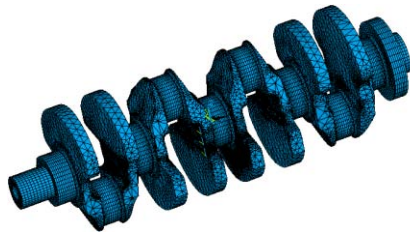


SIMPACK User Meeting - Salzburg, May 19, 2011

# MORPACK interface for importing FE-structures into SIMPACK by using alternative MOR-methods

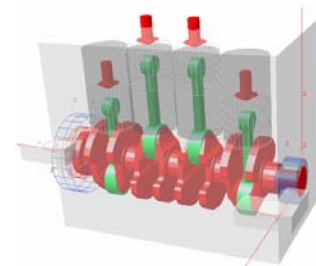
*Claudius Lein, Michael Beitelschmidt*

FEM



DOF  $\approx$  10,000 – 10,000,000

Rigid MBS



DOF  $\approx$  10 – 500

**MODEL-ORDER-  
REDUCTION  
(MOR)**

SIMPACK-Interface  
(FlexModal)

DOF < 10,000

1. Standard Reduction Techniques
2. Work Flow
3. MORPACK-Interface
4. Example
5. Conclusion

## Principle of Model Order Reduction (MOR)



FE-discrete equation of motion (ODE):

$$\underbrace{\begin{matrix} \text{mass} \\ \left[ \begin{array}{c|c} & \\ \hline \mathbf{M} & \ddot{\mathbf{x}} \end{array} \right] \\ n \end{matrix}} + \underbrace{\begin{matrix} \text{damping} \\ \left[ \begin{array}{c|c} & \\ \hline \mathbf{D} & \dot{\mathbf{x}} \end{array} \right] \\ n \end{matrix}} + \underbrace{\begin{matrix} \text{stiffness} \\ \left[ \begin{array}{c|c} & \\ \hline \mathbf{K} & \mathbf{x} \end{array} \right] \\ n \end{matrix}} = \underbrace{\begin{matrix} \text{external loads} \\ \left[ \begin{array}{c|c} & \mathbf{u} \\ \hline \mathbf{B} & \end{array} \right] \\ q \end{matrix}} \cdot \underbrace{\left[ \begin{array}{c} \mathbf{u} \\ \hline 1 \end{array} \right]}_1 \Bigg\} q$$

$$n \in [10^4..10^7]$$



### MODEL-ORDER-REDUCTION

$$\underbrace{\begin{matrix} \left[ \begin{array}{c|c} & \\ \hline \mathbf{M}_R & \ddot{\mathbf{x}}_R \end{array} \right] \\ m \end{matrix}} + \underbrace{\begin{matrix} \left[ \begin{array}{c|c} & \\ \hline \mathbf{D}_R & \dot{\mathbf{x}}_R \end{array} \right] \\ m \end{matrix}} + \underbrace{\begin{matrix} \left[ \begin{array}{c|c} & \\ \hline \mathbf{K}_R & \mathbf{x}_R \end{array} \right] \\ m \end{matrix}} = \underbrace{\begin{matrix} \left[ \begin{array}{c|c} & \mathbf{u} \\ \hline \mathbf{B}_R & \end{array} \right] \\ q \end{matrix}} \cdot \underbrace{\left[ \begin{array}{c} \mathbf{u} \\ \hline 1 \end{array} \right]}_1 \Bigg\} q$$

$$m \ll n$$

## Projection matrix

Relation:  $\mathbf{x} = \mathbf{T}\mathbf{x}_R$

$$\mathbf{M}_R = \mathbf{T}^T \mathbf{M} \mathbf{T}$$

$$\mathbf{D}_R = \mathbf{T}^T \mathbf{D} \mathbf{T}$$

$$\mathbf{K}_R = \mathbf{T}^T \mathbf{K} \mathbf{T}$$

Purpose:  $\mathbf{x}_R \in \mathbb{R}^{m \times 1} \rightarrow \mathbf{T} \in \mathbb{R}^{n \times m}$

