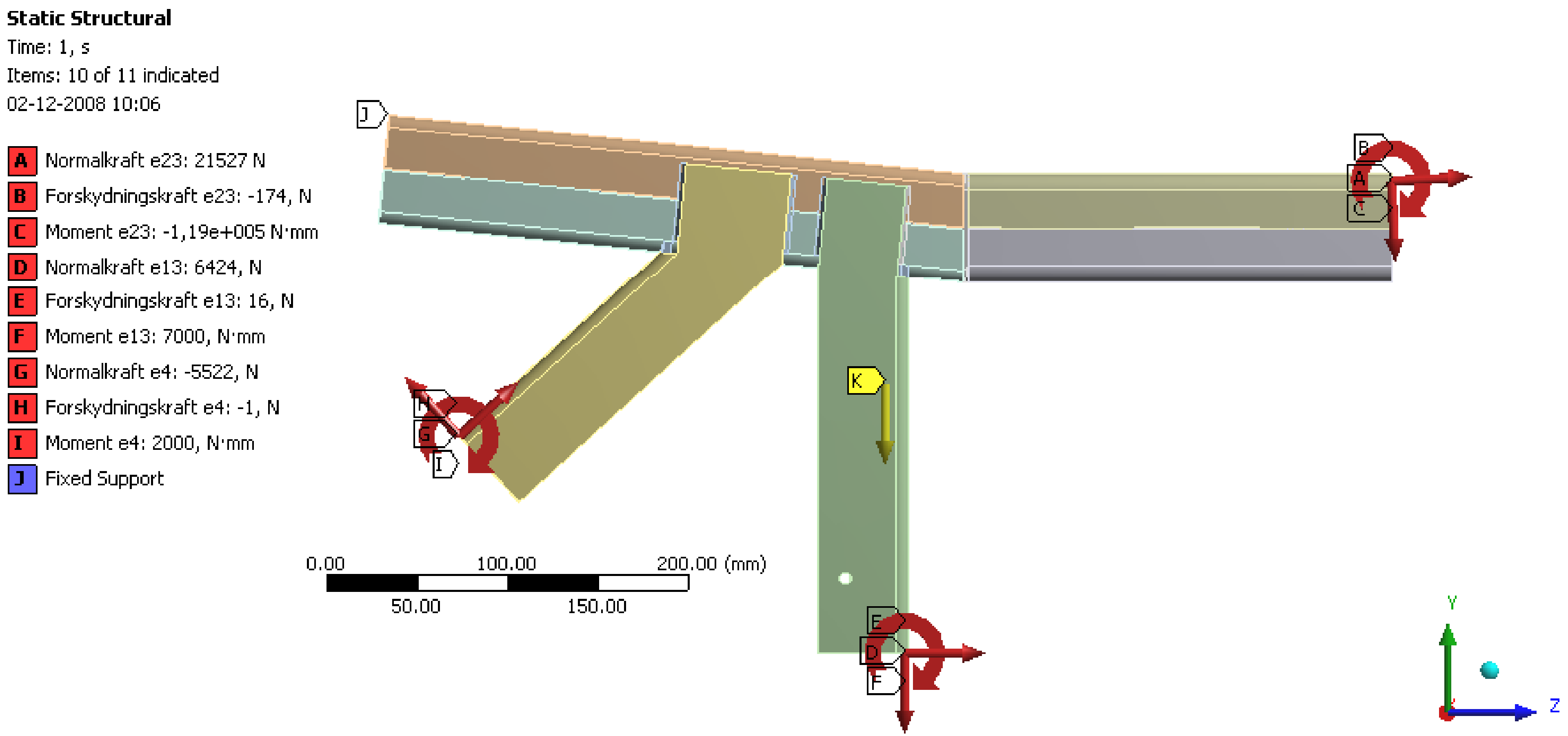
Optimering

- Spændingsanalyse i Ansys Workbench



