Durability analysis of a harvesting vehicle

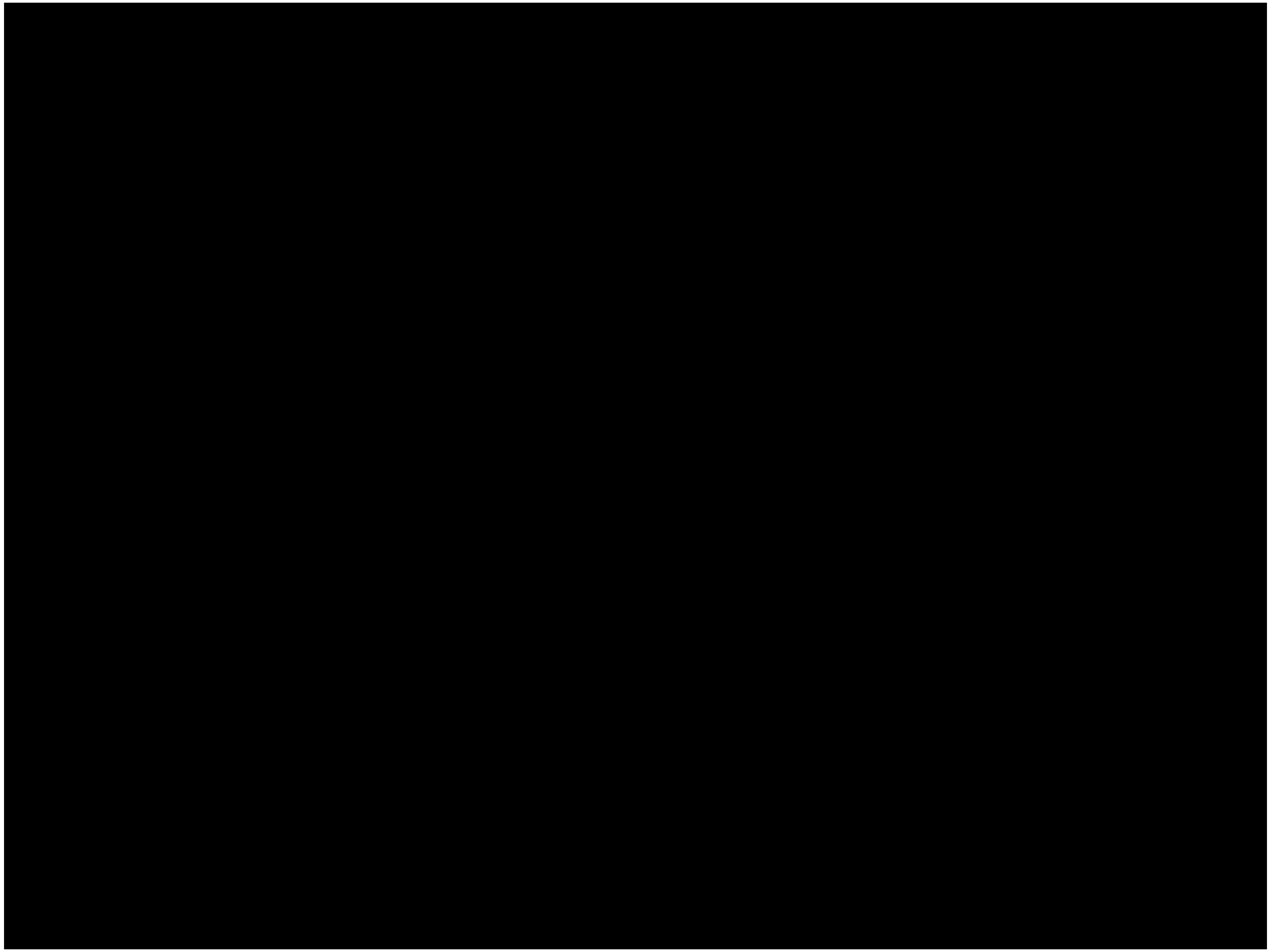
A. Kristensen

Computational Mechanics Group
Esbjerg Institute of Technology
Aalborg University

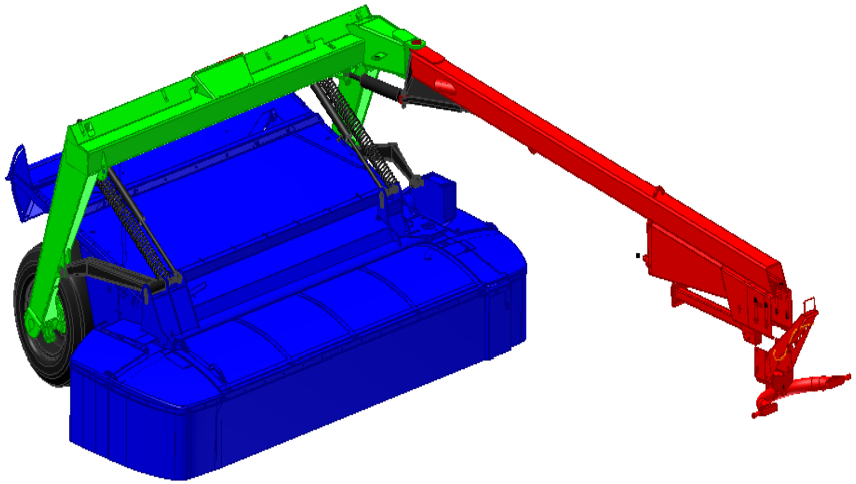
Outline

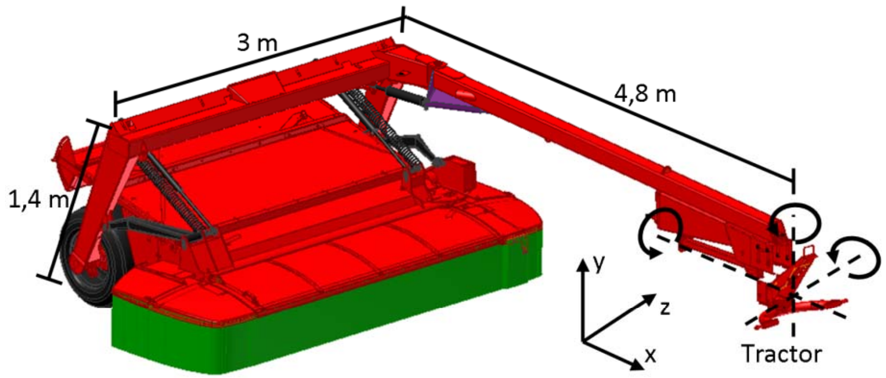
- The harvester vehicle
- Loading scenario
- Load history
- Vehicle modeling – dynamic beam model
- Vehicle modeling – modal system
- ANSYS/MatLab implementation
- Fatigue analysis
- Results
- Conclusions