$m \ll n$



Master-Slave-Partitioning:

$$\mathbf{x} = \begin{pmatrix} \mathbf{x}_R \\ \mathbf{x}_S \end{pmatrix} \begin{matrix} \text{master} \\ \text{slave} \end{matrix}$$

e.g.  $\mathbf{M} = \begin{pmatrix} \mathbf{M}_{RR} & \mathbf{M}_{RS} \\ \mathbf{M}_{SR} & \mathbf{M}_{SS} \end{pmatrix}$

$$\mathbf{K} = \begin{pmatrix} \mathbf{K}_{RR} & \mathbf{K}_{RS} \\ \mathbf{K}_{SR} & \mathbf{K}_{SS} \end{pmatrix}$$

## Standard Reduction Techniques

(included in commercial software, e.g. ANSYS)

Static reduction (GUYAN):

$$\mathbf{x} = \mathbf{T}_{GUYAN} \mathbf{x}_R$$

$$\mathbf{T}_{GUYAN} = \begin{pmatrix} \mathbf{I} \\ -\mathbf{K}_{SS}^{-1} \mathbf{K}_{SR} \end{pmatrix}$$

- mass independent
- applicable for **static** analyses

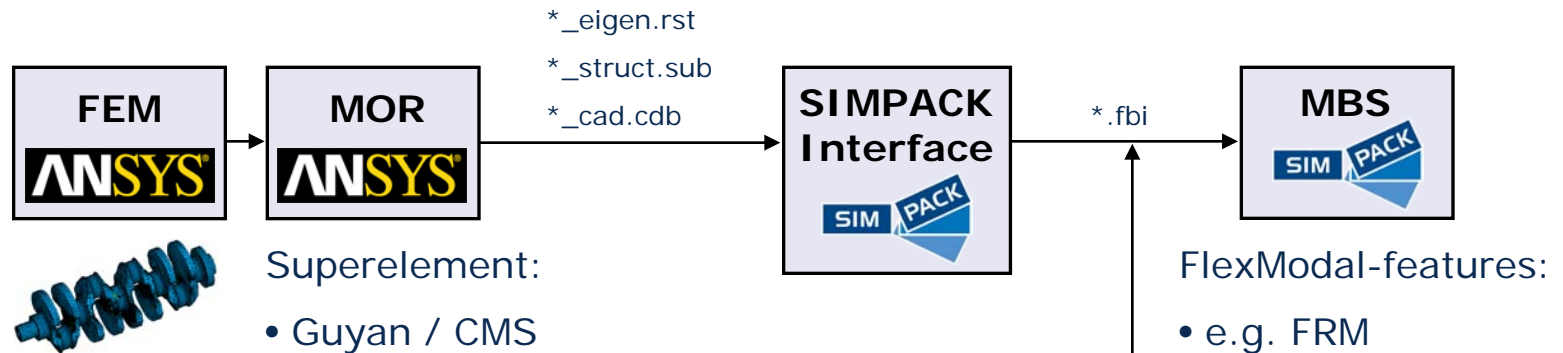
Component Mode Synthesis (CMS):

