TECHNISCHE UNIVERSITÄT DRESDEN

SIMPACK

Institute for Rail Vehicle Engineering Chair of Vehicle Modeling and Simulation

SIMPACK User Meeting - Salzburg, May 19, 2011

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

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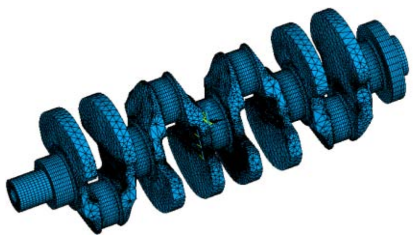
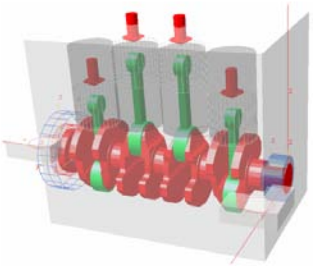
Need for reduction techniques

FEM



DOF ≈ 10,000 – 10,000,000

Rigid MBS



DOF ≈ 10 – 500

MODEL-ORDER-REDUCTION (MOR)

SIMPACK-Interface (FlexModal)

DOF < 10,000

Scope

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):

mass, damping, stiffness, external loads

$$\underbrace{\mathbf{M}}_{n\times n}\ddot{\mathbf{x}} + \mathbf{D}\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \underbrace{\mathbf{B}}_{n\times q}\bullet\underbrace{\mathbf{u}}_{q\times 1}$$

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

MODEL-ORDER-REDUCTION

$$\underbrace{\mathbf{M}_R}_{m\times m}\ddot{\mathbf{x}}_R + \mathbf{D}_R\dot{\mathbf{x}}_R + \mathbf{K}_R\mathbf{x}_R = \underbrace{\mathbf{B}_R}_{m\times q}\bullet\underbrace{\mathbf{u}}_{q\times 1}$$

$$m \ll n$$

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:

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

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):

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

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

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

2 Work Flow

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

FEM ANSYS → MOR ANSYS → SIMPACK Interface → MBS

*_eigen.rst
*_struct.sub
*_cad.cdb

*.fbi

Superelement:

- Guyan / CMS

FlexModal-features:

- e.g. FRM

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

FEM ANSYS → MORPACK Interface → MBS

*.fbi

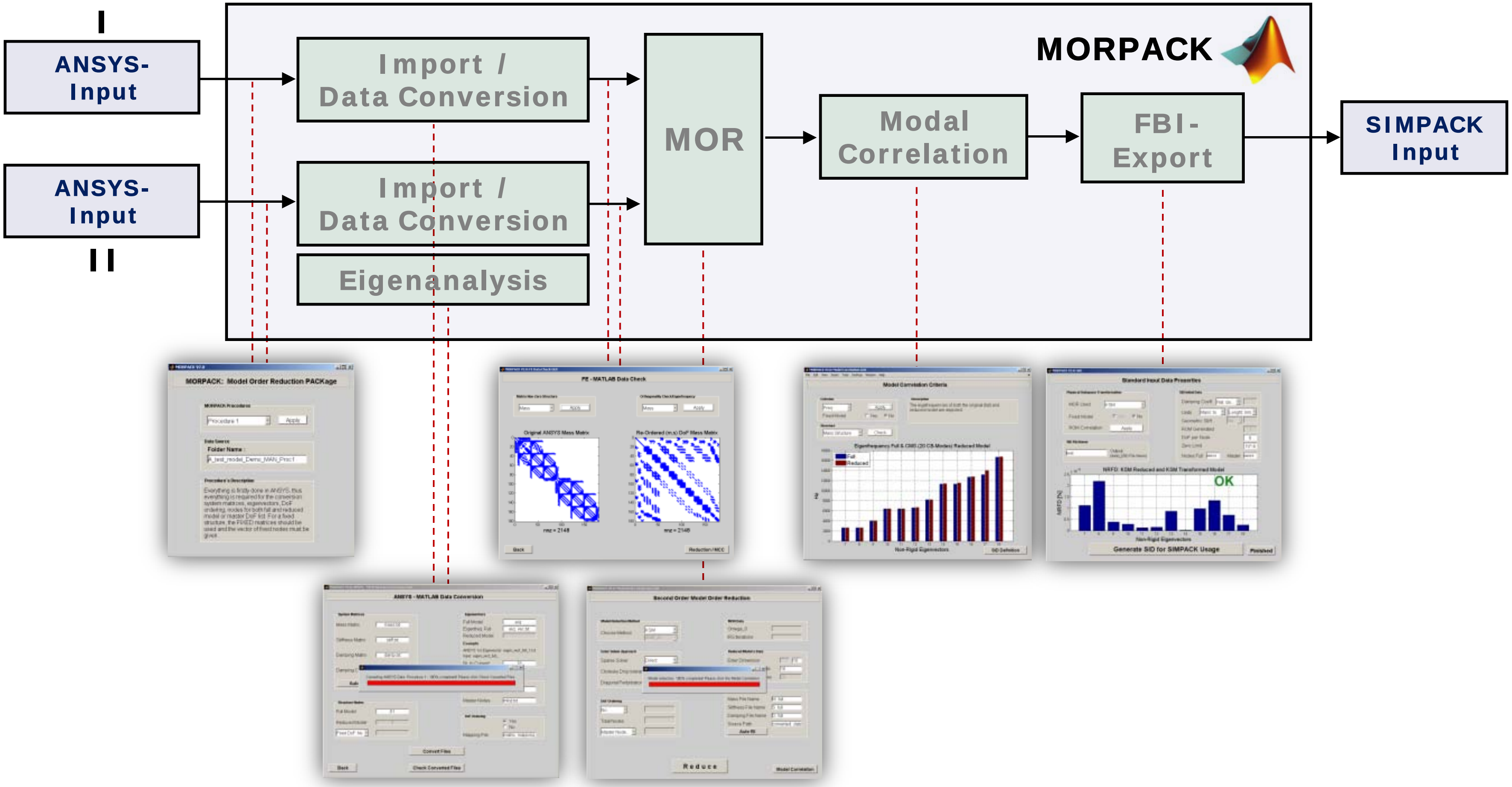
MACRO

- system matrixes + mapping
- nodes + master nodes
- (eigenvalues + eigenvectors)

Main-features:

- alternative MOR
- modal correlation
- FBI-export

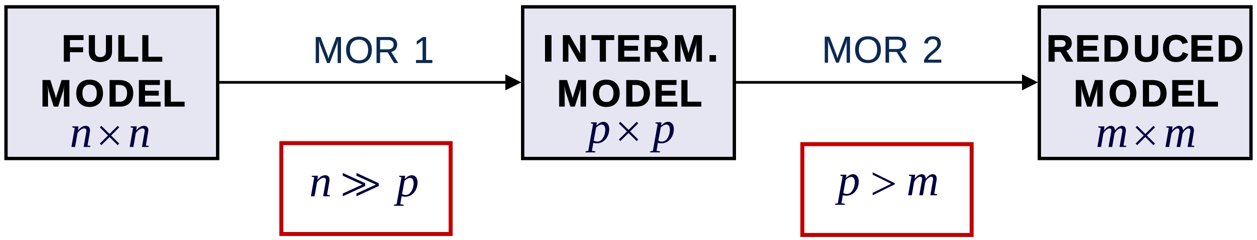
Model-**O**rder-**R**eduction-**PAC**kage