The harvester vehicle



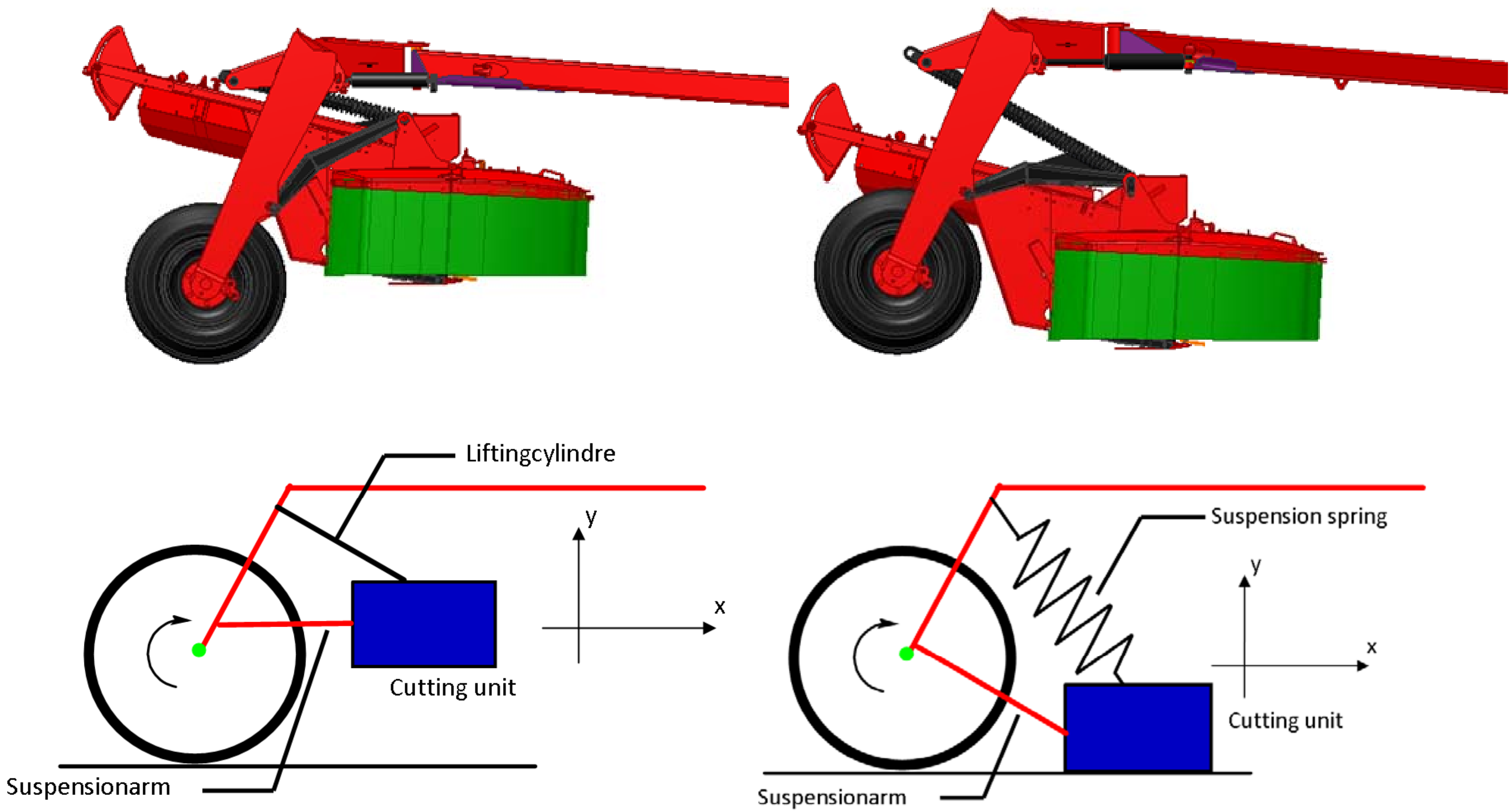
The harvester vehicle





Loading scenario

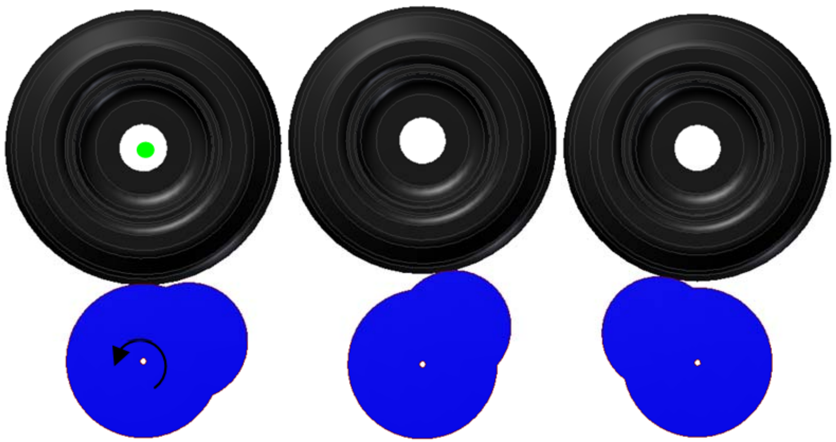
Loading scenario

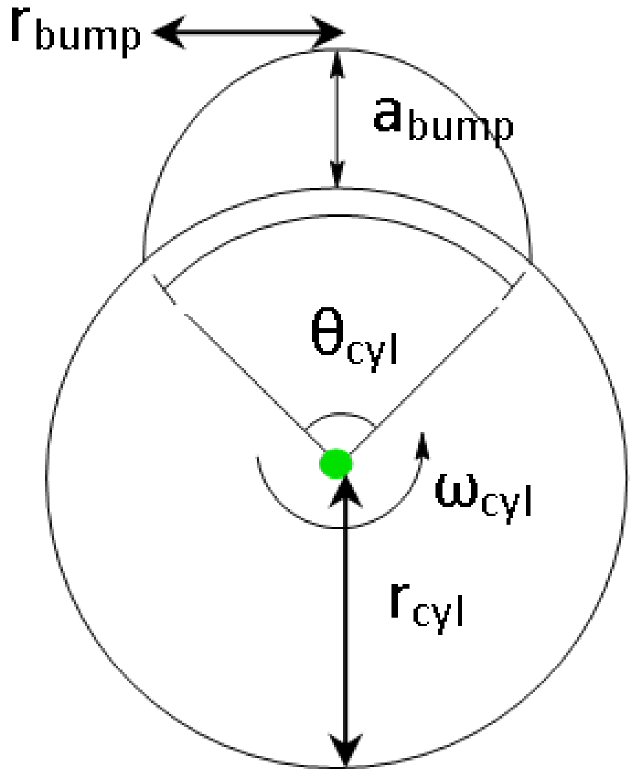


Load history

$$T_{bump} = \frac{2 \cdot \theta_{bump}}{\omega_{rulle}}$$

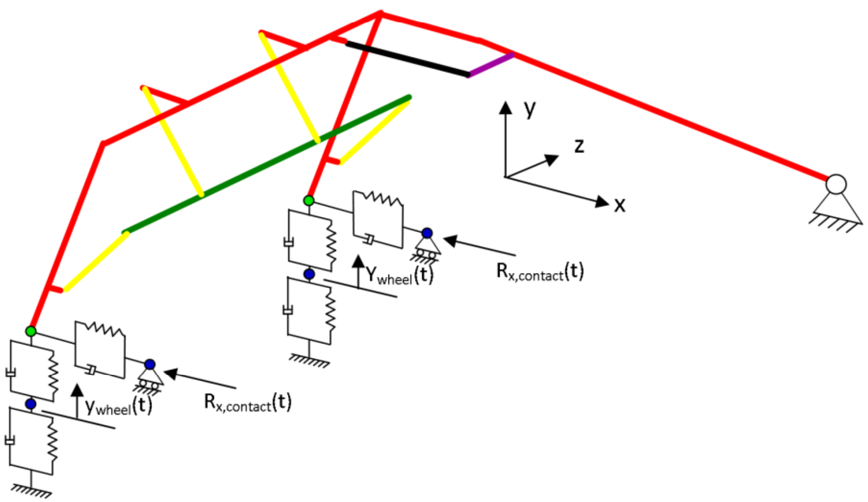
Example: 30 rev/min → f = 0,5 Hz
Equivalent to app. 30 km/t