$$\mathbf{x} = \mathbf{T}_{CMS} \mathbf{x}_R$$

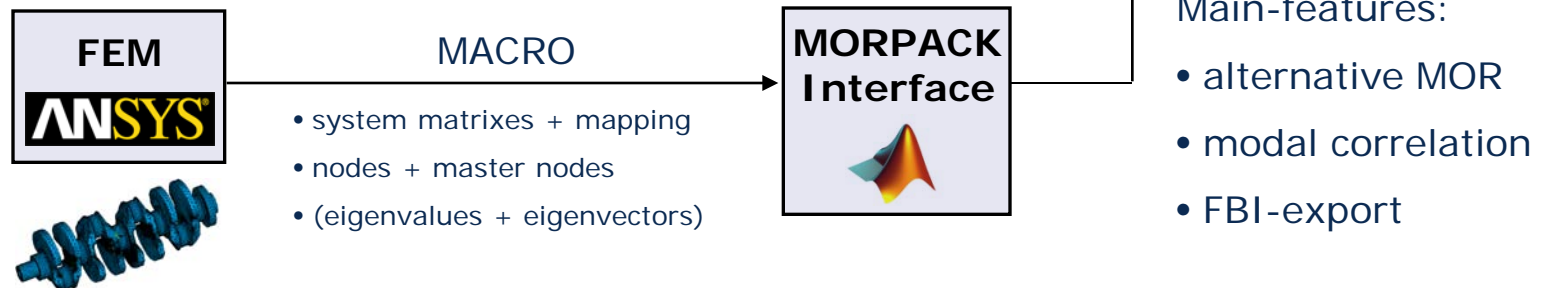
$$\mathbf{T}_{CMS} = \begin{pmatrix} \mathbf{I} & \mathbf{0} \\ -\mathbf{K}_{SS}^{-1} \mathbf{K}_{SR} & \Phi_{CB} \end{pmatrix}$$

- mass independent
- consideration of **additional modes**
- applicable for **dynamic** analyses
- **DOF increase**

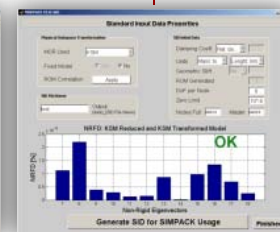
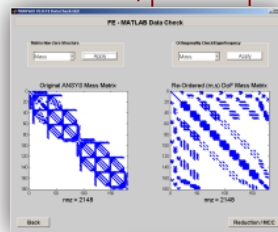
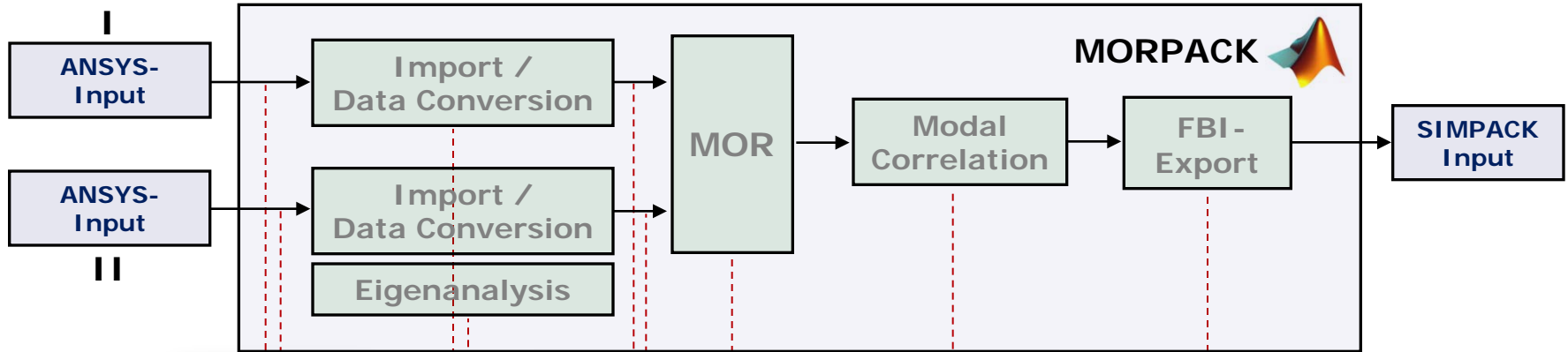
## Standard Work Flow (e.g. ANSYS–SIMPACK)