Implemented Reduction Methods

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

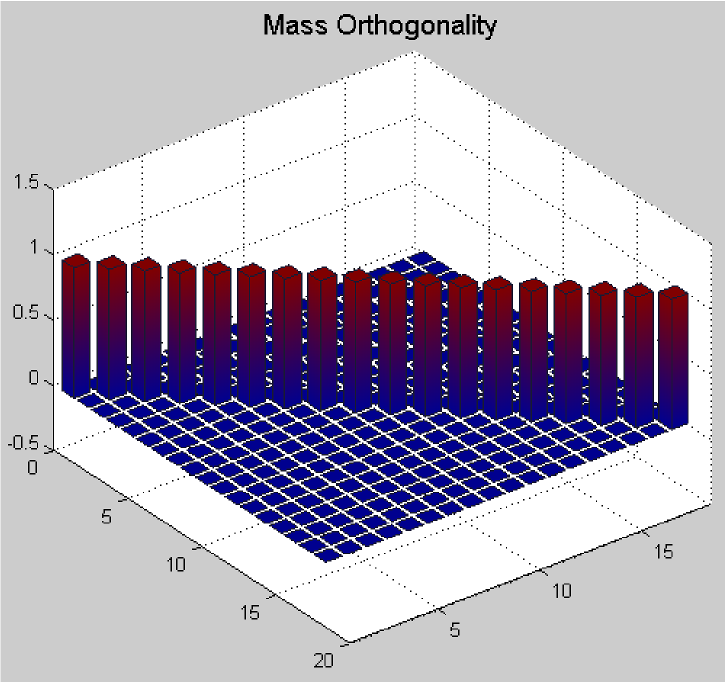
Two-Step Reduction Techniques

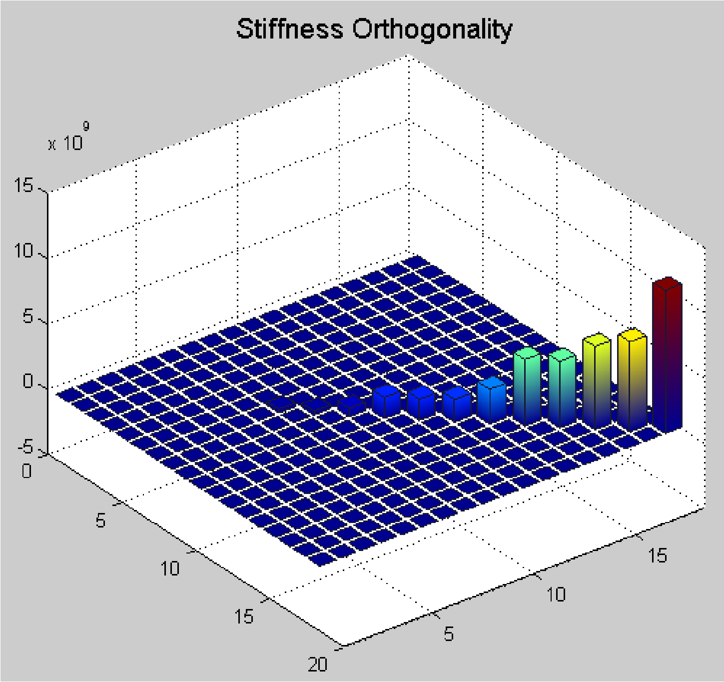


- combination of 2 reduction methods
- intermediate model dimension

- up to 18 combined MOR-methods

Orthogonality Check (after data conversion)