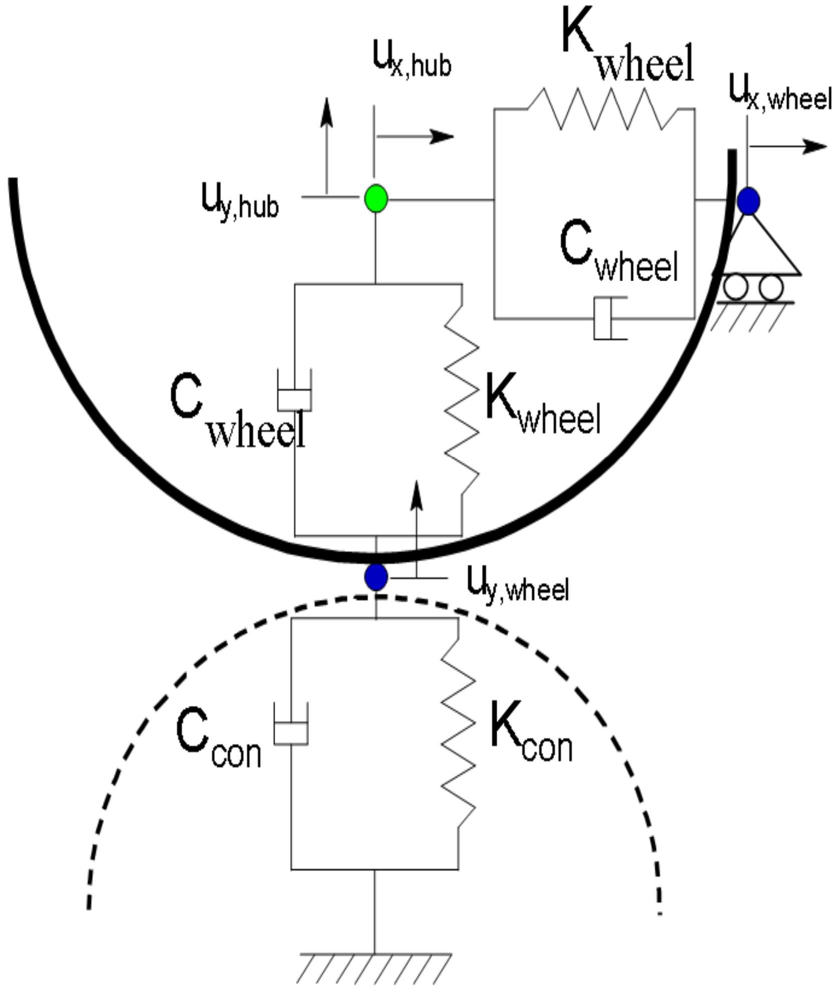


Modeled using Fourier

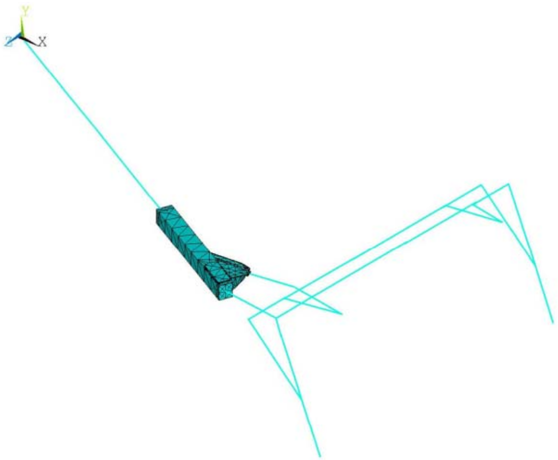
Vehicle modeling – dynamic beam model

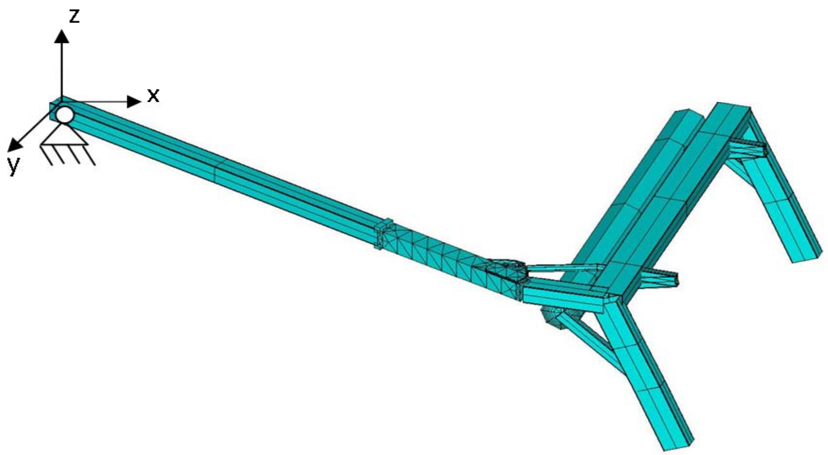


Solved using Newmark

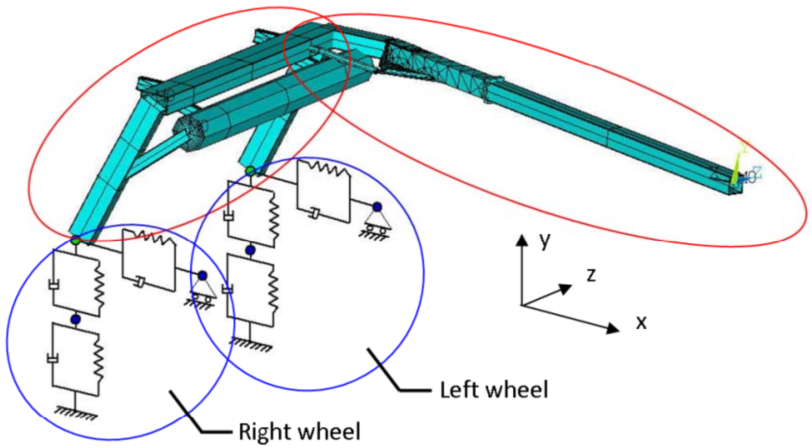


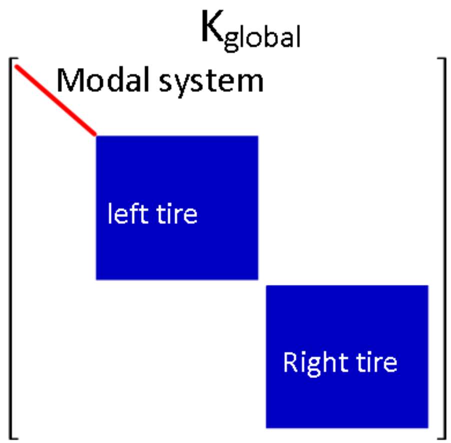
Vehicle modeling – modal system

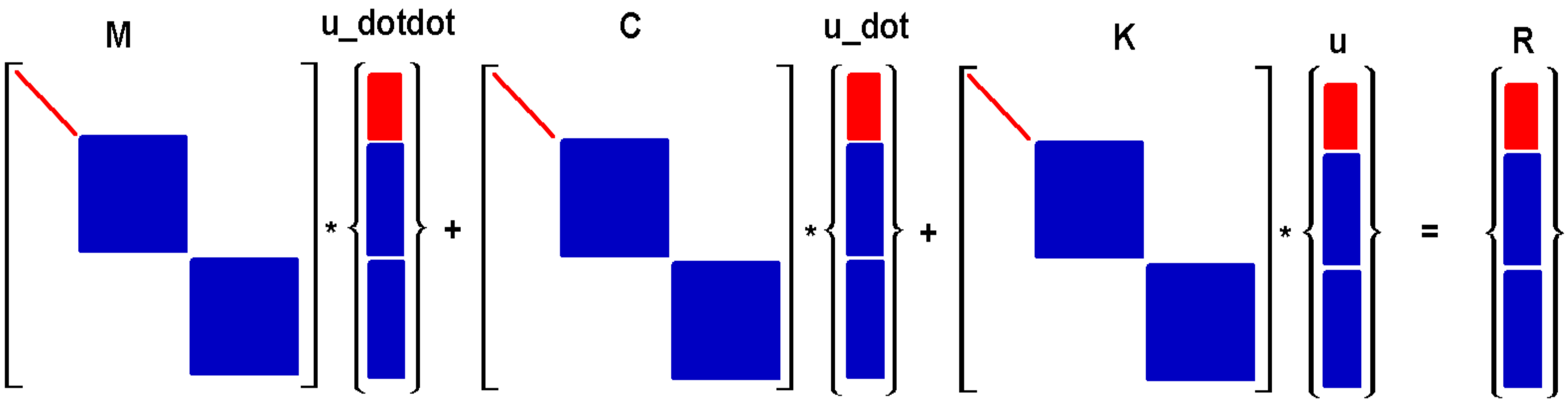




Vehicle modeling – modal system







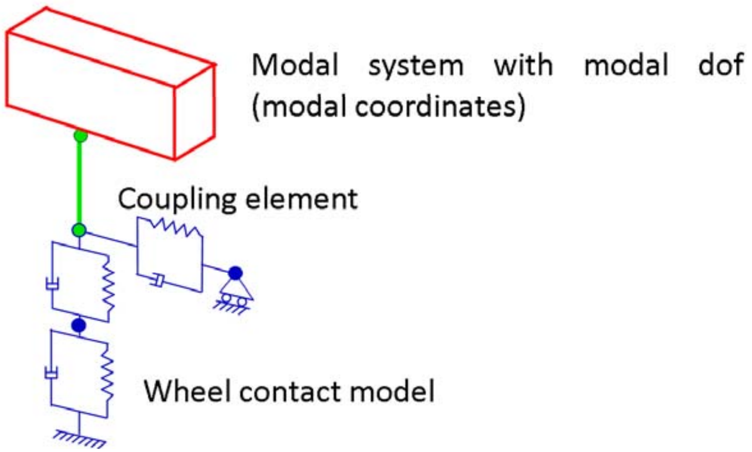
Vehicle modeling – modal system

Using the specific damping

$$\ddot{\eta}_i + 2\zeta_i\omega_i\dot{\eta}_i + \omega_i^2\eta_i = \frac{\bar{r}_i}{m_i}$$

Modal superposition

$$u_{y,h,fulnav} = \sum_{i=1}^{m} u^{\omega}_{y,h,fulnav}\cdot\eta_i$$



Modal coordinates

$$\{\eta\} = \begin{Bmatrix} \eta_1 \\ \vdots \\ \eta_i \\ \vdots \\ \eta_m \end{Bmatrix}$$

Transformation

$$[K_{global}] = [T]^T \cdot [K_{lokal}] \cdot [T]$$

Coupling

$$u_j = \sum_{i=1}^{m} u_j^{\omega}\cdot\eta_i$$

ANSYS/MatLab implementation

For 30 rev/min → f = 0,5 Hz

$$[U] = [u^{(1)} \quad u^{(2)} \quad \cdots \quad u^{(i)} \quad \cdots \quad u^{(n)}] = \begin{bmatrix} u_1^{(1)} & u_1^{(2)} & \cdots & u_1^{(n)} \\ u_2^{(1)} & u_2^{(2)} & \cdots & u_2^{(n)} \\ \cdots & \cdots & \cdots & \cdots \\ u_{n_d}^{(1)} & u_{n_d}^{(2)} & \cdots & u_{n_d}^{(n)} \end{bmatrix}$$

Eigensvingeformer.lgw - Notepad

