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Deformable Rigid Bodies in LS-DYNA with Applications – Merits and Limits

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Modal Methods and Deformable Rigid Bodies

- **Modal Methods**
  - Eigenmodes as a useful problem dependent basis
  - Basically a completely linear concept
  - Unknowns are modal amplitudes instead of nodal displacements
  - Method is
    - exact for a full set of modes
    - approximate for a reduced set of modes
- **Flexible Rigid Bodies**
  - Eigenmodes superimposed onto a nonlinear rigid body motion
  - Major Goal: Efficiency can be considerably improved
- **Reference**
  - Bradley N. Maker, David J. Benson: Modal Methods for Transient Dynamics Analysis in LS-DYNA. *Livermore Software Technology Corporation.*

Basic Procedure – Mechanical Background and Creation of a LS-DYNA Keyword File

- Identify all parts to be treated as rigid bodies with superimposed modes

- Treatment of boundary constraints of these bodies:
  - exclude all elements with Dirichlet data, i.e. by giving them an own part-ID
  - remove all boundary constraints

- Solve the eigenvalue problem

$$\left(\mathbf{K} - \omega^2 \mathbf{M}\right)\mathbf{\Phi} = \mathbf{0}$$

  to get the n eigenmodes wanted

- Eigenmodes are orthogonal

$$\mathbf{\Phi}^{\mathrm{T}}\mathbf{M}\mathbf{\Phi} = \mathbf{I} \qquad \text{and} \qquad \mathbf{\Phi}^{\mathrm{T}}\mathbf{K}\mathbf{\Phi} = \left[\omega^2\right]$$

Basic Procedure – Mechanical Background and Creation of a LS-DYNA Keyword File

- Orthogonality is used to reduce original system

$$\mathbf{M}\ddot{\mathbf{u}} + \mathbf{K}\mathbf{u} = \mathbf{f}(\mathbf{t}) \qquad \text{to} \qquad \mathbf{I}\ddot{\mathbf{z}} + [\omega^2]\mathbf{z} = \mathbf{p}(\mathbf{t})$$

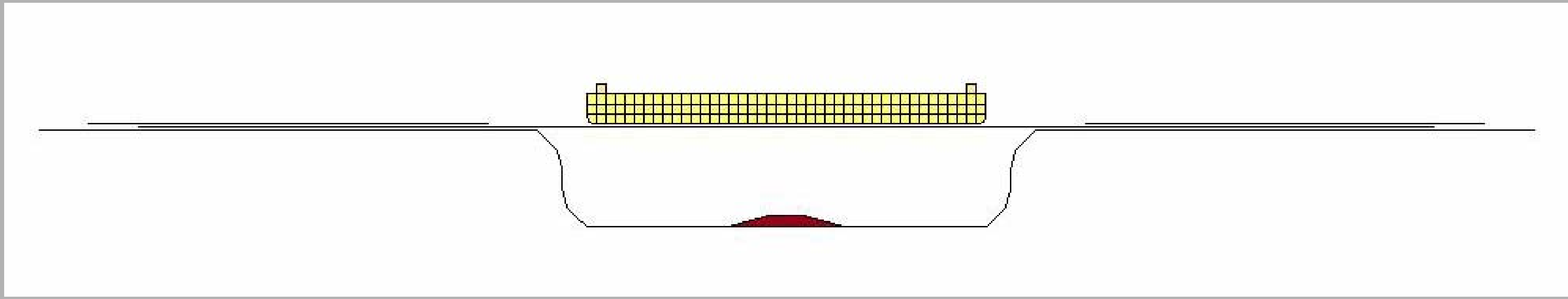
- Resulting equation system
  - is considerably smaller (dep. on used number of modes)
  - is diagonal
  - can also be treated with explicit time integration
- Full system solution is recovered via

$$\mathbf{u} = \mathbf{\Phi}\mathbf{z} \quad , \quad \ddot{\mathbf{u}} = \mathbf{\Phi}\ddot{\mathbf{z}} \quad , \quad \mathbf{p}(\mathbf{t}) = \mathbf{\Phi}^{\mathrm{T}}\mathbf{f}(\mathbf{t})$$

