



Durability analysis of a harvesting vehicle

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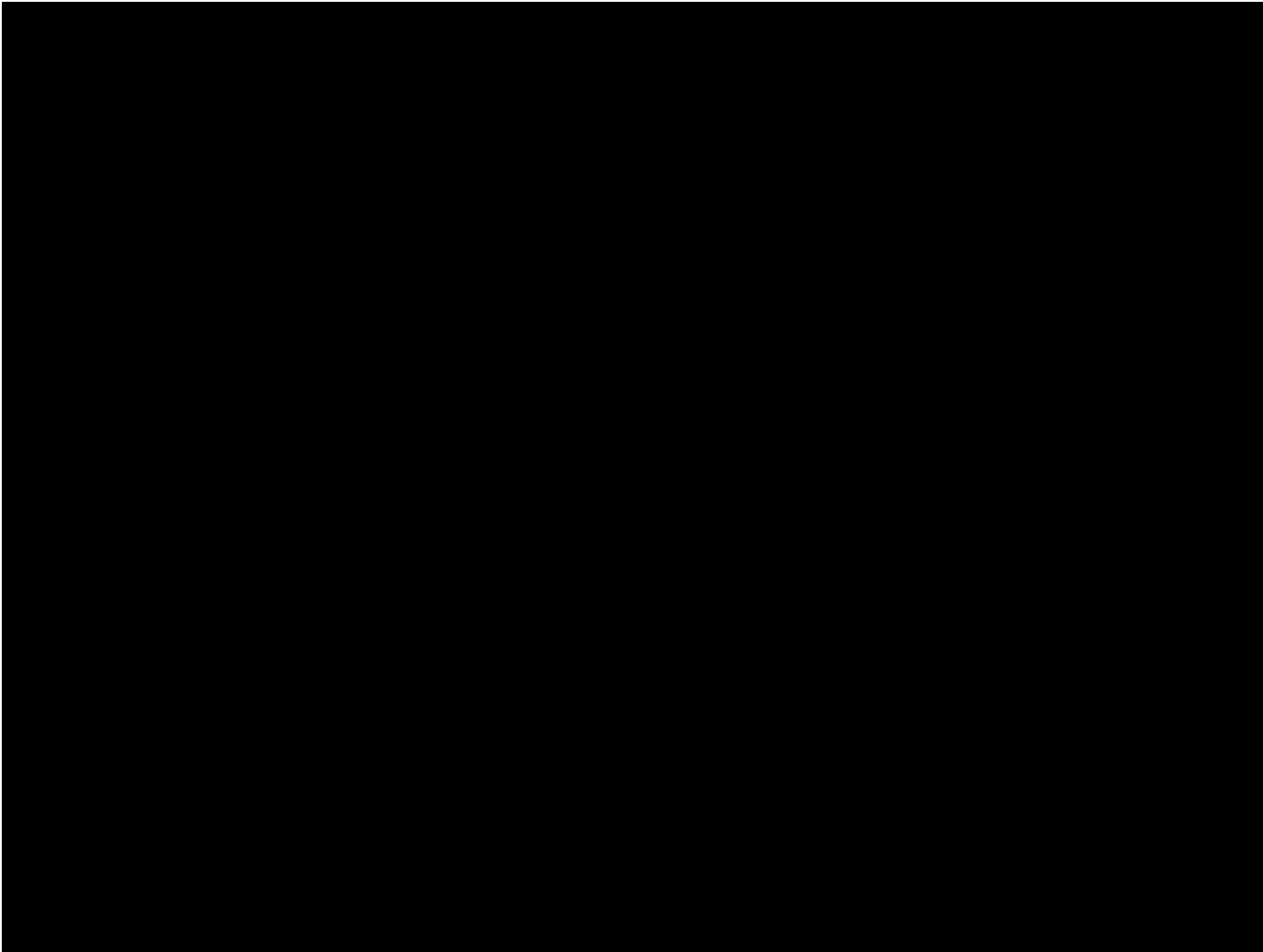
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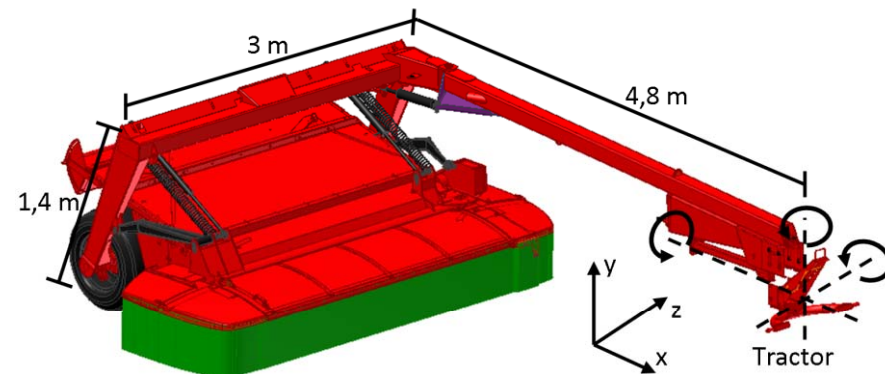
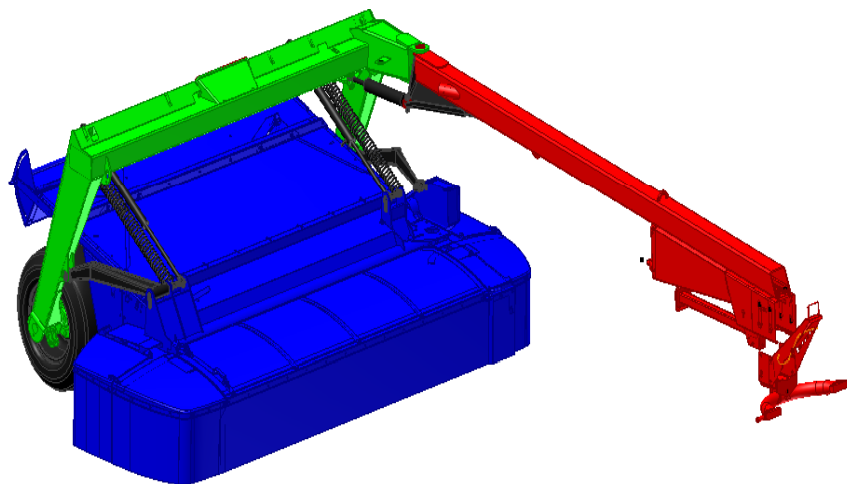
Outline