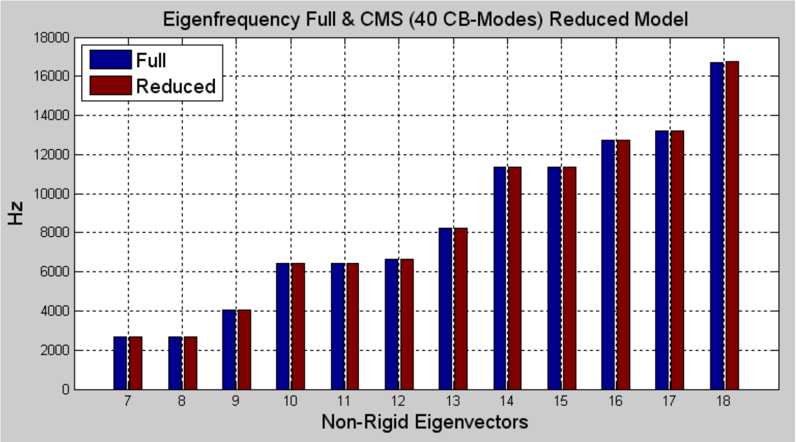


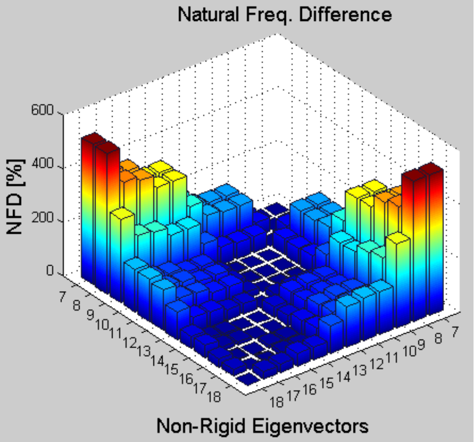
$$\mathbf{\Phi}_m^T \mathbf{M} \mathbf{\Phi}_m = \mathbf{I}$$