## Alternative Work Flow (e.g. ANSYS-MORPACK-SIMPACK)



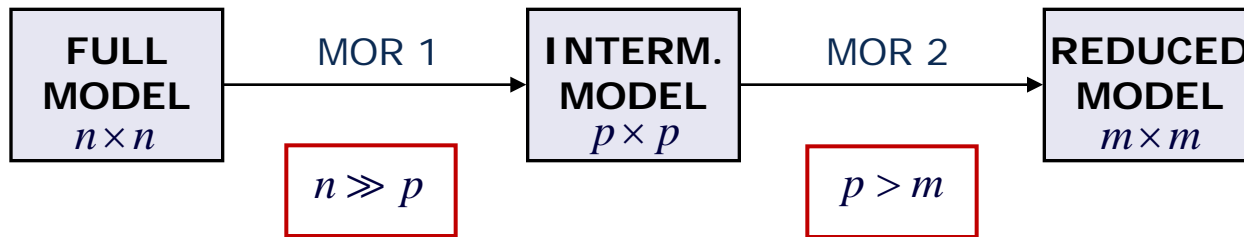
## Model-Order-Reduction-PACKage



## Implemented Reduction Methods

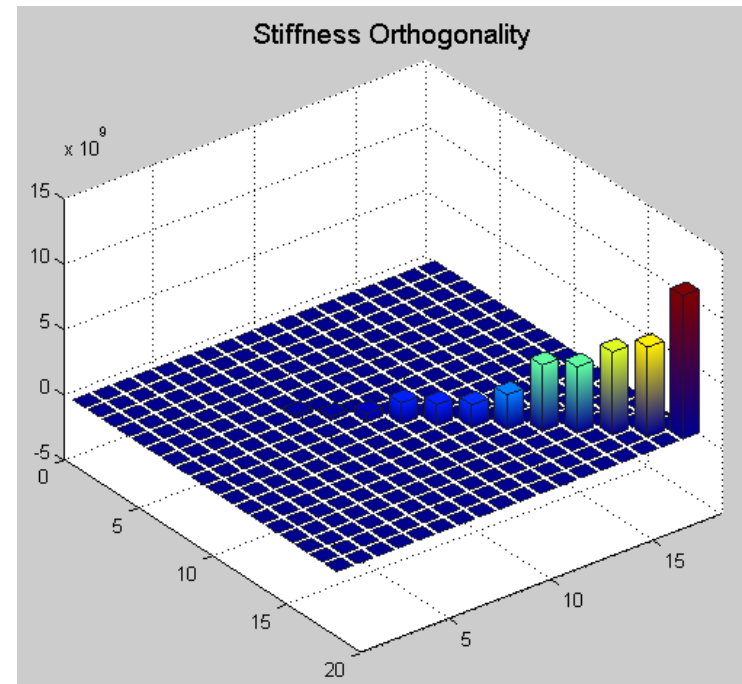
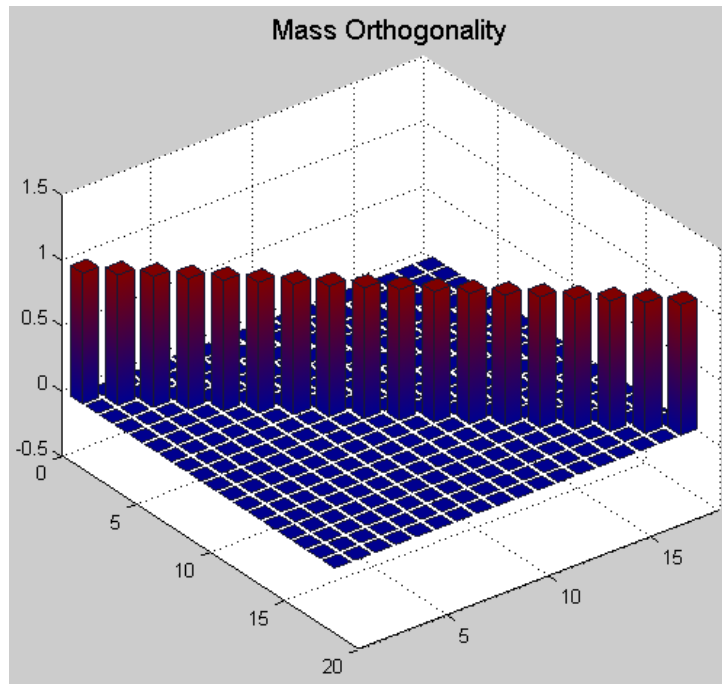
<b>Basic Methods</b>	<b>physical</b>	<b>semi-physical</b>	<b>non-physical</b>	<b>ANSYS</b>	<b>MORPACK</b>
Static Reduction <b>Guyan</b>	<b>X</b>			<b>X</b>	<b>X</b>
Dynamic Reduction	<b>X</b>				<b>X</b>
Standard Improved Reduction System Method <b>IRS</b>	<b>X</b>				<b>X</b>
System Equivalent Reduction Expansion Process <b>SEREP</b>		<b>X</b>			<b>X</b>
Component Mode Synthesis <b>CMS / Craig-Bampton Method</b>		<b>X</b>		<b>X</b>	<b>X</b>
Krylov Subspace Method <b>KSM</b>			<b>X</b>		<b>X</b>
Balanced Truncation <b>BT</b>			<b>X</b>		<b>X</b>