- 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



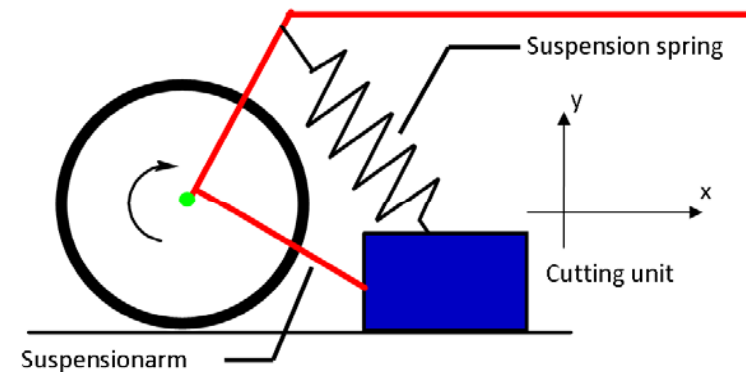
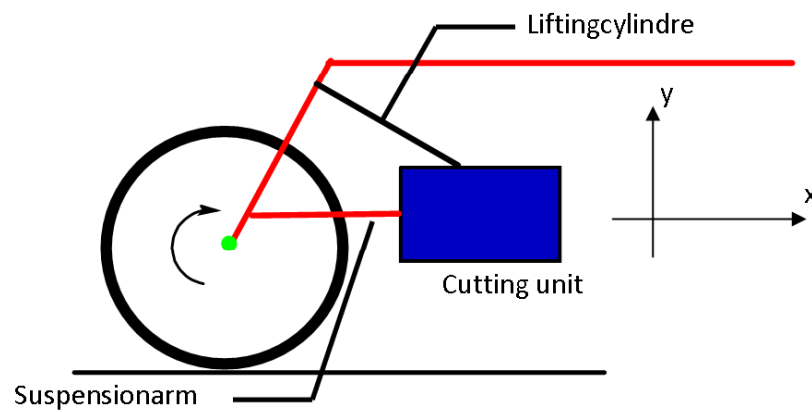
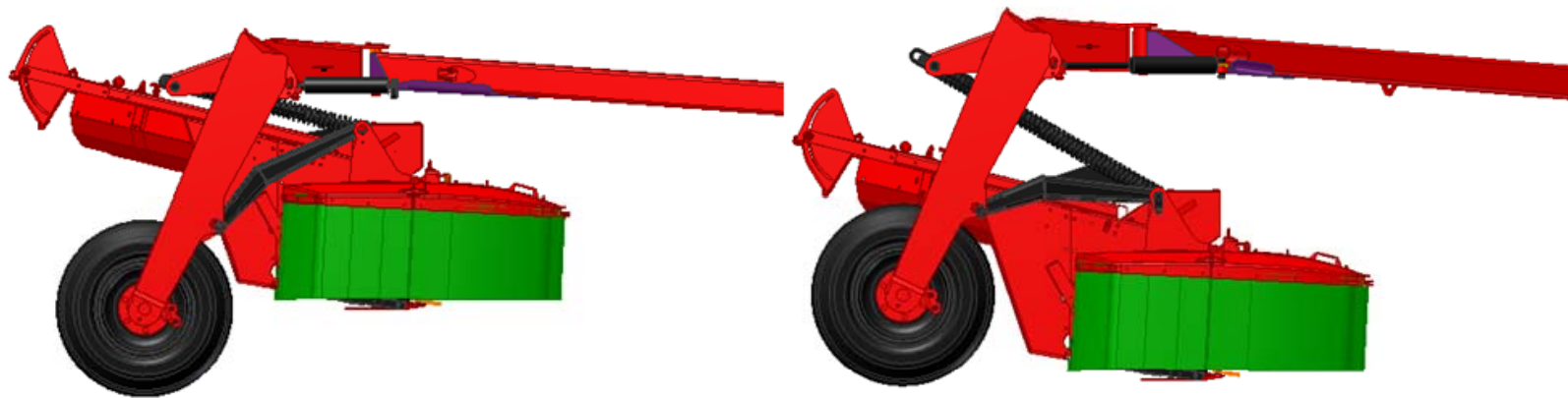
The harvester vehicle