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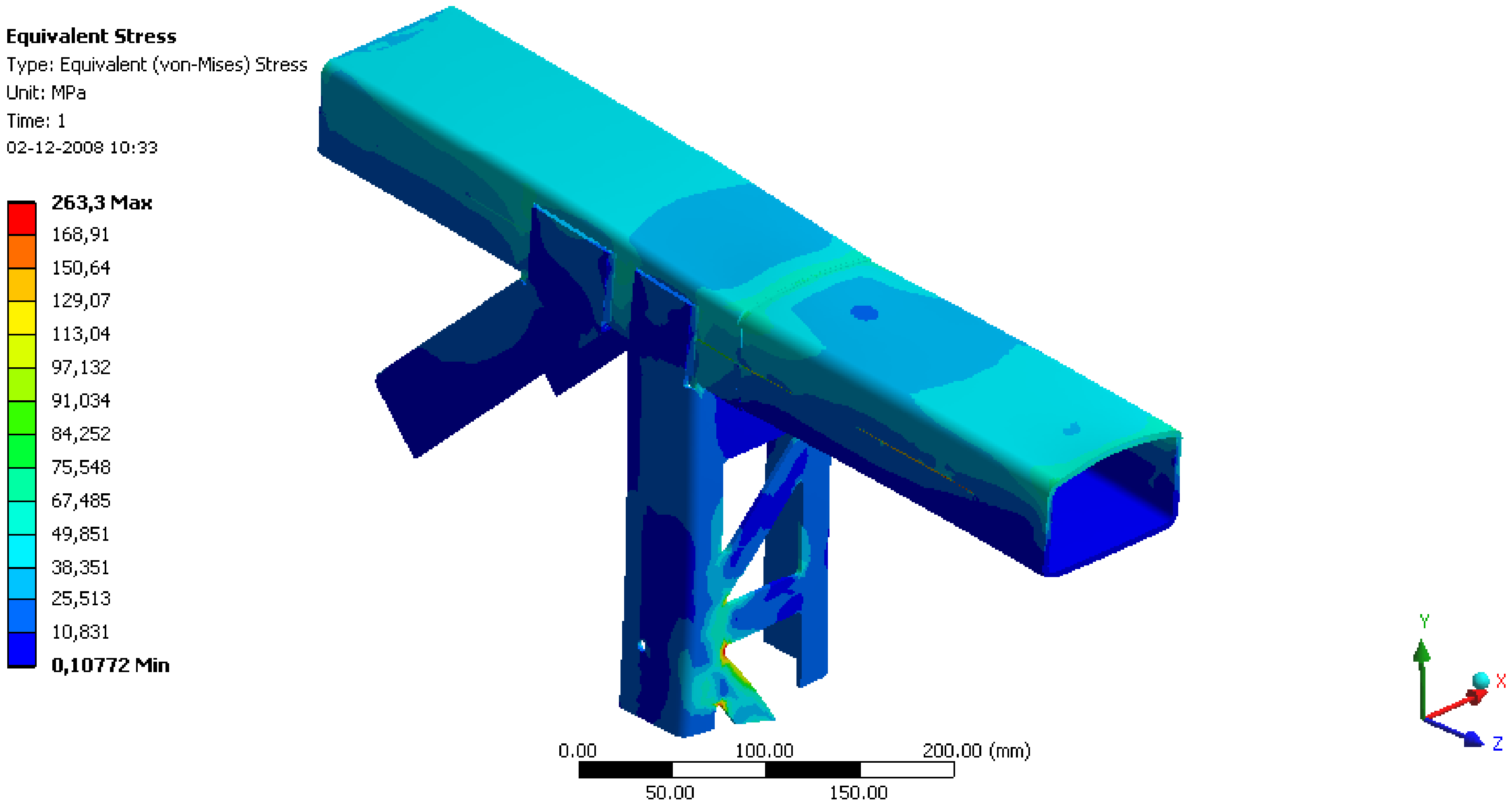
Optimering