Filer Rediger Formater Vis Hjælp

MODE	FREQUENCY (HERTZ)
1	0.000000000000
2	0.000000000000
3	0.1398996663387E-02
4	3.408209065152
5	7.987011282382
6	14.69531076444
7	17.74289055414
8	18.61305658289
9	27.34653332936
10	31.94430578412
11	44.75244615001
12	50.38647585420
13	78.57828913839
14	99.66265826185
15	110.6871746843
16	119.7678569450
17	134.4367747851
18	163.7499638405
19	178.8415703681
20	189.1393535452

$$\{u^{(i)}\}^T [M]\{u^{(i)}\}\{\eta_i\} = \{m_i\}\{\eta_i\}$$

$$\{u^{(i)}\}^T [K]\{u^{(i)}\}\{\eta_i\} = \{\bar{k}_i\}\{\eta_i\}$$

$$\{r_i\} = [u^{(i)}]^T \{R\}$$

8 separate modeshapes are selected

Eigensvingeformer.lgw - Notepad

Filer Rediger Formater Vis Hjælp

MODE	FREQUENCY (HERTZ)
1	0.000000000000
2	0.000000000000
3	0.1398996663387E-02
4	3.408209065152
5	7.987011282382
6	14.69531076444
7	17.74289055414
8	18.61305658289
9	27.34653332936
10	31.94430578412
11	44.75244615001
12	50.38647585420

$[U]$

Editor - D:\Dokumenter\Dokumenter\Aue\P10-projek...

File Edit Text Desktop Window Help

```
%Cykliske egenfrekvenser bestemt i Ansys
f_eig_ansys = [ 1    0.000000000000
                2    0.000000000000
                3    0.1398996663387E-02
                4    3.408209065152
                5    7.987011282382
                6    14.69531076444
                7    17.74289055414
                8    18.61305658289    ];
```