Loading scenario

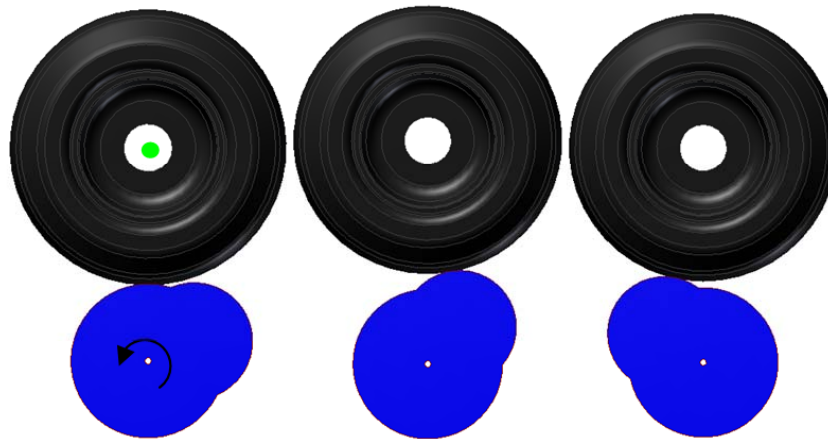


Loading scenario

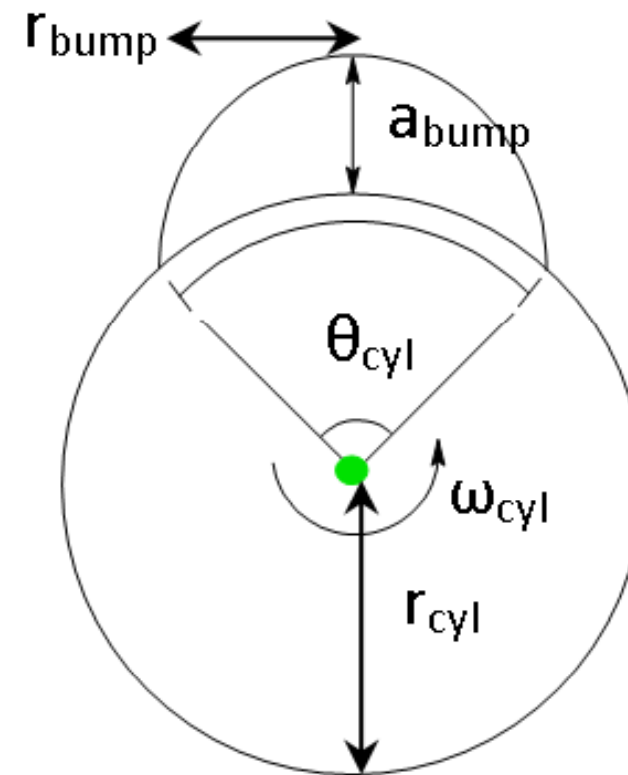


Load history

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

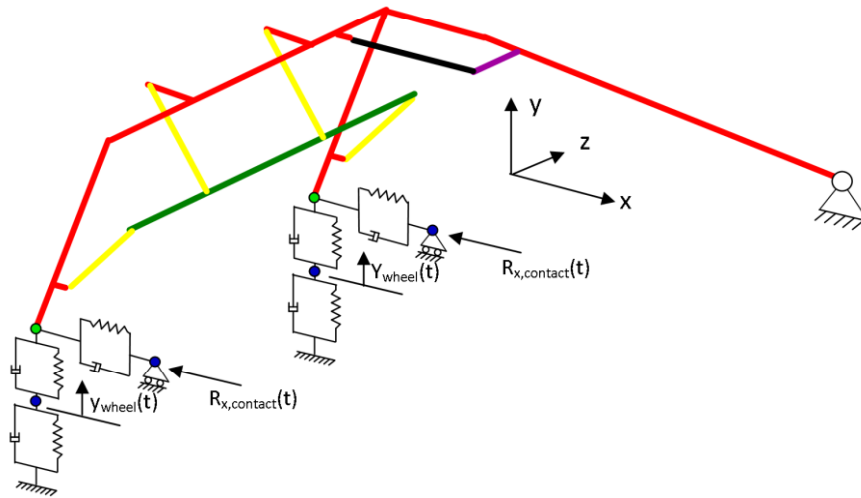


$$T_{bump} = \frac{2 \cdot \theta_{bump}}{\omega_{rulle}}$$

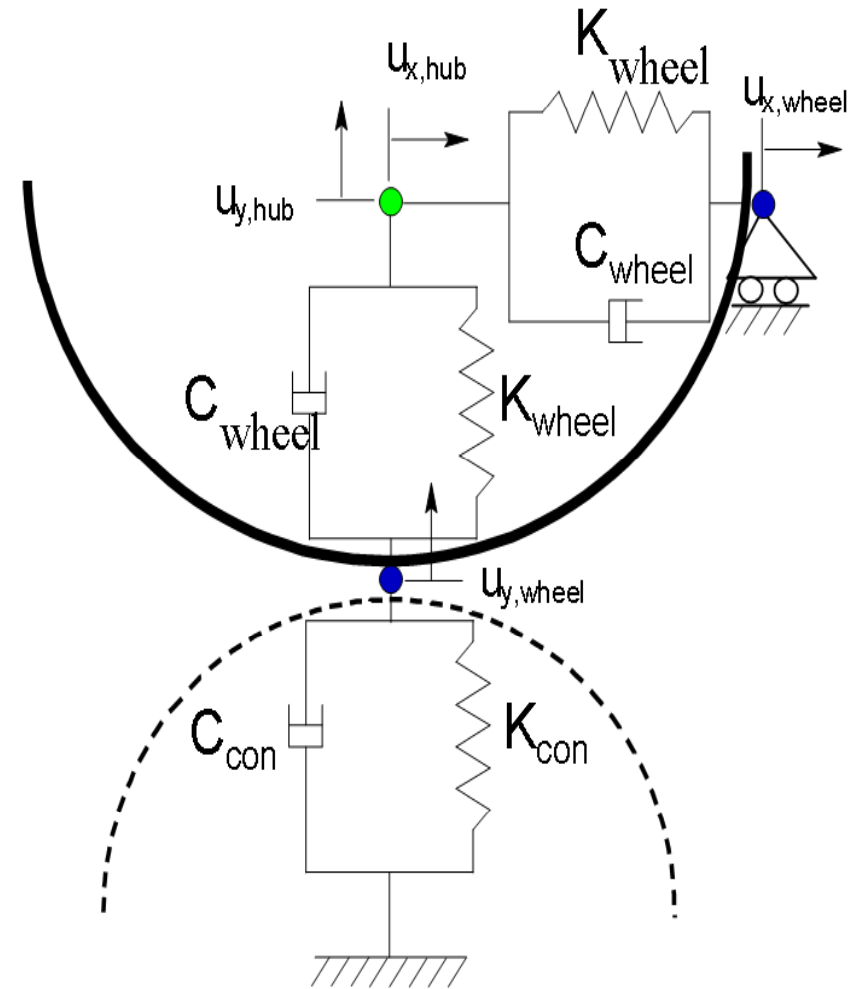


Modeled using Fourier

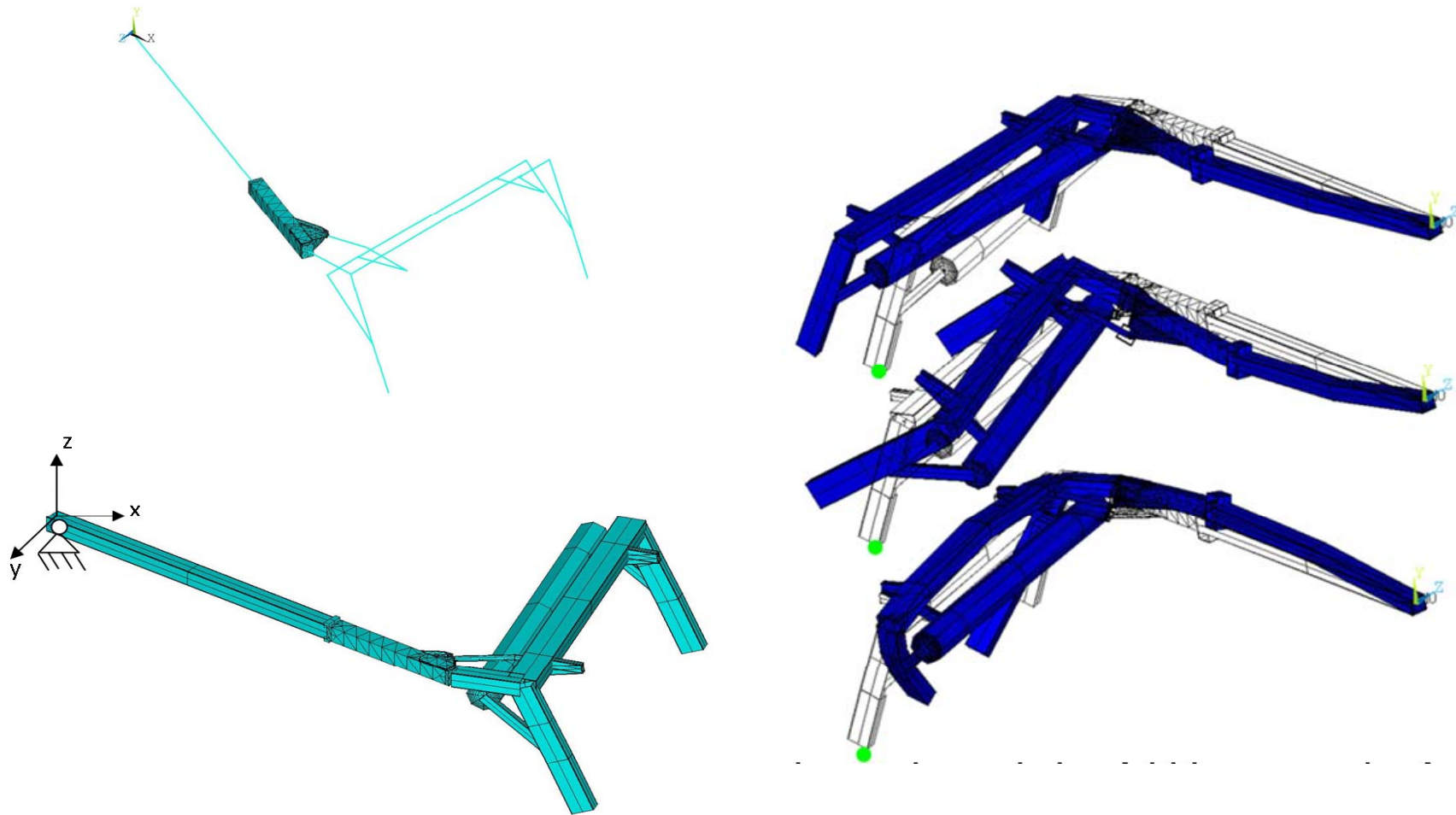
Vehicle modeling – dynamic beam model



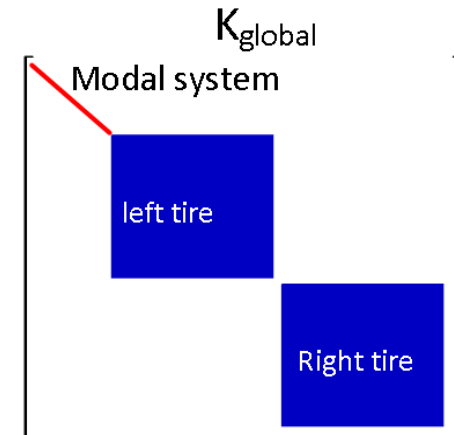
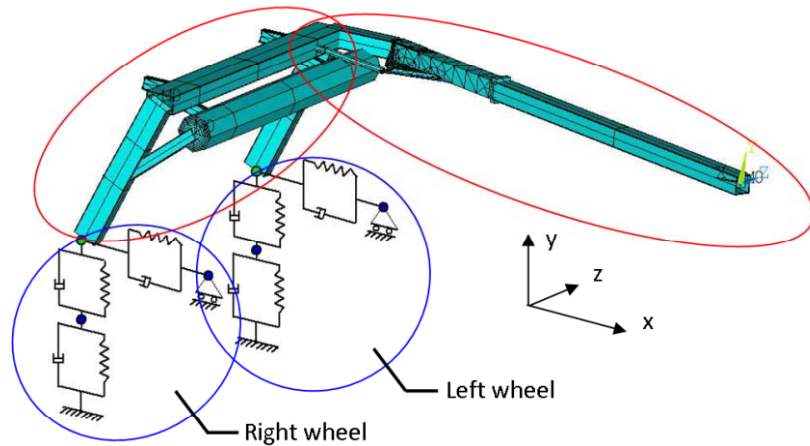
Solved using Newmark



Vehicle modeling – modal system



Vehicle modeling – modal system



$$\begin{bmatrix} \text{Modal system} \\ \text{left tire} \\ \text{Right tire} \end{bmatrix} \begin{bmatrix} M \\ C \\ K \end{bmatrix} \begin{bmatrix} u_{dotdot} \\ u_{dot} \\ u \end{bmatrix} = \begin{bmatrix} R \end{bmatrix}$$

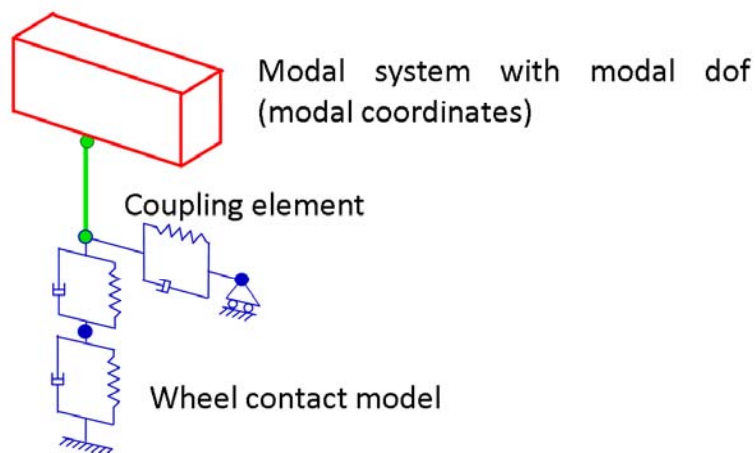
Vehicle modeling – modal system