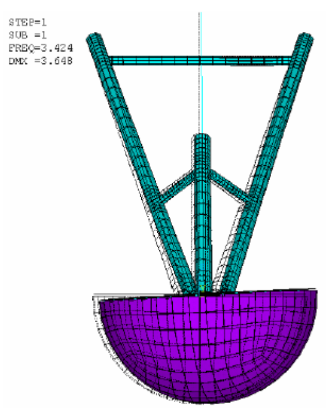
- Spændinger i redesignede knude



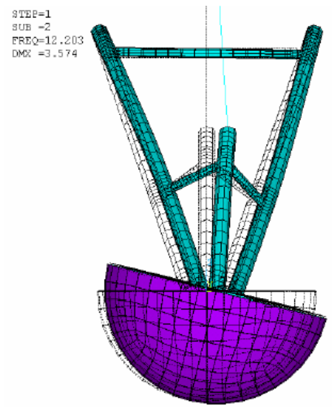
Example - Master

- Static models to identify loading conditions employing a varity of elementtypes in ANSYS Classic
- Dynamic models to compute eigenfrequency
- Establish flexible multibody dynamic models
- Joint flexible study by ANSYS Classic beam models
- JONSWAP spectrum for fatigue analysis
- Hot-spot stress by DNV

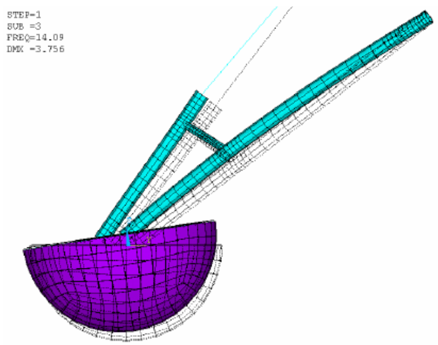
Example - Master



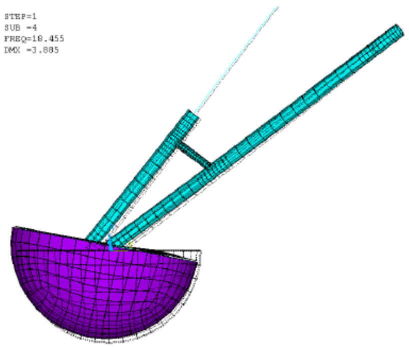
Mode 1: Flyder og arm bøjer let ud til siden



Mode 2: Flyder og arm vrides sidevejs

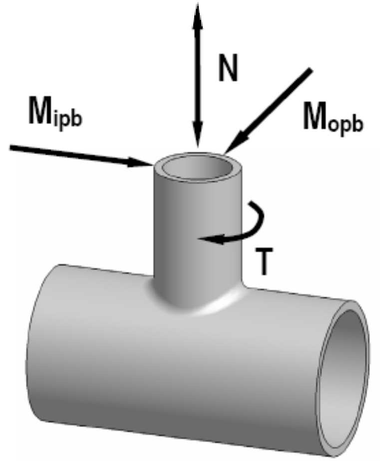


Mode 3: flyder og arm vrides forover.

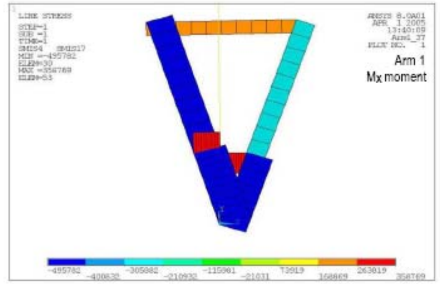


Mode 4: Flyder og arm bøjes op.

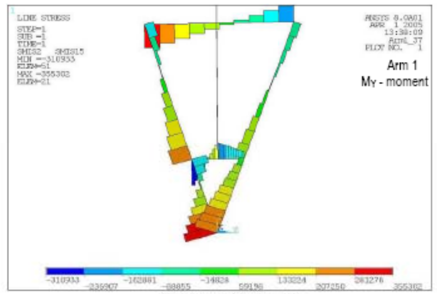
Figur 87: De 4 laveste mode shapes



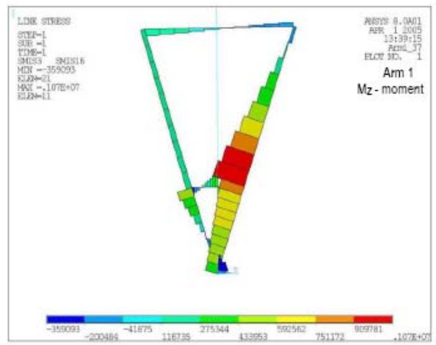
Rørknudesamling påsat dimensionsgivende kræfter