## Two-Step Reduction Techniques



- combination of 2 reduction methods
- intermediate model dimension
- up to 18 combined MOR-methods

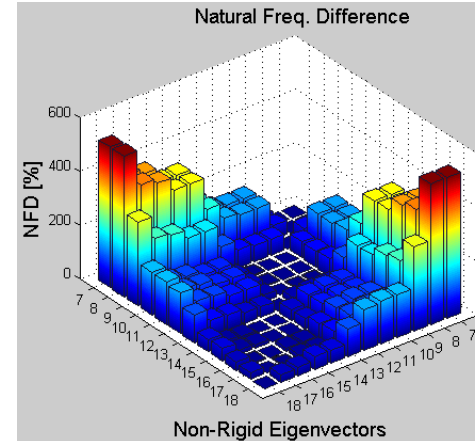
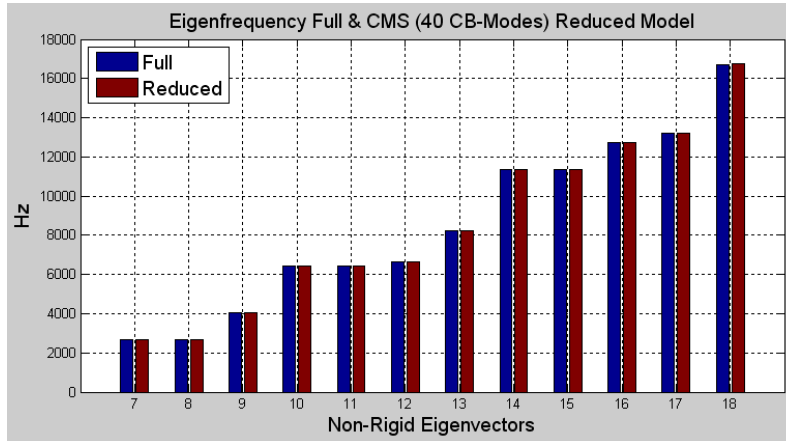
## Orthogonality Check (after data conversion)