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

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



Modal coordinates

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

Transformation

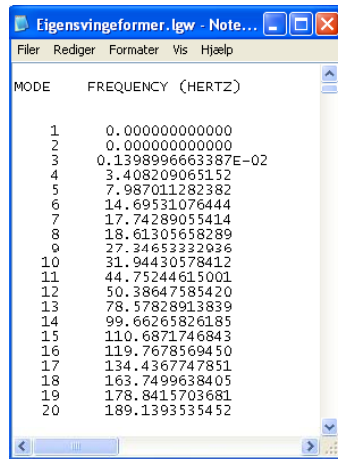
$$[K_{global}] = [T]^T \cdot [K_{local}] \cdot [T]$$

Coupling

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

ANSYS/MatLab implementation

For 30 rev/min $\rightarrow f = 0,5$ Hz



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	27.34653322936
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

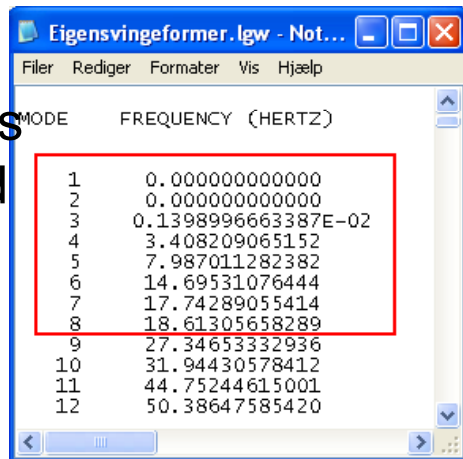
$$[U] = [u^{(1)} \quad u^{(2)} \quad \dots \quad u^{(n)} \quad \dots \quad u^{(N)}] = \begin{bmatrix} u_1^{(1)} & u_1^{(2)} & \dots & u_1^{(N)} \\ u_2^{(1)} & u_2^{(2)} & \dots & u_2^{(N)} \\ \vdots & \vdots & \ddots & \vdots \\ u_{n_f}^{(1)} & u_{n_f}^{(2)} & \dots & u_{n_f}^{(N)} \end{bmatrix}$$