Figur 171: Arm 1 – M_X



Figur 172: Arm 1 – M_Y



Figur 173: Arm 1 – M_Z

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Example - Master

Armen beregnes nu for udmattelse ud fra det forventede antal påvirkninger i den budgetterede levetid. Dertil anvendes elasticitetsteorien, og det forudsættes, at armen er effektivt korrosionsbeskyttet under hele sin levetid. Til beregning af levetiden og under forudsætning af at påvirkningerne er tilfældigt fordelte spændingsvidder, anvendes Palmgren-Miners formel (65) til kontrol.

$$\sum_i \left(n_{f,i} / n_{fatd,i}\right) \leq 1 \qquad (65)$$

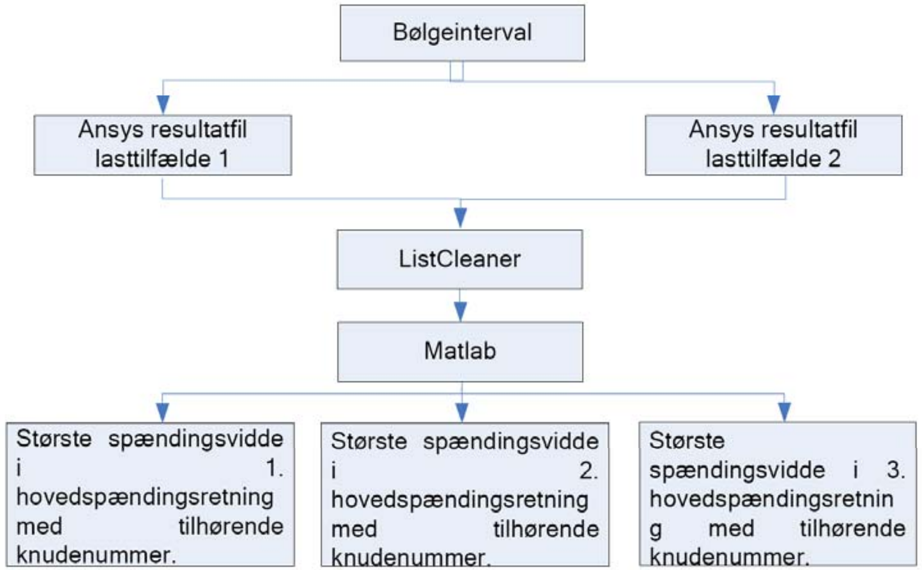
$n_{f,i}$ er det aktuelle antal påvirkninger ved en spændingsvidde $\Delta\sigma_{hot\ spot}$

$n_{fatd,i} = \dfrac{n_{fat,i}}{\gamma_m}$ er den regningsmæssig udmattelsestallet svarende til $\Delta\sigma_{hot\ spot}$

$n_{fat,i}$ er udmattelses tallet som kan aflæses ved en given σ_{fat} i Figur 100

$\gamma_m = 1.43$ er partialkoefficienten for udmattelsesstyrken σ_{fat} efter DS 412

$$n_{fat} = \begin{cases} \dfrac{3.72 \cdot 10^{14}}{\left(\sigma_{fat}\right)^{4.1}} & for \quad \sigma_{fat} \geq 34\,MPa \\ \infty & for \quad \sigma_{fat} < 34\,MPa \end{cases} \qquad (66)$$