$$\mathbf{\Phi}_m^T \mathbf{K} \mathbf{\Phi}_m = \mathbf{\Lambda}$$

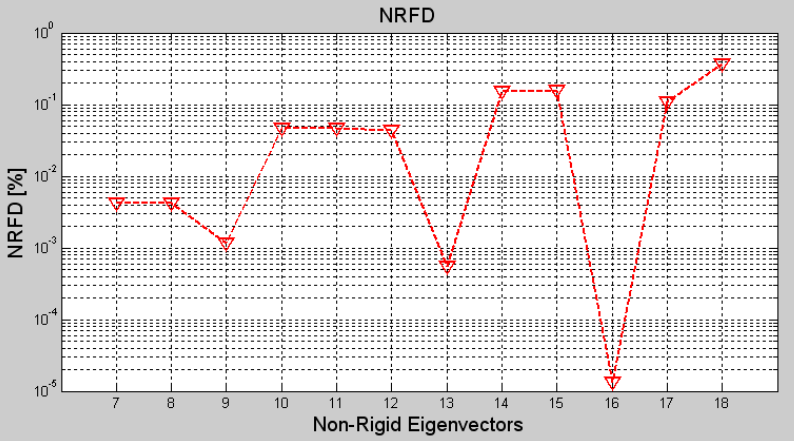
3 MORPACK-Interface

Modal Correlation – eigenfrequency-related



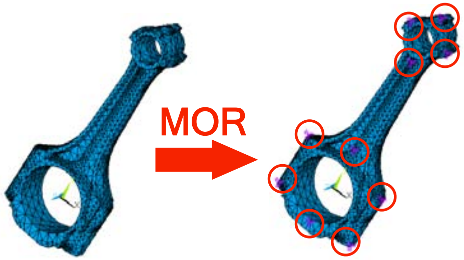


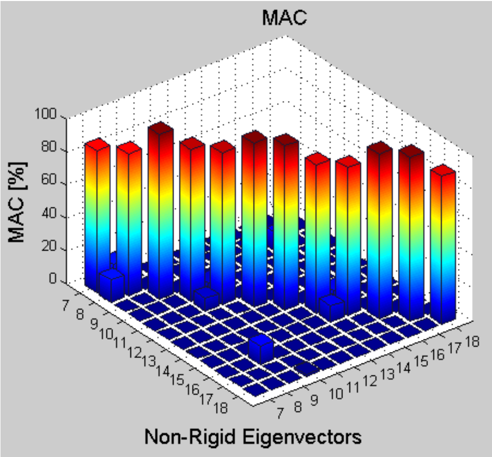
NFD



NRFD

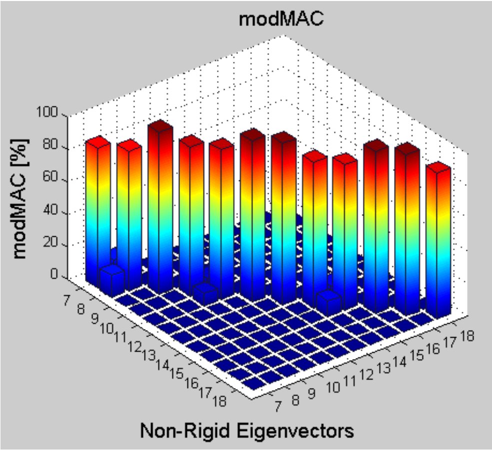
Modal Correlation – eigenvector-related





MAC

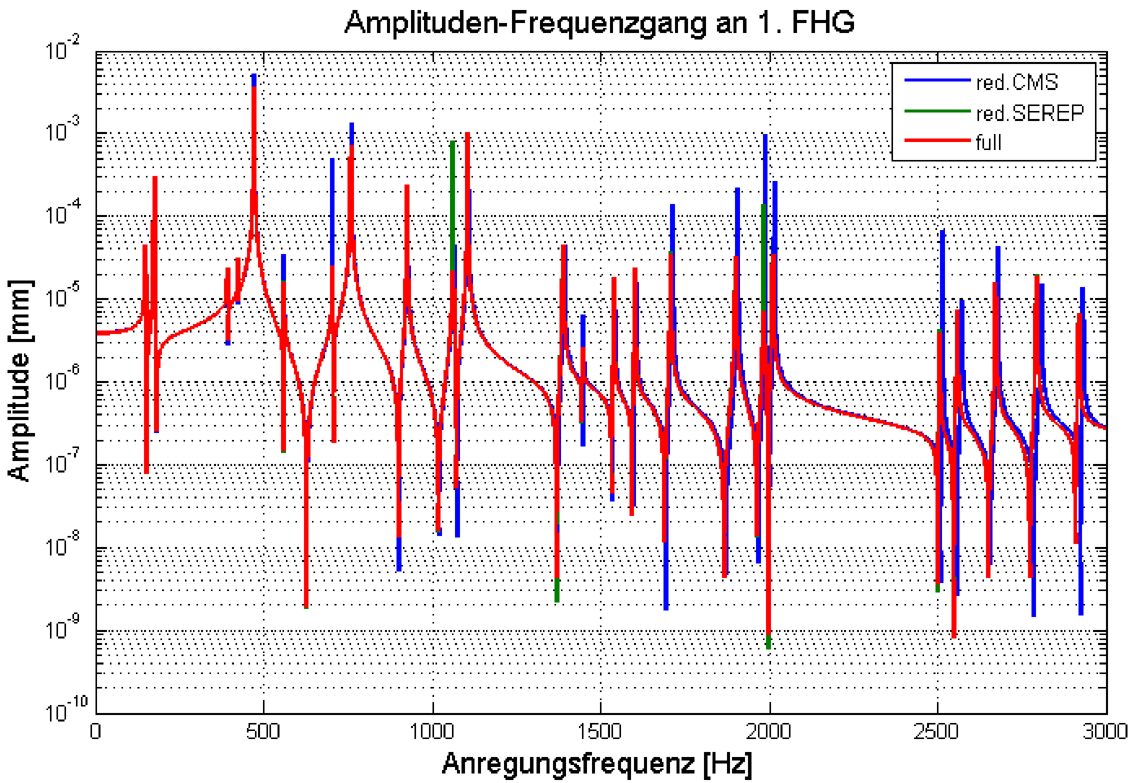
$$MAC_{k,l} = \frac{\left(\vec{\Phi}^T_{red,k}\vec{\Phi}_{full,l}\right)^2}{\left(\vec{\Phi}^T_{red,k}\vec{\Phi}_{red,k}\right)\left(\vec{\Phi}^T_{full,l}\vec{\Phi}_{full,l}\right)} \cdot 100\%$$