- Resulting deformations are superimposed onto the center of mass of the rigid body
- For more detailed description see conference paper and references given

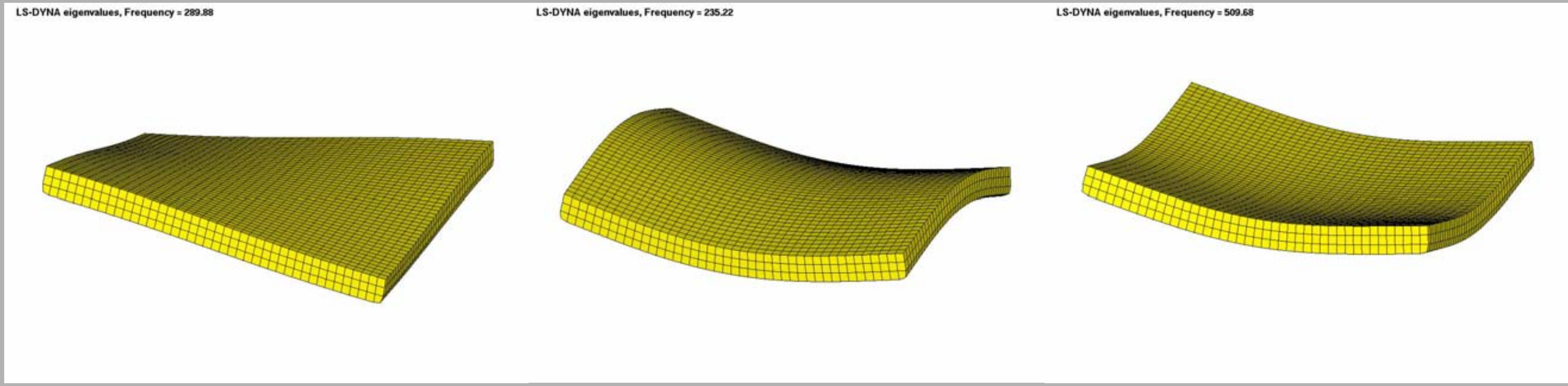
Introductory Example: Sheet Metal Forming

- **Simple test example for sheet metal forming**
  - **thin blank:**
    - **discretized with 4719 shell elements**
    - **treated as a fully nonlinear structure, modeled with *MAT_3-PARAMETER-BARLAT**
  - **die:** ***Rigid body with superimposed modes***
    - **originally discretized with 5292 solid elements**
    - **linear response, modes from d3eigv database of FE model**



Introductory Example: Sheet Metal Forming

- **Eigenmodes of the tool – free flying !**
  - ***unique*** **due to absence of boundary conditions**
  - **first three of them shown below**