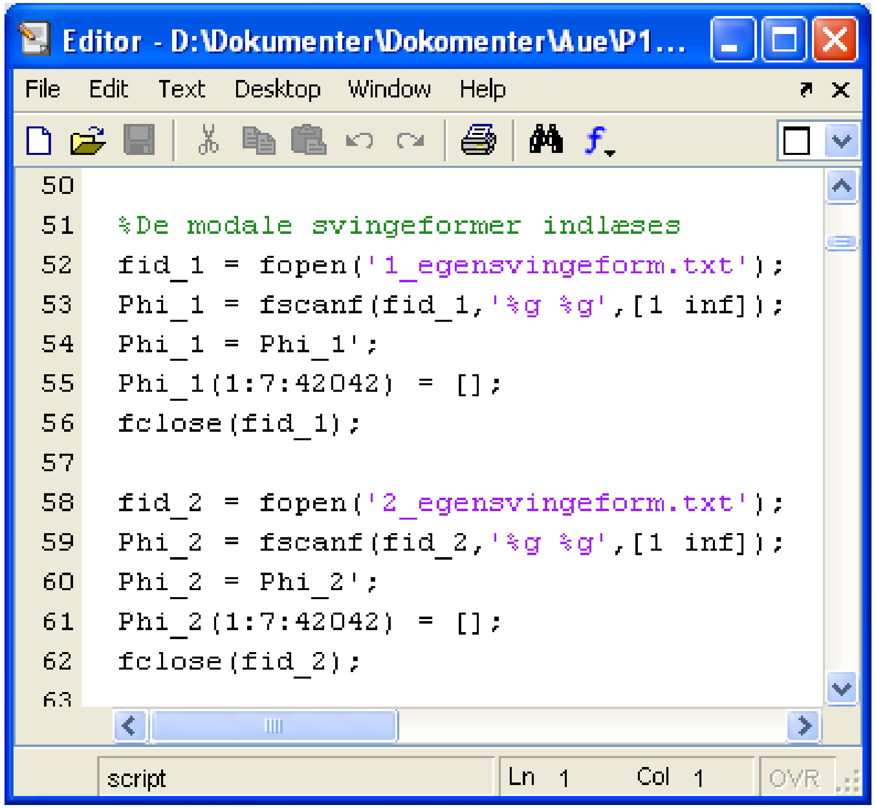
script Ln 40 Col 1 OVR

Experimental found f = 1,32 Hz

ANSYS/MatLab implementation

8 separate modeshapes are collected in

$[U]$



Normalizing

$[M]$

From

$$\frac{\bar{k}_i}{\bar{m}_i} = \omega_i^2 \qquad \omega_i = 2\pi f_i$$

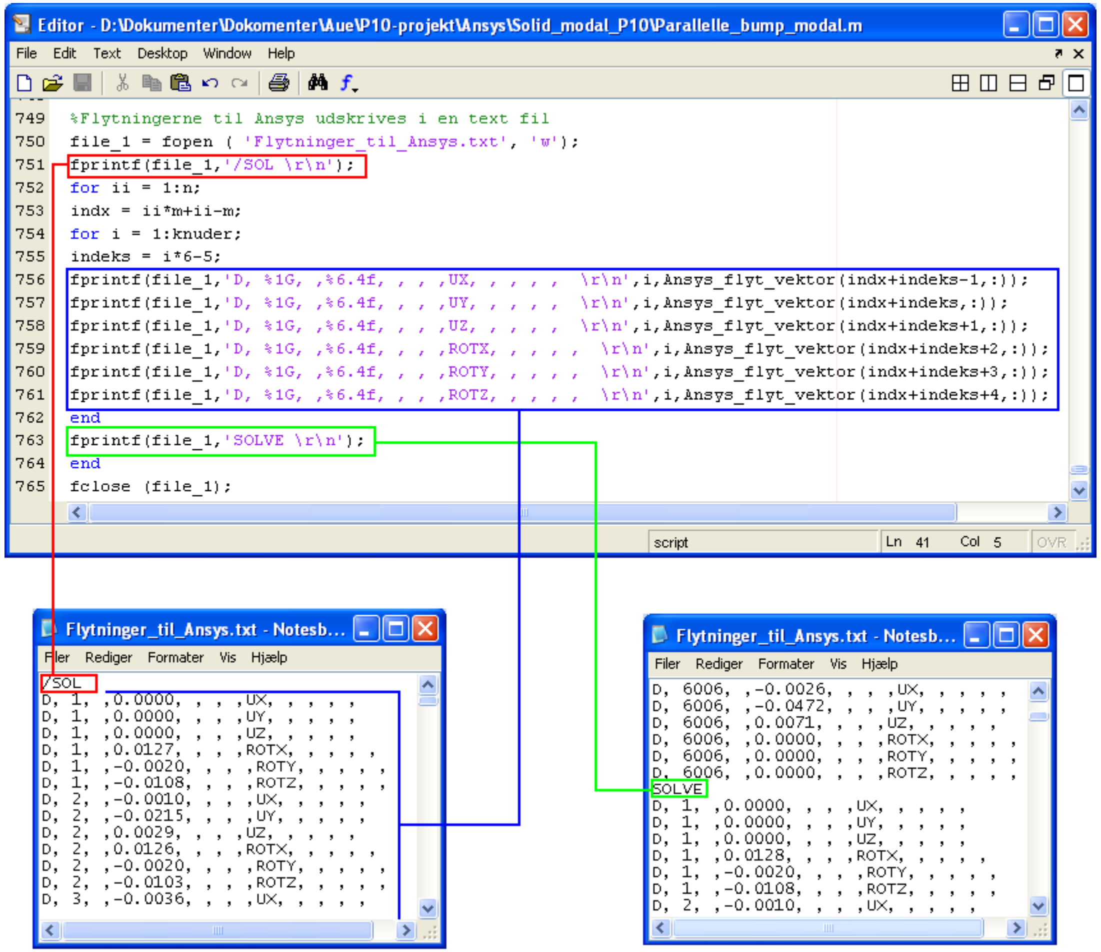
Determine

$[K]$

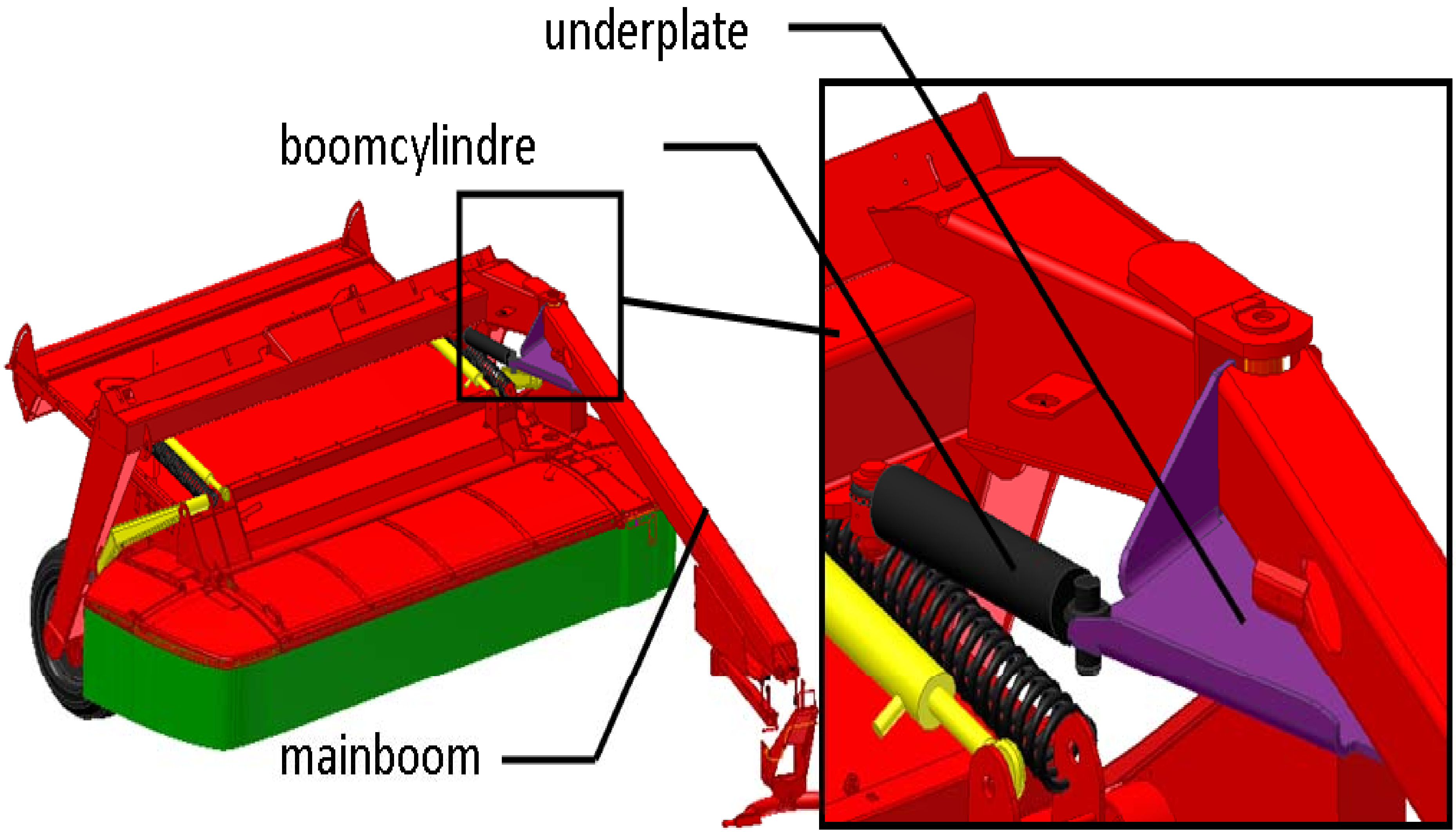
ANSYS/MatLab implementation

$$\{u\} = [\Phi]\{\eta\}$$

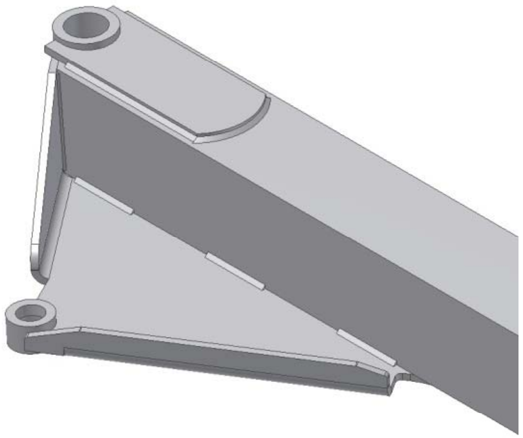
$$\{\eta\} = \begin{Bmatrix} \eta_1 \\ \vdots \\ \eta_i \\ \vdots \\ \eta_m \end{Bmatrix}$$

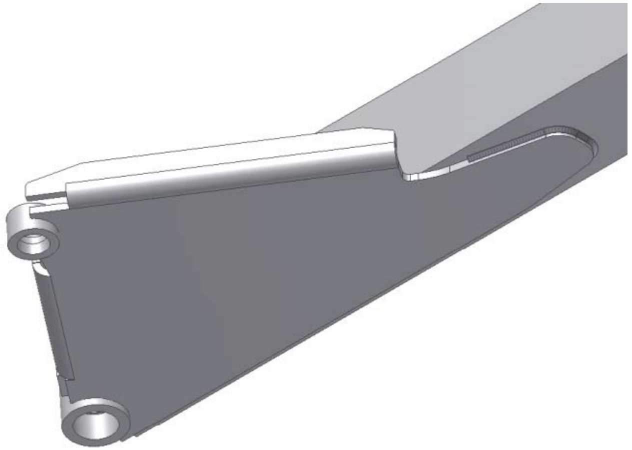


Fatigue analysis