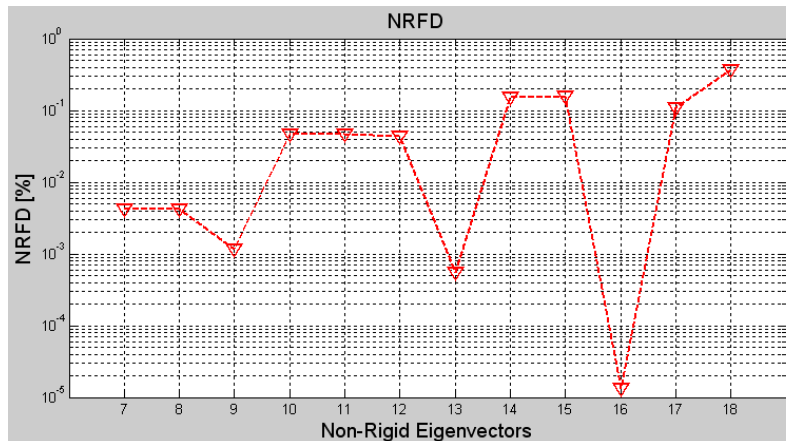
$$\Phi_m^T \mathbf{M} \Phi_m = \mathbf{I}$$

$$\Phi_m^T \mathbf{K} \Phi_m = \Lambda$$

## Modal Correlation – eigenfrequency-related

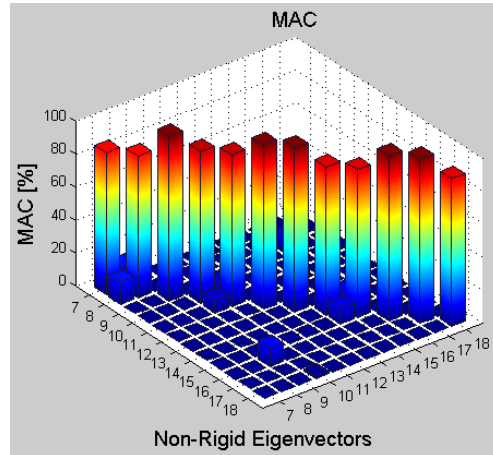


NFD



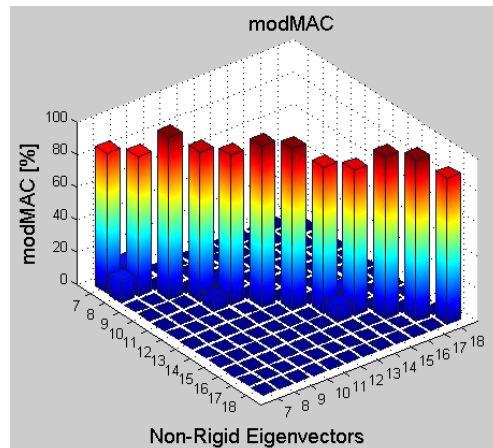
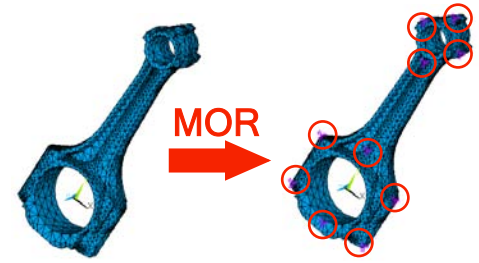
NRFD