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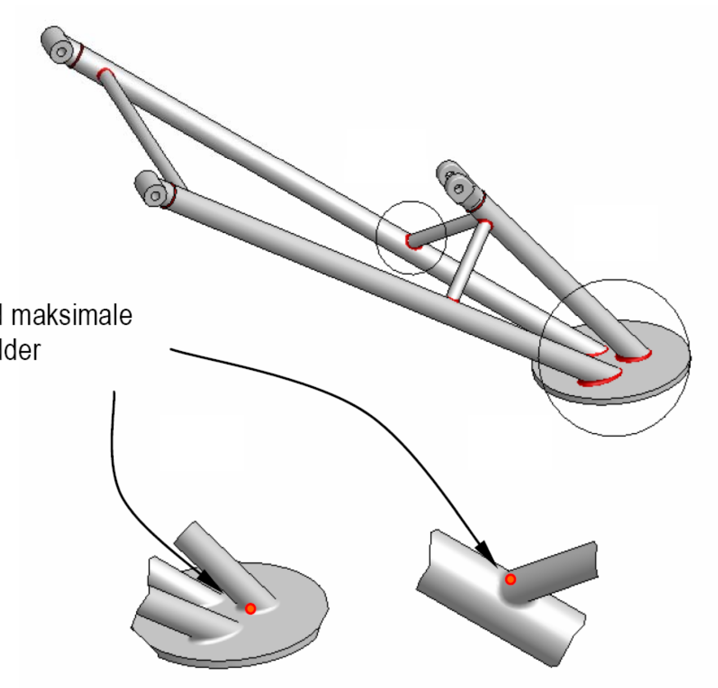
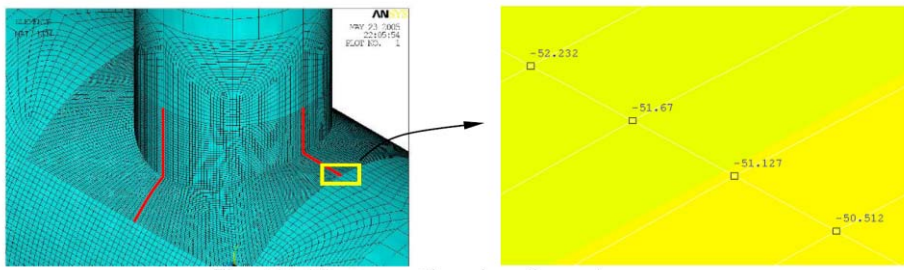
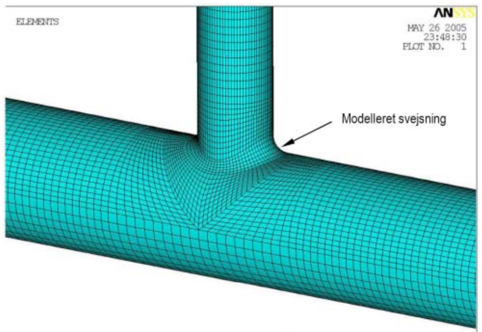
Example - Master

Områder med maksimale spændingsvidder





Figur 195: Aflæste spændinger i samlingens krone



Figur 198: Solidmodel af T-samling

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Current projects

- Analysis of snow blasting machine – 5. semester project
- Fatigue analysis of flame cut steel components - bachelor graduate project
- Development of fatigue test rig for educational purposes – bachelor graduate project
- Fatigue analysis of lazer welded steel components – master graduate project
- Large deformation analysis of solar panel structure – research project