Fatigue analysis





Fatigue analysis

Hot-spot stress

$$\sigma_p = [C_{influ}]:[F] = \sum_i \sum_j c_{ij} F_{ij}$$

$$\sigma_p = C_{11}FX_1 + C_{12}FY_1 + \cdots + C_{25}MY_2 + C_{26}MZ_2$$

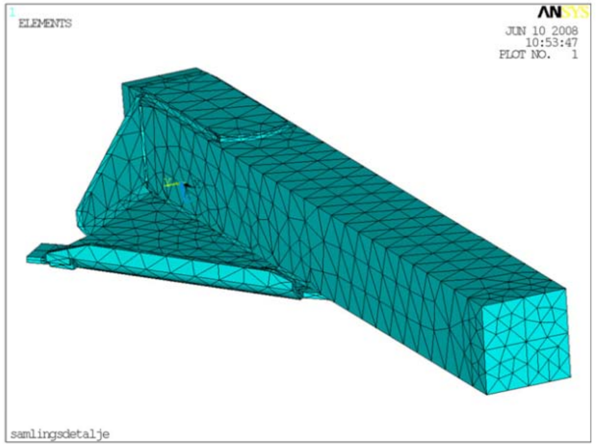
Influence matrix

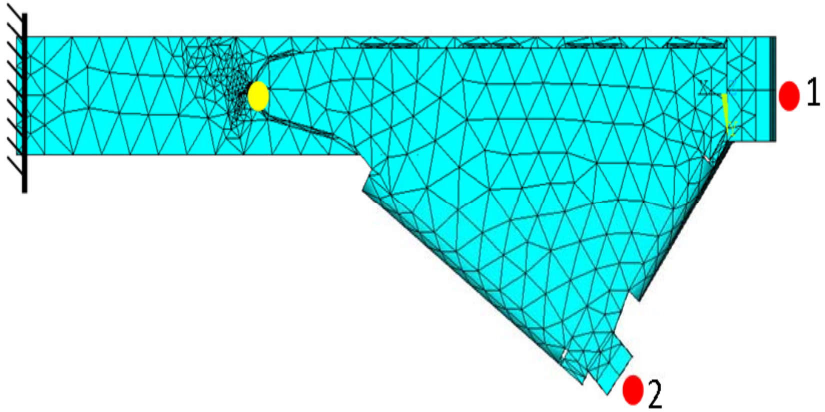
$$[C_{influ}] = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{21} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \end{bmatrix}$$

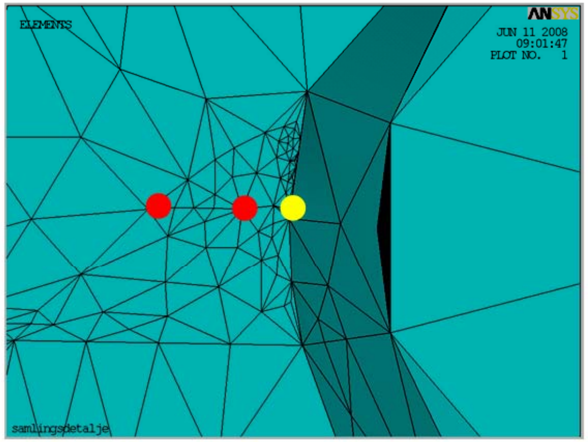
Sectional forces and moments

$$[F] = \begin{bmatrix} FX_1 & FY_1 & FZ_1 & MX_1 & MY_1 & MZ_1 \\ FX_2 & FY_2 & FZ_2 & MY_2 & MY_2 & MZ_2 \end{bmatrix}$$