$$\{u^{(n)}\}^T [M] \{u^{(n)}\} \eta_t = \{m_t\} \eta_t$$

$$\{u^{(n)}\}^T [K] \{u^{(n)}\} \eta_t = \{k_t\} \eta_t$$

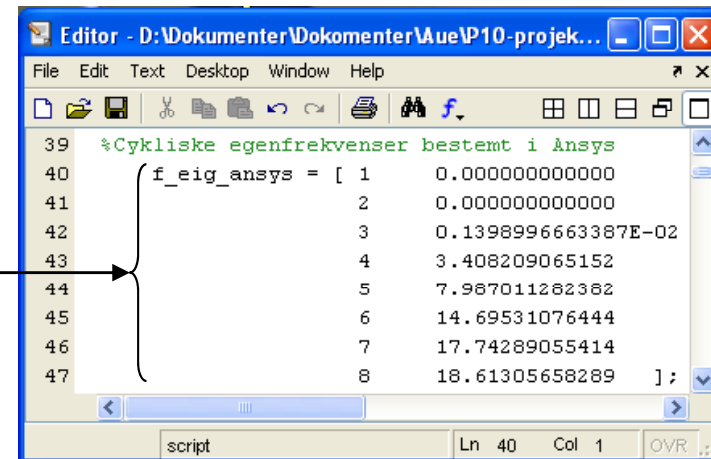
$$\{F_t\} = \{u^{(n)}\}^T \{R\}$$

8 separate
modeshapes
are selected



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	27.34653322936
10	31.94430578412
11	44.75244615001
12	50.38647585420

$[U]$



```

39 %Cykliske egenfrekvenser bestemt i Ansys
40 f_eig_ansys = [ 1 0.000000000000
41                2 0.000000000000
42                3 0.1398996663387E-02
43                4 3.408209065152
44                5 7.987011282382
45                6 14.69531076444
46                7 17.74289055414
47                8 18.61305658289 ];
    
```

Experimental found $f = 1,32$ Hz

ANSYS/MatLab implementation

8 separate
modeshapes
are collected
in

[U]

```

50
51 %De modale svingeformer indlæses
52 fid_1 = fopen('1_egensvingeform.txt');
53 Phi_1 = fscanf(fid_1,'%g %g',[1 inf]);
54 Phi_1 = Phi_1';
55 Phi_1(1:7:42042) = [];
56 fclose(fid_1);
57
58 fid_2 = fopen('2_egensvingeform.txt');
59 Phi_2 = fscanf(fid_2,'%g %g',[1 inf]);
60 Phi_2 = Phi_2';
61 Phi_2(1:7:42042) = [];
62 fclose(fid_2);
63

```

Normalizing

[M]

From

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

Determine

[K]

ANSYS/MatLab implementation

$$\{u\} = [U]\{q\}$$

$$\{q\} = \begin{Bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \\ q_6 \\ q_7 \\ q_8 \end{Bmatrix}$$

```

Editor - D:\Dokumenter\Dokumenter\Aue\P10-projekt\Ansys\Solid_modal_P10\Parallell_bump_modal.m
File Edit Text Desktop Window Help
749 %Flytningerne til Ansys udskrives i en text fil
750 file_1 = fopen ('Flytninger_til_Ansys.txt', 'w');
751 fprintf(file_1, '/SOL \r\n');
752 for ii = 1:n;
753     indx = ii*m+ii-m;
754     for i = 1:knuder;
755         indeks = i*6-5;
756         fprintf(file_1, 'D, %1G, %6.4f, , , UX, , , , \r\n', i, Ansys_flyt_vektor(indx+indeks-1,:));
757         fprintf(file_1, 'D, %1G, %6.4f, , , UY, , , , \r\n', i, Ansys_flyt_vektor(indx+indeks,:));
758         fprintf(file_1, 'D, %1G, %6.4f, , , UZ, , , , \r\n', i, Ansys_flyt_vektor(indx+indeks+1,:));
759         fprintf(file_1, 'D, %1G, %6.4f, , , ROTX, , , , \r\n', i, Ansys_flyt_vektor(indx+indeks+2,:));
760         fprintf(file_1, 'D, %1G, %6.4f, , , ROTY, , , , \r\n', i, Ansys_flyt_vektor(indx+indeks+3,:));
761         fprintf(file_1, 'D, %1G, %6.4f, , , ROTZ, , , , \r\n', i, Ansys_flyt_vektor(indx+indeks+4,:));
762     end
763     fprintf(file_1, 'SOLVE \r\n');
764 end
765 fclose (file_1);
    
```

Flytninger_til_Ansys.txt - Notesb...

File Rediger Formater Vis Hjælp

```

/SOL
D, 1, ,0.0000, , , UX, , , ,
D, 1, ,0.0000, , , UY, , , ,
D, 1, ,0.0000, , , UZ, , , ,
D, 1, ,0.0127, , , ROTX, , , ,
D, 1, , -0.0020, , , ROTY, , , ,
D, 1, , -0.0108, , , ROTZ, , , ,
D, 2, , -0.0010, , , UX, , , ,
D, 2, , -0.0215, , , UY, , , ,
D, 2, , ,0.0029, , , UZ, , , ,
D, 2, , ,0.0126, , , ROTX, , , ,
D, 2, , -0.0020, , , ROTY, , , ,
D, 2, , -0.0103, , , ROTZ, , , ,
D, 3, , -0.0036, , , UX, , , ,
    
```