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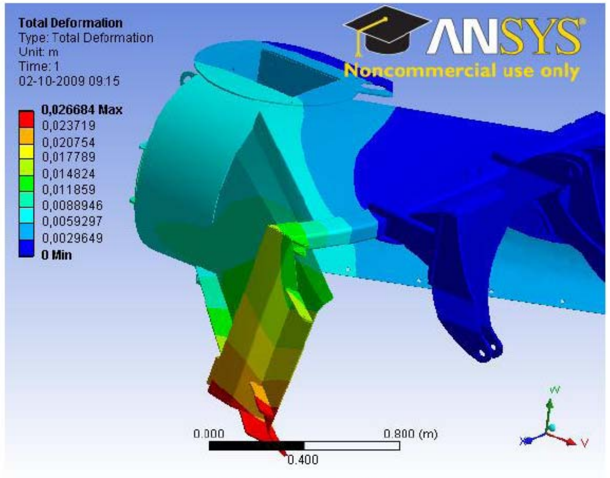
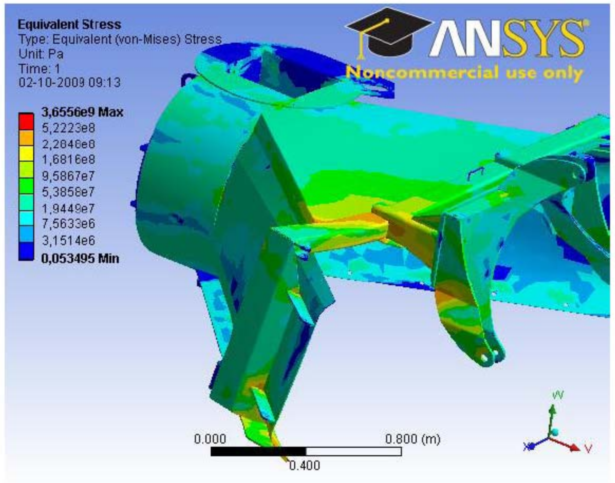
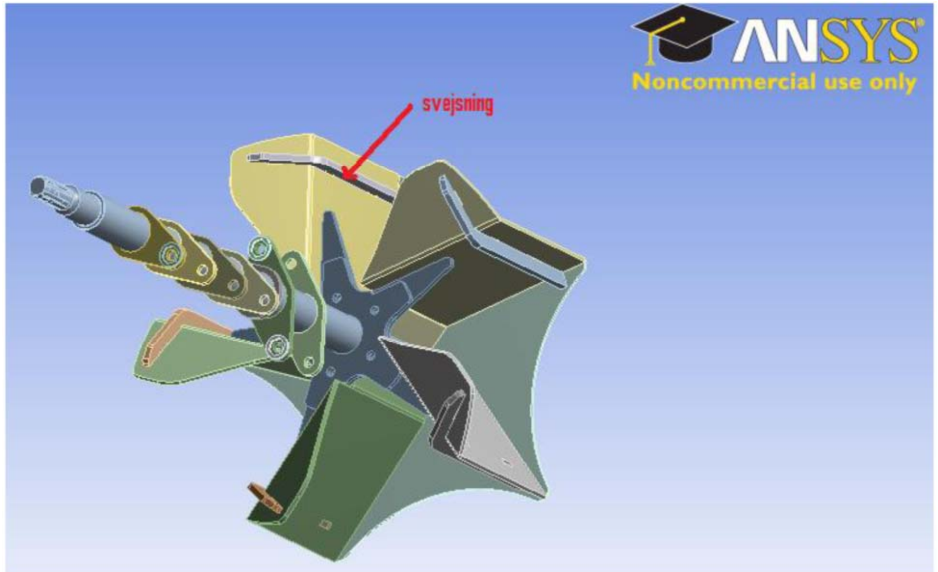
Example – Snow blasting machine

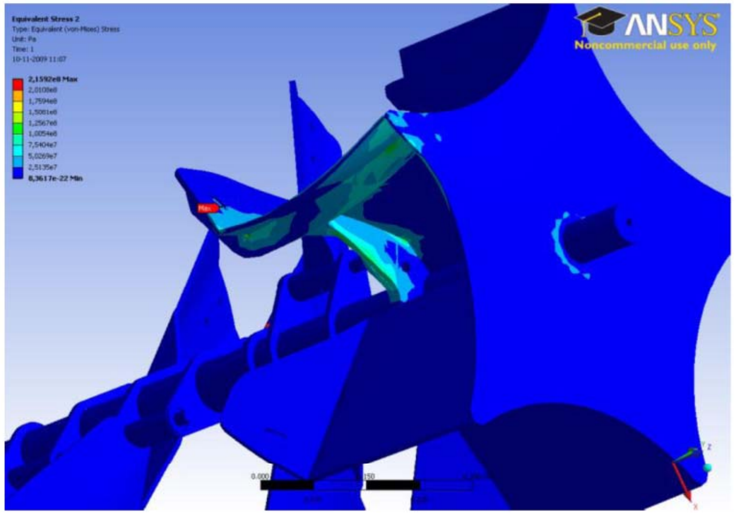


Figur 6 udbøjning i Ansys



Figur 7 spændingen i Ansys





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Summary

- Full 3D solid FEA will increase
- Emphasize on FE teaching
- Focus on mechanical and structural behavior
- Validation is key
- Important with real problems to push technology transfer and build students confidence

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