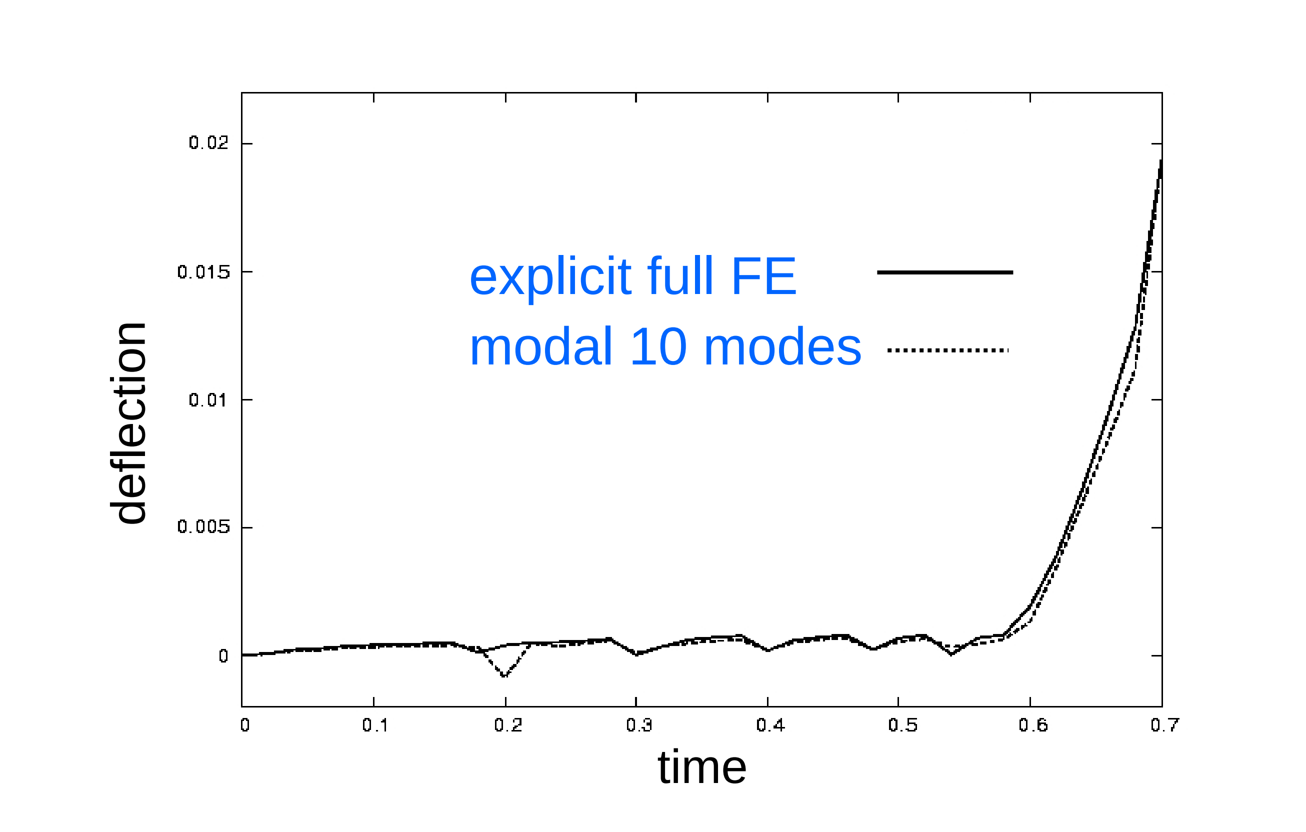


- **In presence of boundary conditions to eliminate rigid body motion**
  - **eigenmodes depend on choice of boundary conditions**
  - **visibility of modes is reduced**

Introductory Example: Sheet Metal Forming

- comparison of solution with fully explicit and modal method,

displacements of a typical node



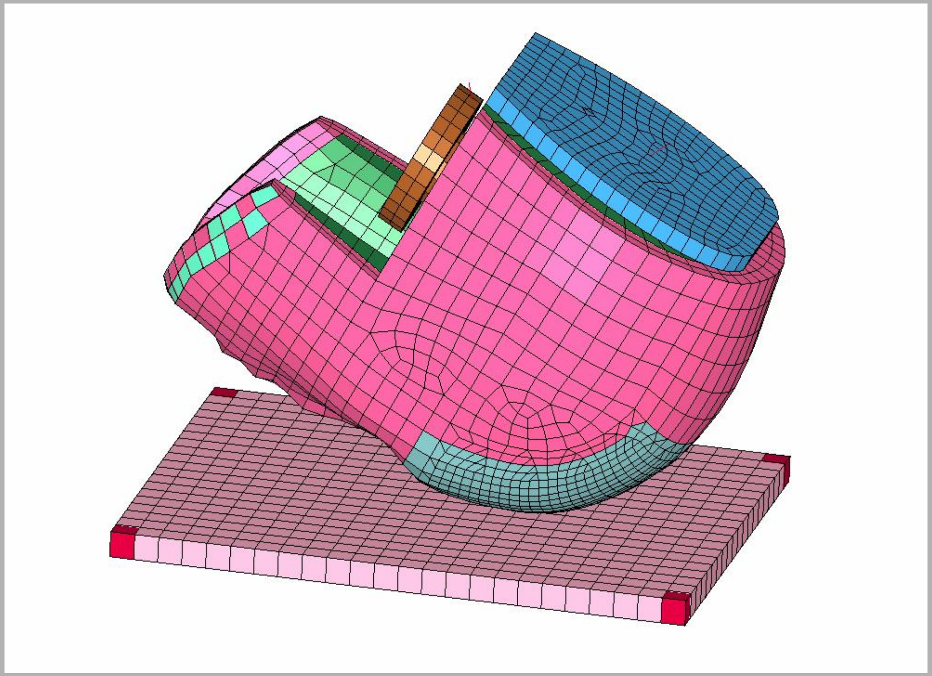
Introductory Example: Sheet Metal Forming