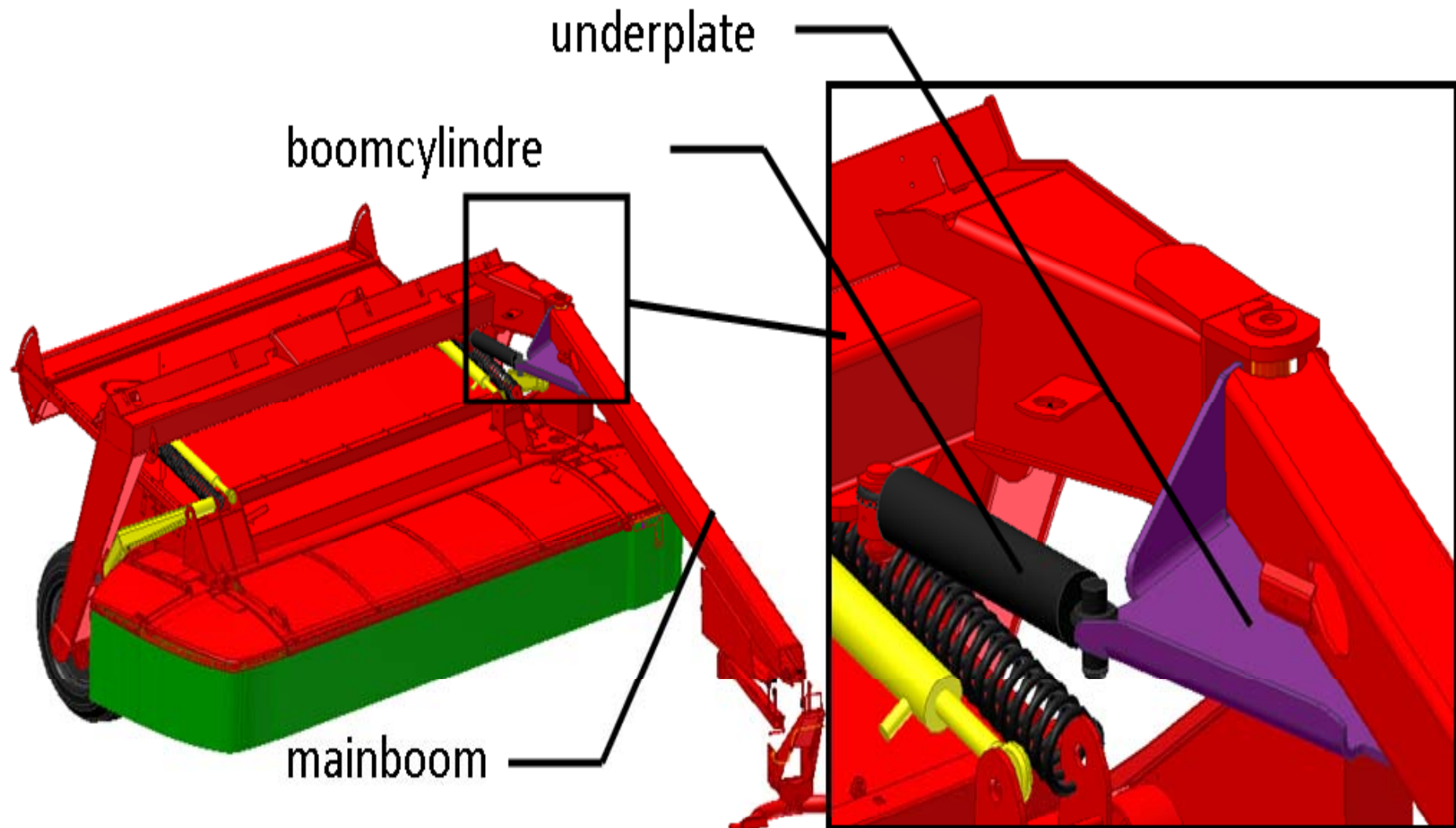
Flytninger_til_Ansys.txt - Notesb...

File Rediger Formater Vis Hjælp

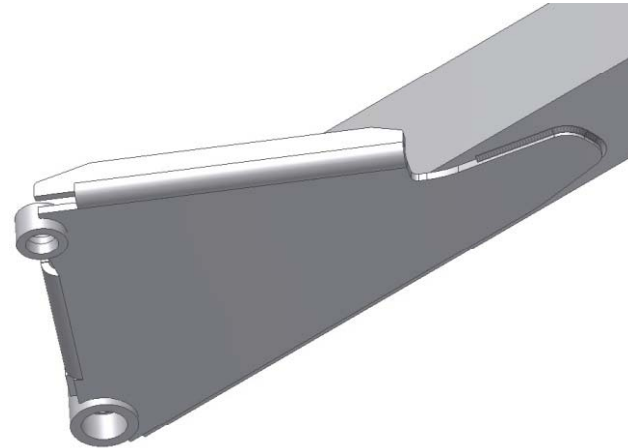
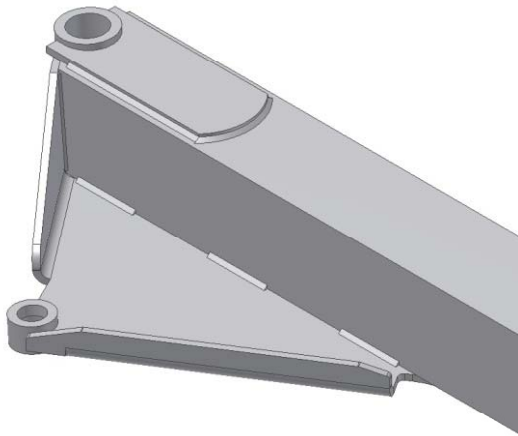
```

D, 6006, , -0.0026, , , UX, , , ,
D, 6006, , -0.0472, , , UY, , , ,
D, 6006, , ,0.0071, , , UZ, , , ,
D, 6006, , ,0.0000, , , ROTX, , , ,
D, 6006, , ,0.0000, , , ROTY, , , ,
D, 6006, , ,0.0000, , , ROTZ, , , ,
SOLVE
D, 1, ,0.0000, , , UX, , , ,
D, 1, ,0.0000, , , UY, , , ,
D, 1, ,0.0000, , , UZ, , , ,
D, 1, , ,0.0128, , , ROTX, , , ,
D, 1, , -0.0020, , , ROTY, , , ,
D, 1, , -0.0108, , , ROTZ, , , ,
D, 2, , -0.0010, , , UX, , , ,
    
```

Fatigue analysis



Fatigue analysis



Fatigue analysis

Hot-spot stress

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

$$\sigma_P = C_{11}FX_1 + C_{12}FY_1 + \dots + C_{25}MY_2 + C_{26}MZ_2$$

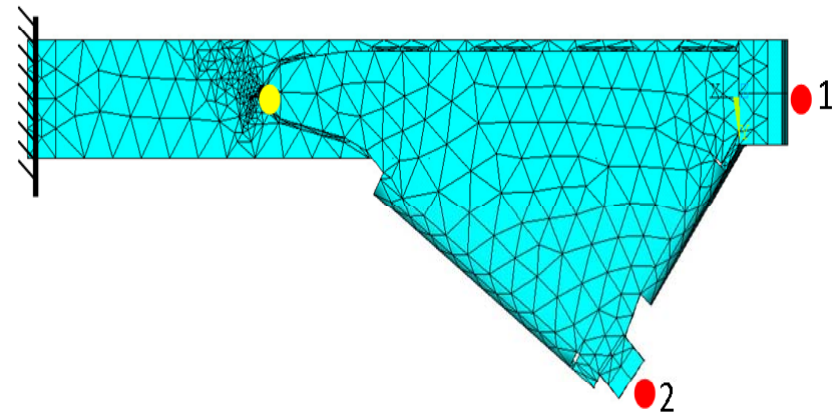
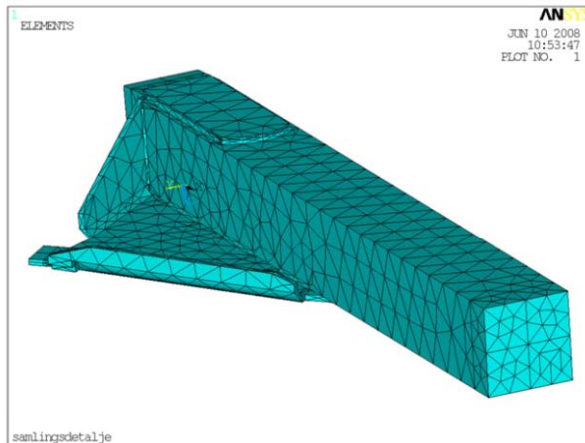
Influence matrix