## Modal Correlation – eigenvector-related



MAC

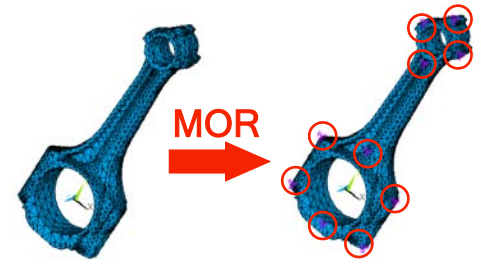
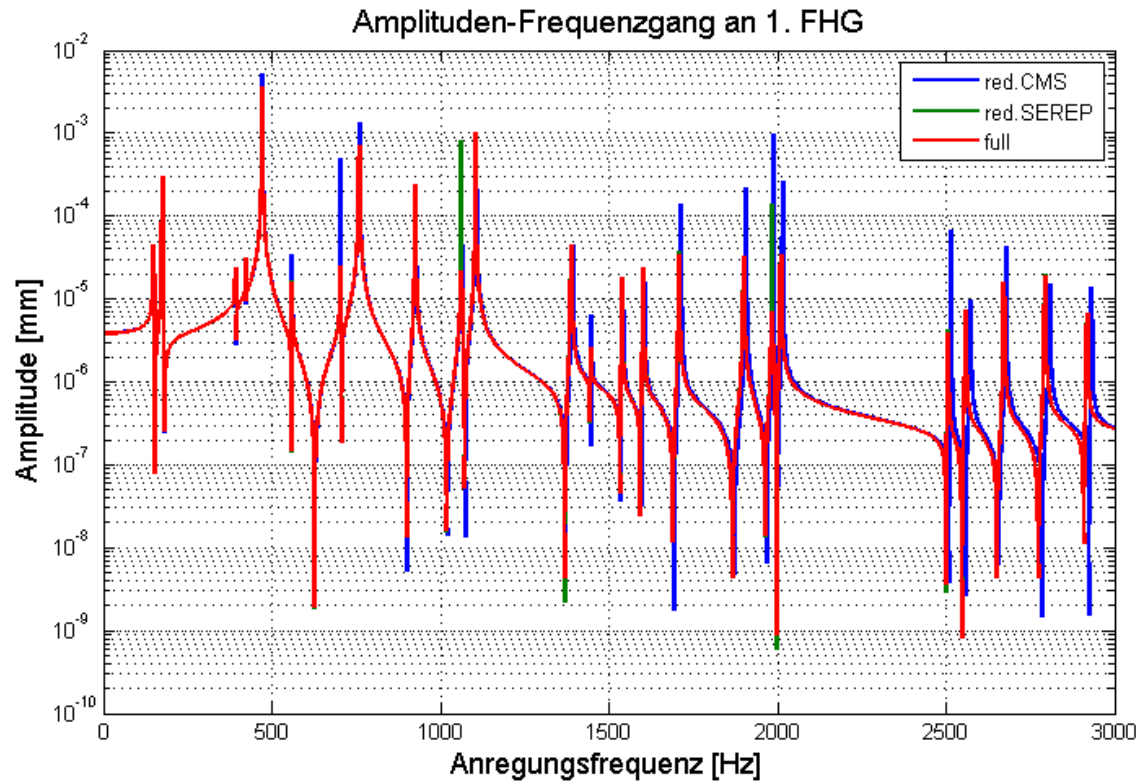
$$MAC_{k,l} = \frac{\left(\vec{\Phi}_{red,k}^T \vec{\Phi}_{full,l}\right)^2}{\left(\vec{\Phi}_{red,k}^T \vec{\Phi}_{red,k}\right)\left(\vec{\Phi}_{full,l}^T \vec{\Phi}_{full,l}\right)} \cdot 100\%$$



modMAC (mass-weighted)

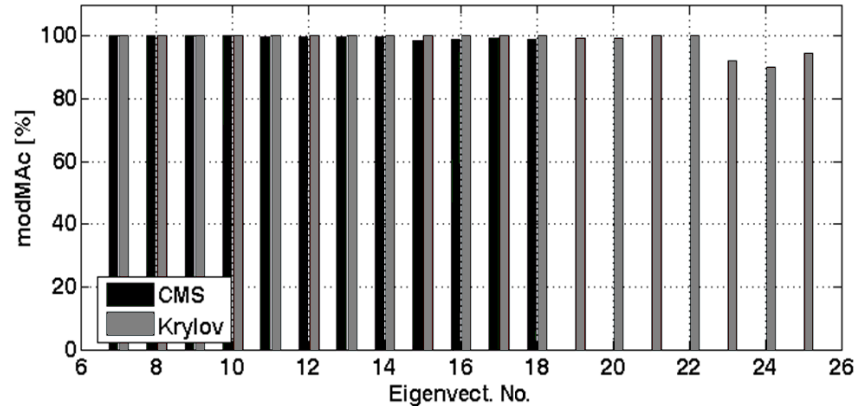
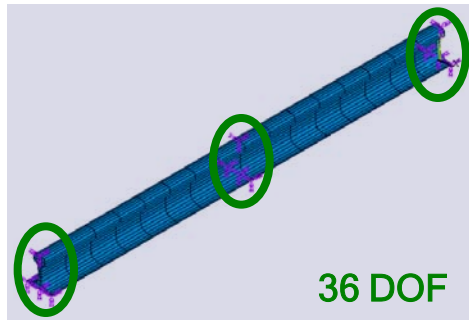
$$modMAC_{k,l} = \frac{\left(\vec{\Phi}_{red,k}^T \mathbf{M} \vec{\Phi}_{full,l}\right)^2}{\left(\vec{\Phi}_{red,k}^T \mathbf{M} \vec{\Phi}_{red,k}\right)\left(\vec{\Phi}_{full,l}^T \mathbf{M} \vec{\Phi}_{full,l}\right)} \cdot 100\%$$