Fatigue analysis



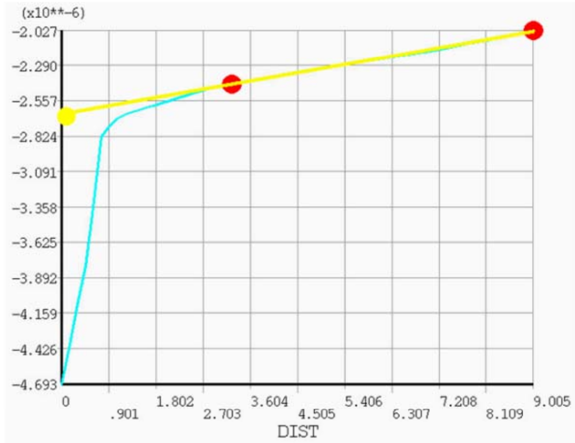




- Influence value found by applying a moment (z-axis) in point 2

Fatigue analysis

- Extrapolation of influence value

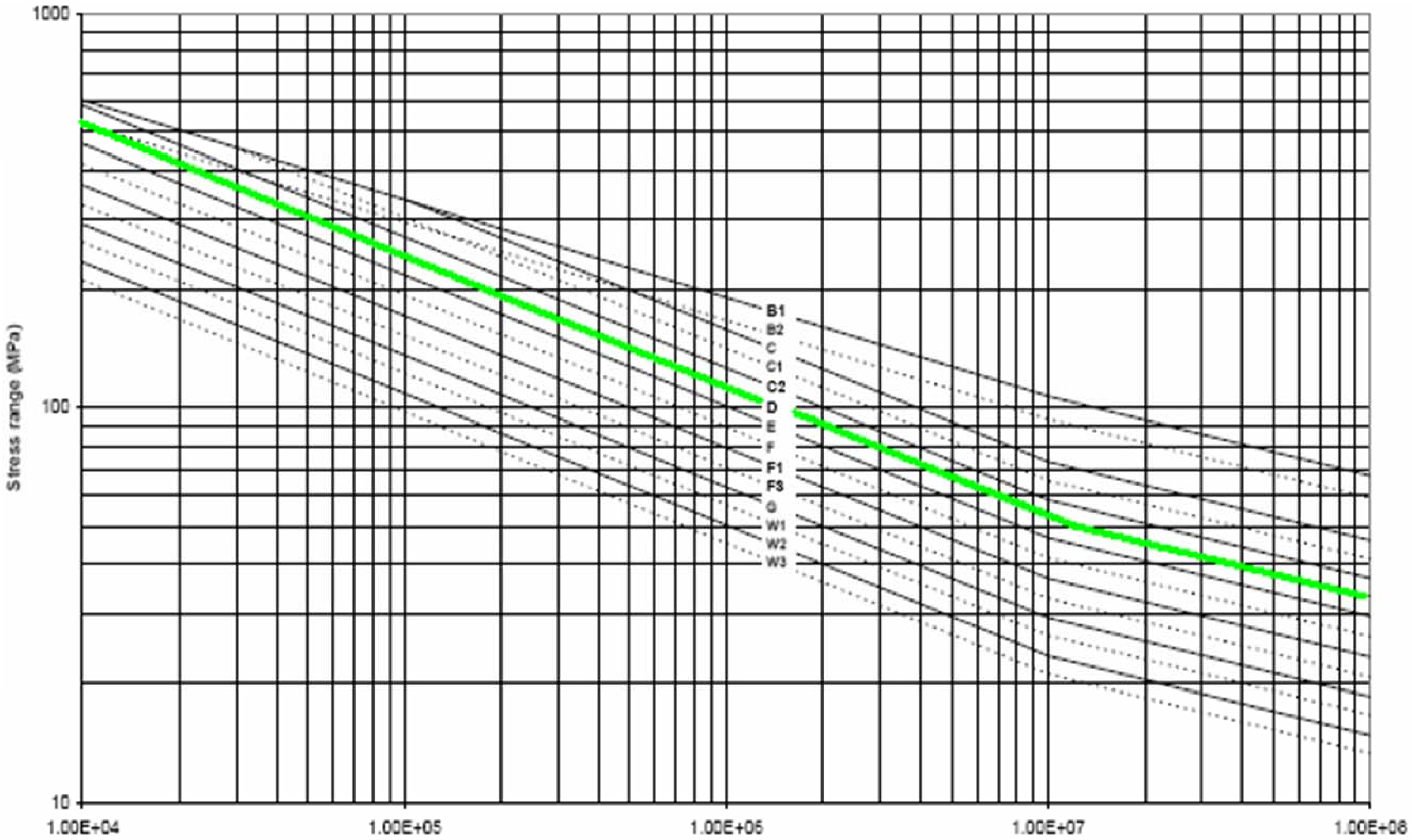


Influence matrix

$$[C_{influ}] = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{21} & C_{22} & C_{23} & C_{24} & C_{25} & -2{,}652E-6 \end{bmatrix}$$

Fatigue analysis

According to DNV RP-C203



Fatigue analysis

N-values

$$\log N = \log \bar{a} - m \log \Delta\sigma$$

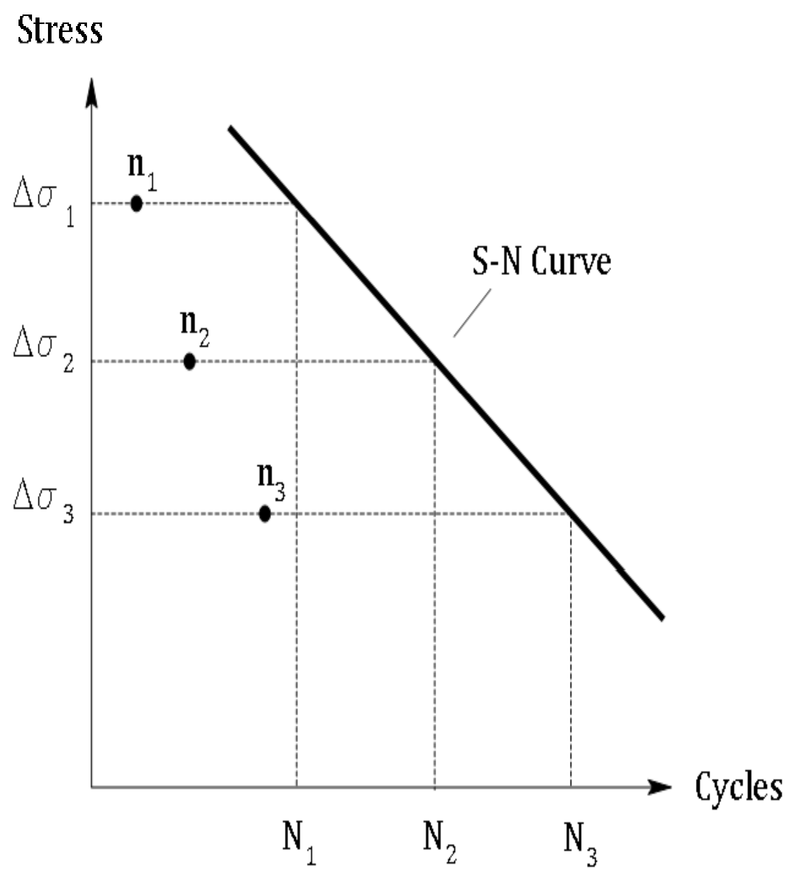
According to DNV RP-C203

$$\log \bar{a} = 12{,}164 \qquad m = 3{,}0$$

Miners rule

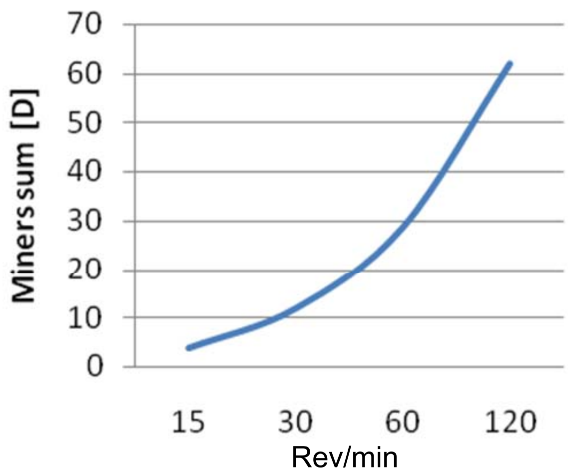
$$D = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \cdots + \frac{n_i}{N_i} = \sum_i \frac{n_i}{N_i} \leq 1.0$$