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

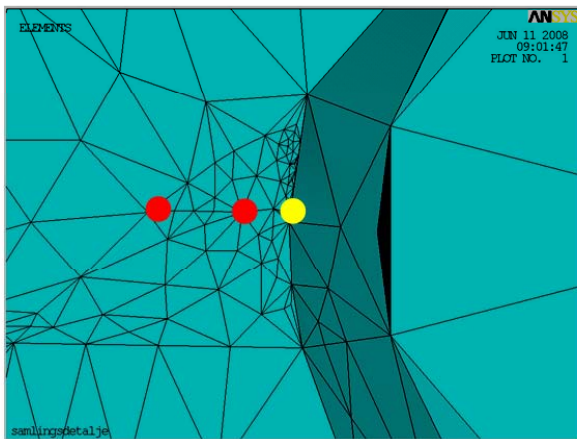
Sectional forces and moments

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

Fatigue analysis

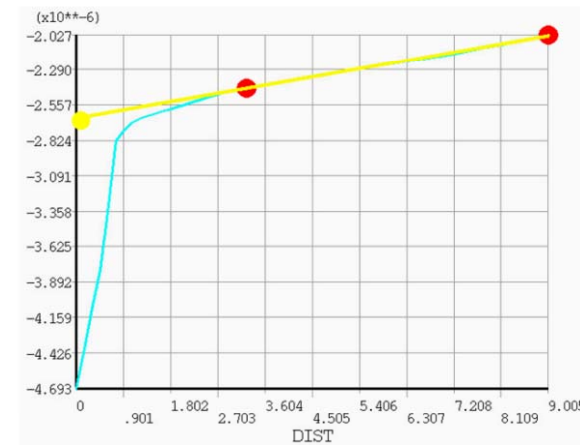


- Influence value found by applying a moment (z-axis) in point 2



Fatigue analysis

- Extrapolation of influence value

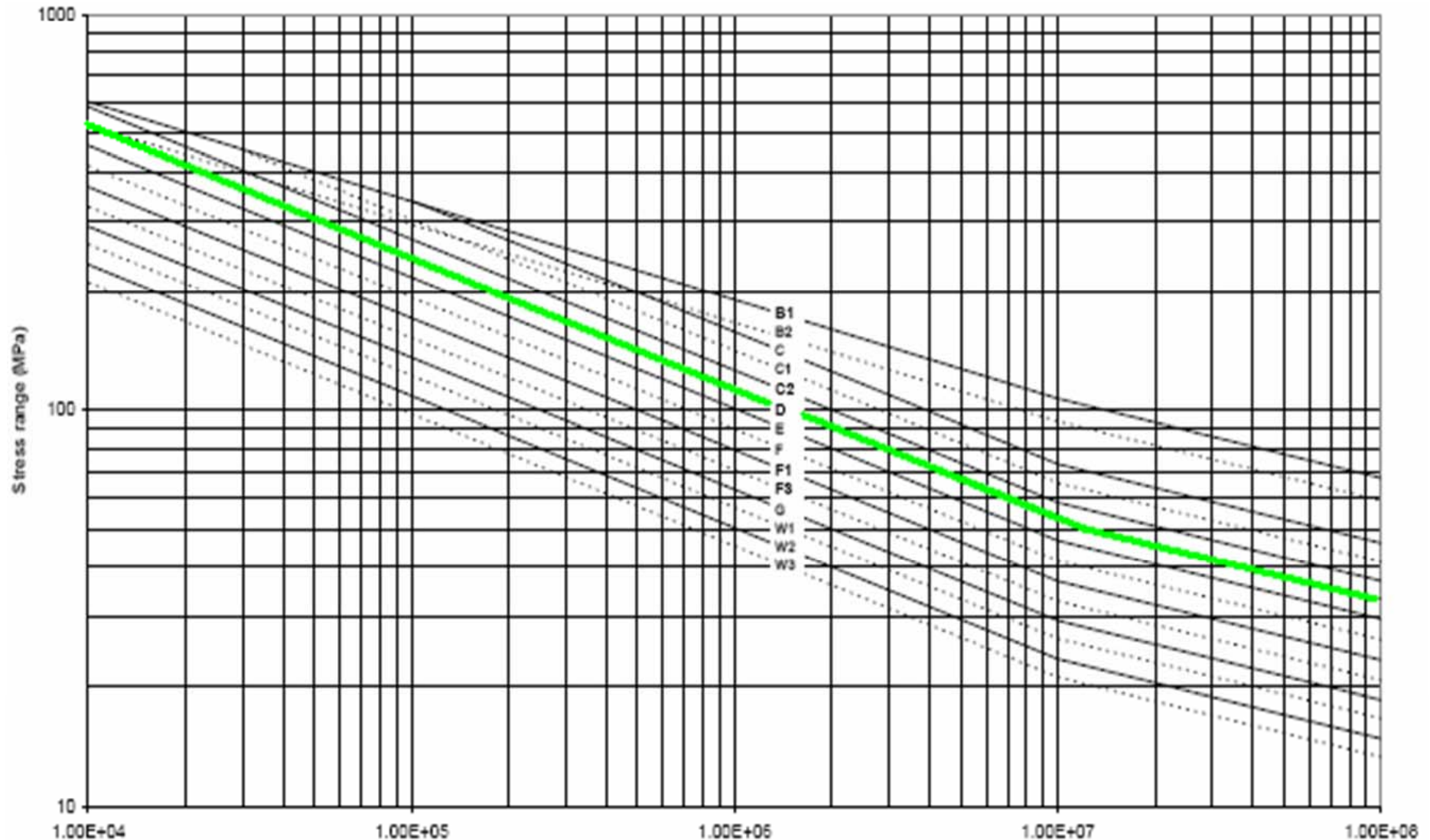


Influence matrix

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

Fatigue analysis

According to DNV RP-C203



Fatigue analysis

N-values

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