## Modal Correlation – frequency response



## Example – Selection of Master Nodes (UIC60 rail, free structure, 12 master nodes)

Good selection



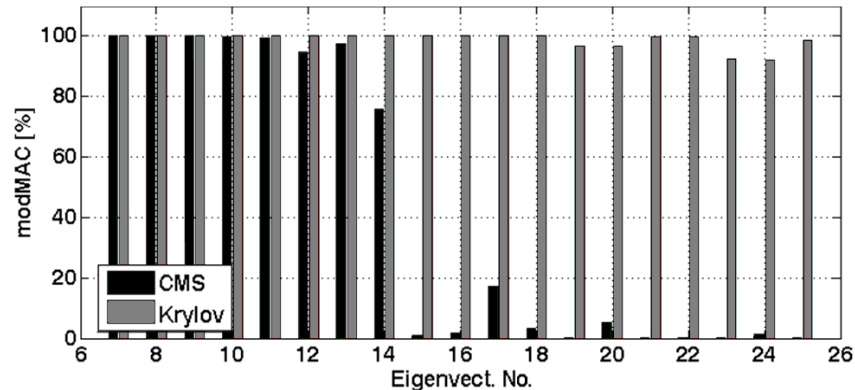
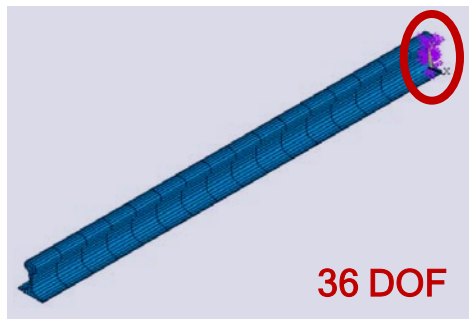
$$CB_{CMS} = 10$$

$$CB_{KSM} = 0$$

$$\mathbf{M}, \mathbf{K} \in \mathbb{R}^{m \times m}$$

$$m = DOF + CB$$

Poor selection



**CMS:**

$$\mathbf{M}_R, \mathbf{K}_R \in \mathbb{R}^{46 \times 46}$$

**KSM:**

$$\mathbf{M}_R, \mathbf{K}_R \in \mathbb{R}^{36 \times 36}$$

## Standard reduction techniques

- 2 methods available in commercial software (e.g. ANSYS)
- no validation, no user feedback

## MORPACK-features

- interface available for NASTRAN and ANSYS
- up to 18 combined MOR-methods
- several correlation methods implemented
- FBI-export
- consideration of constraints and boundary conditions
- mixed DOF

### Main advantages

- qualitatively better reduced models
- handling of large models by using iterative techniques
- low computation time by using iterative techniques
- less DOF compared to standard-techniques (e.g. CMS)
- quality of reduced model partly independent from master-set



**»Wissen schafft Brücken.«**