n_1, n_2, …. n_i = 160.000 cycles



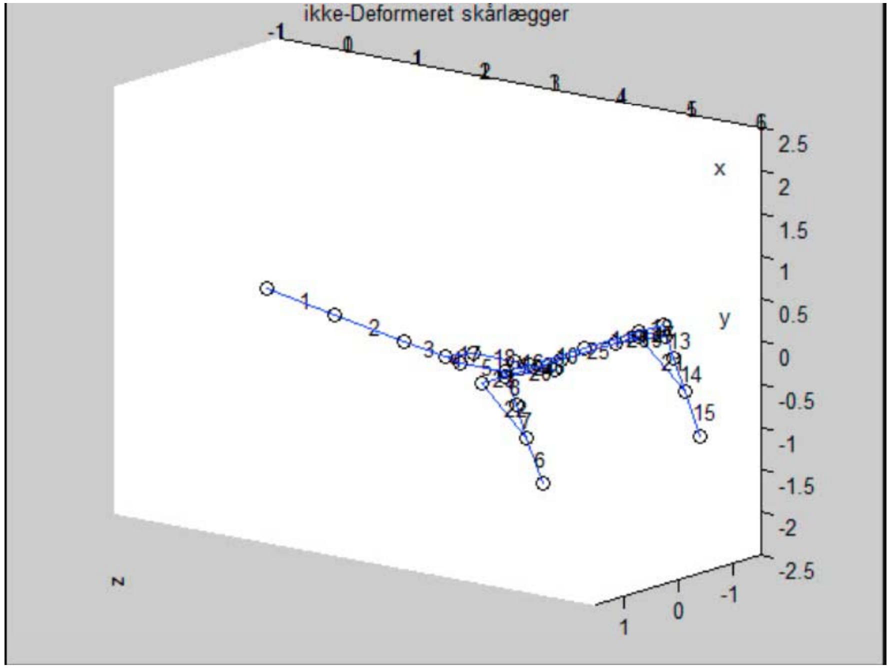
Results

Revolutions pr. min	Total damage for 160.000 cycles [D]	Number of cycles at failure
15 rev./min	3,66	43.700
30 rev./min	11,8	13.600
60 rev./min	28,7	5.590
120 rev./min	62,1	2.580

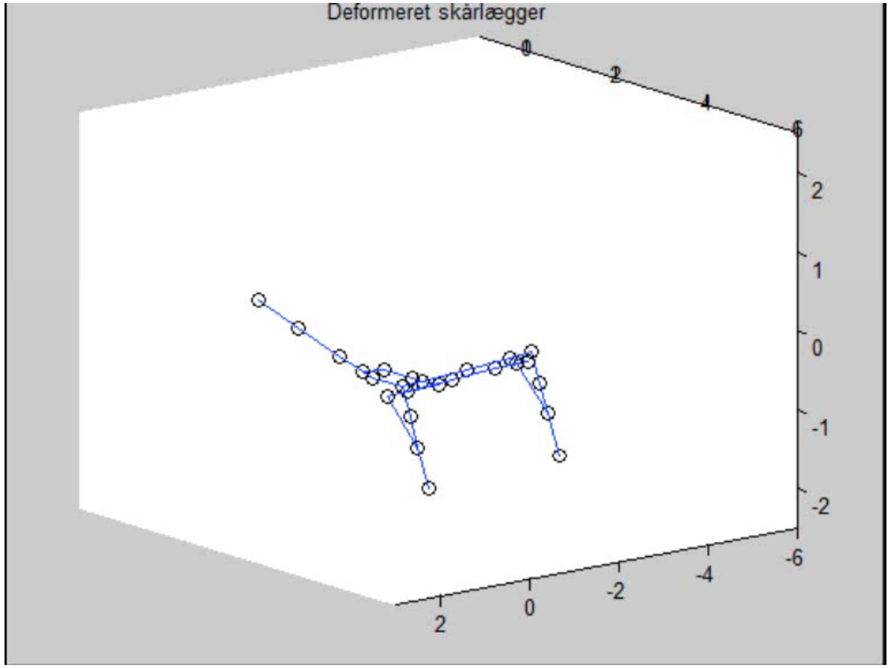


Example on Experimental found fatigue failure:
N = 24500 cycles

Parallel bumps - beam model

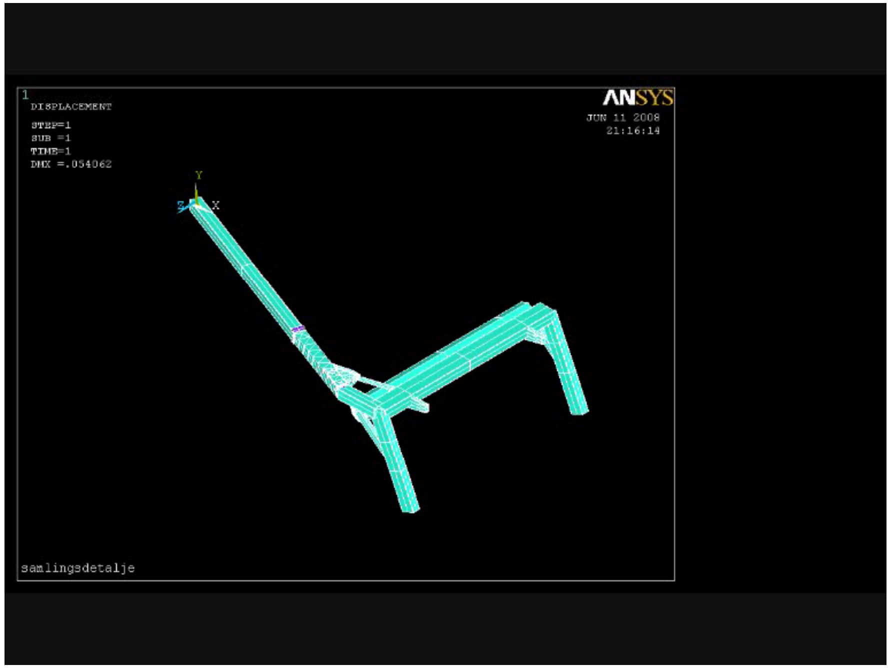


Displaced bumps - beam model



Parallel bumps - modal

Displaced bumps - modal



Conclusion

- The importance of modal analysis – recognizing that the eigenfrequency is the key
- Focus on implementation in smaller company
- Good initial agreement with observations and test results
- Platform for further development and improvement of methods

Future work

- The nonlinear wheel contact model should be modified to include rotation of coordinate system
- Adjustment of the chosen fatigue data and closer comparison with actual testing