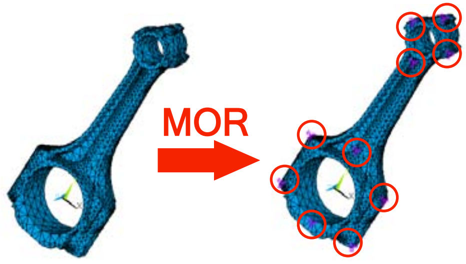


modMAC (mass-weighted)

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

Modal Correlation – frequency response

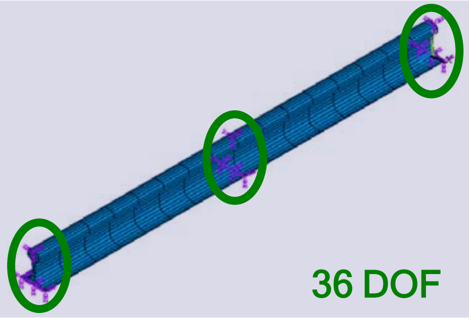


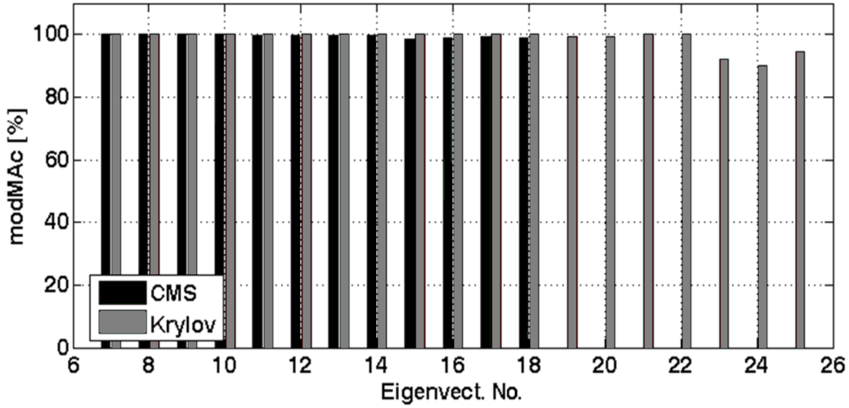


Example – Selection of Master Nodes

(UIC60 rail, free structure, 12 master nodes)

Good selection





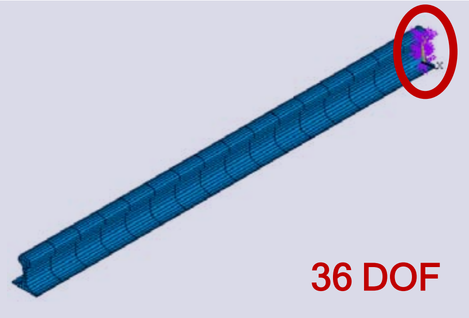
$$CB_{CMS} = 10$$

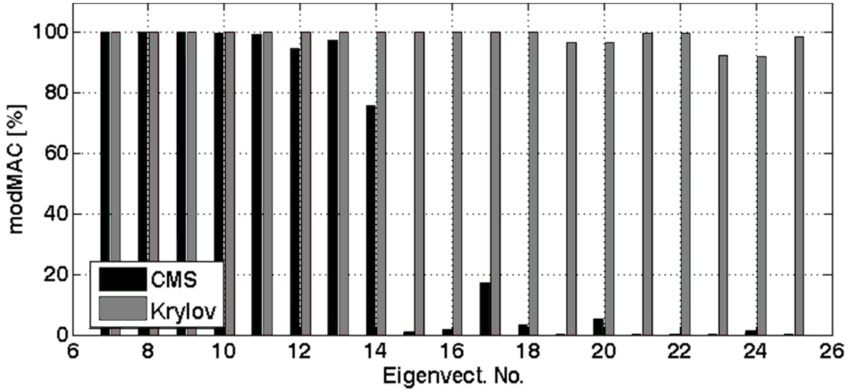
$$CB_{KSM} = 0$$

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

$$m = DOF + CB$$

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

5 Conclusion

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

Thank You For Your Attention

»Wissen schafft Brücken.«