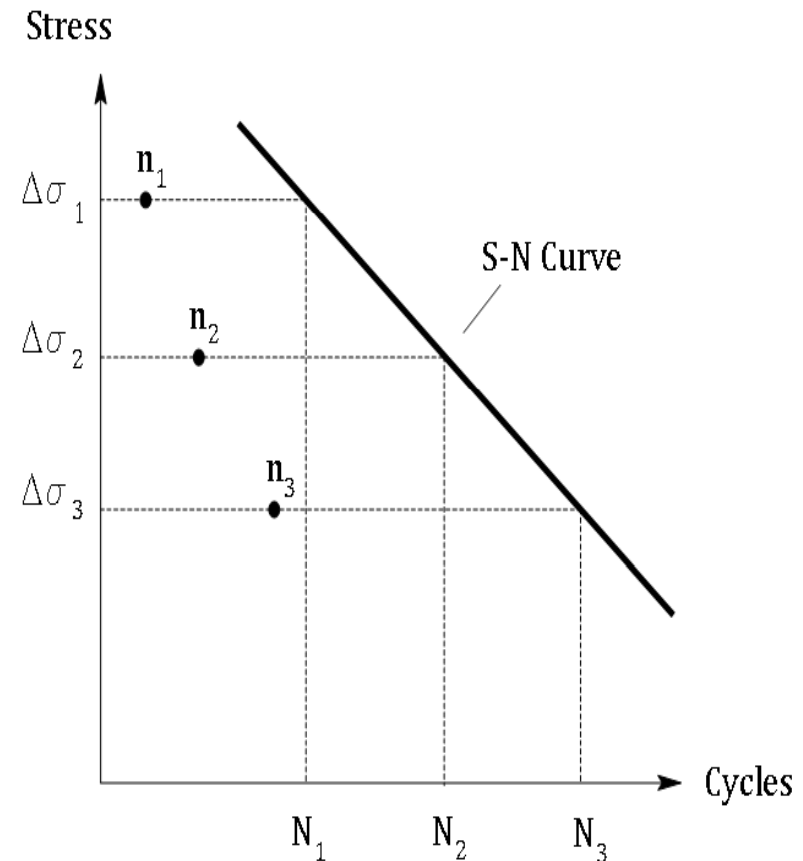
According to DNV RP-C203

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

Miners rule

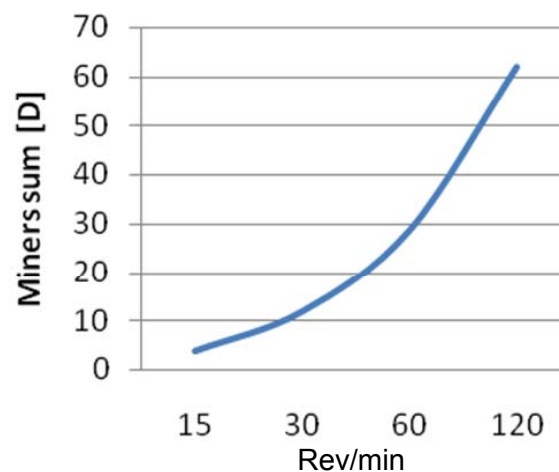
$$D = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \dots + \frac{n_i}{N_i} = \sum_i \frac{n_i}{N_i} \leq 1.0$$

$$n_1, n_2, \dots, n_i = 160.000 \text{ cycles}$$



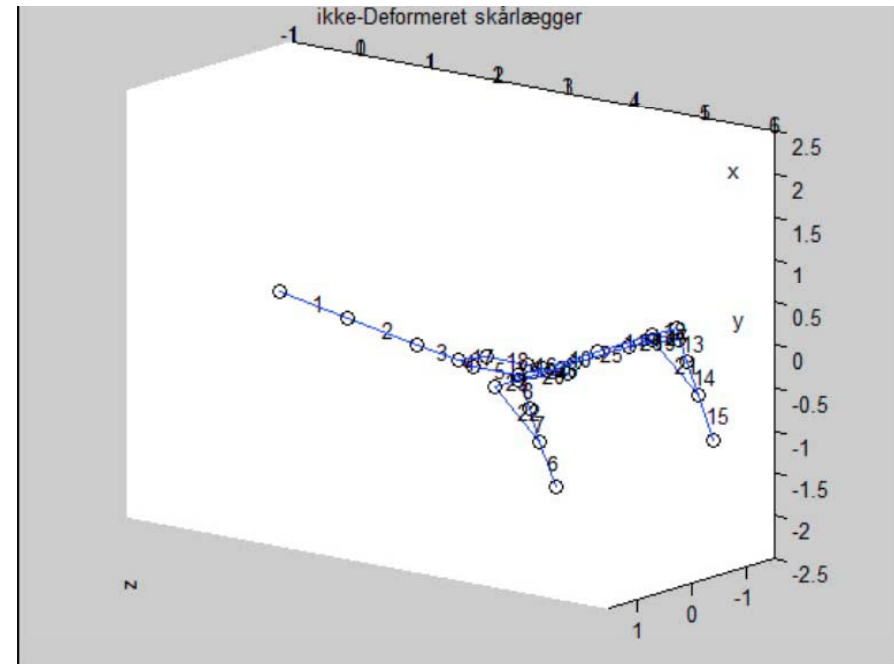
Results

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

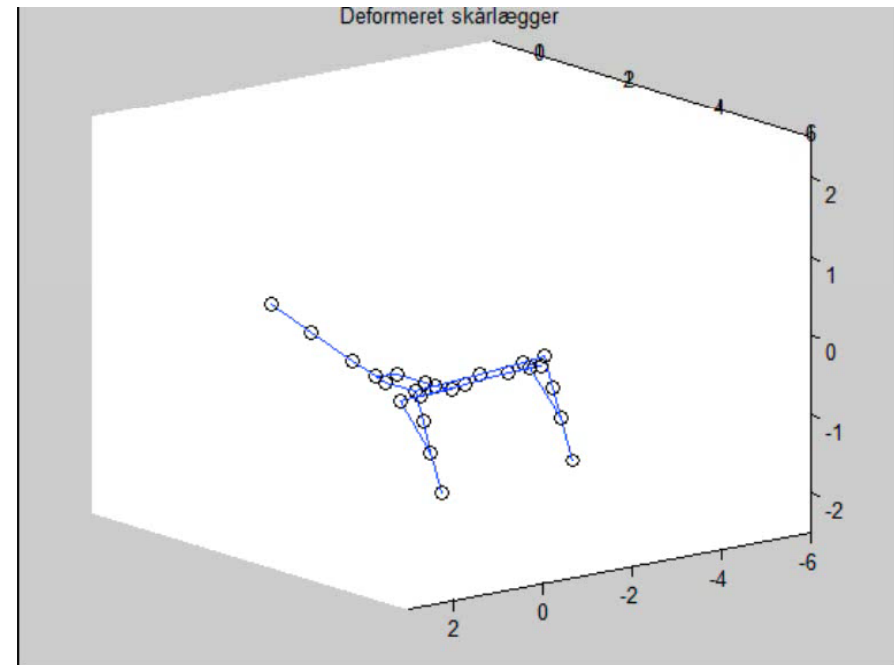


Example on
Experimental
found fatigue
failure:
N = 24500 cycles

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