- nearly all deformations are dominated by the contact conditions
  - modal approximation with 10 modes → fully acceptable results
  - in case of a *rigid* die, all deformations of the tool would be zero
- computation time on a AMD Athlon 2200 machine
  - explicit time integration of fully discretized model: 599 min
  - computation of 70 modes: 122 sec
  - tool modeled with flexible rigid bodies, using
    - 10 modes: 233 min
    - 20 modes: 271 min
    - 30 modes: 298 min
    - 40 modes: 331 min
    - 50 modes: 382 min
    - 60 modes: 408 min
    - 70 modes: 459 min

Considerable efficiency gain up to 70 modes !

Head Impact against a Plate

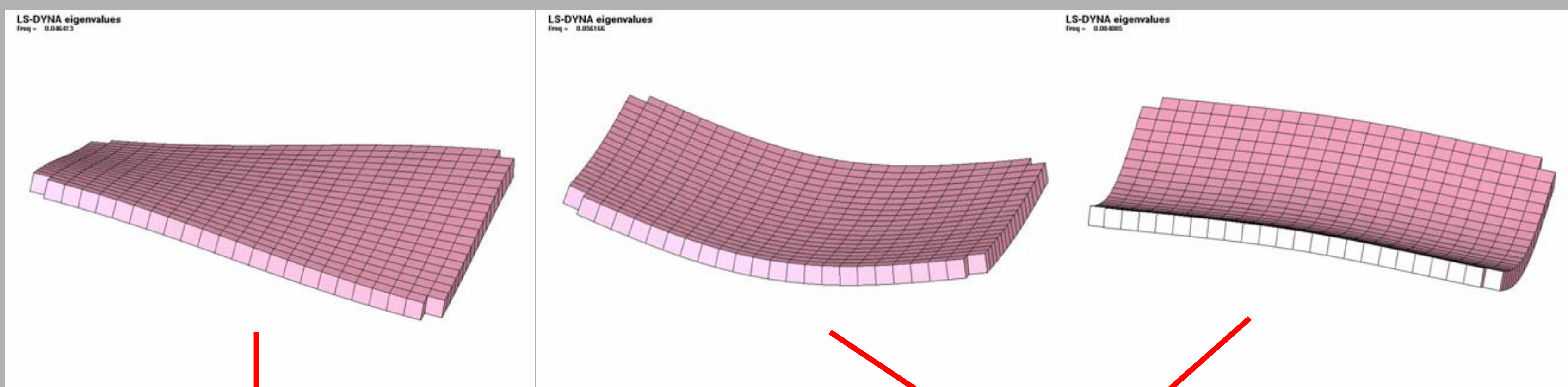
- **LS-DYNA Model of the Hybrid III 50th Free Motion Head Form**
  - **5935 nodes, 4374 shell, 3028 solid and 12 beam elements**
  - **skin modeled with Ogden material, skull rigid**
- **Plate: 1050 nodes, 480 shell elements, fully elastic (= def. rigid body)**



- **Corner elements have own part ID and are excluded from modal analysis to incorporate Dirichlet BC**
- **Head is dropped with v_{init} = 0.2 m/s**

Head Impact against a Plate

- **Eigenmodes of plate – free flying !**
  - ***unique*** **due to absence of boundary conditions**
  - **first three of them shown below**

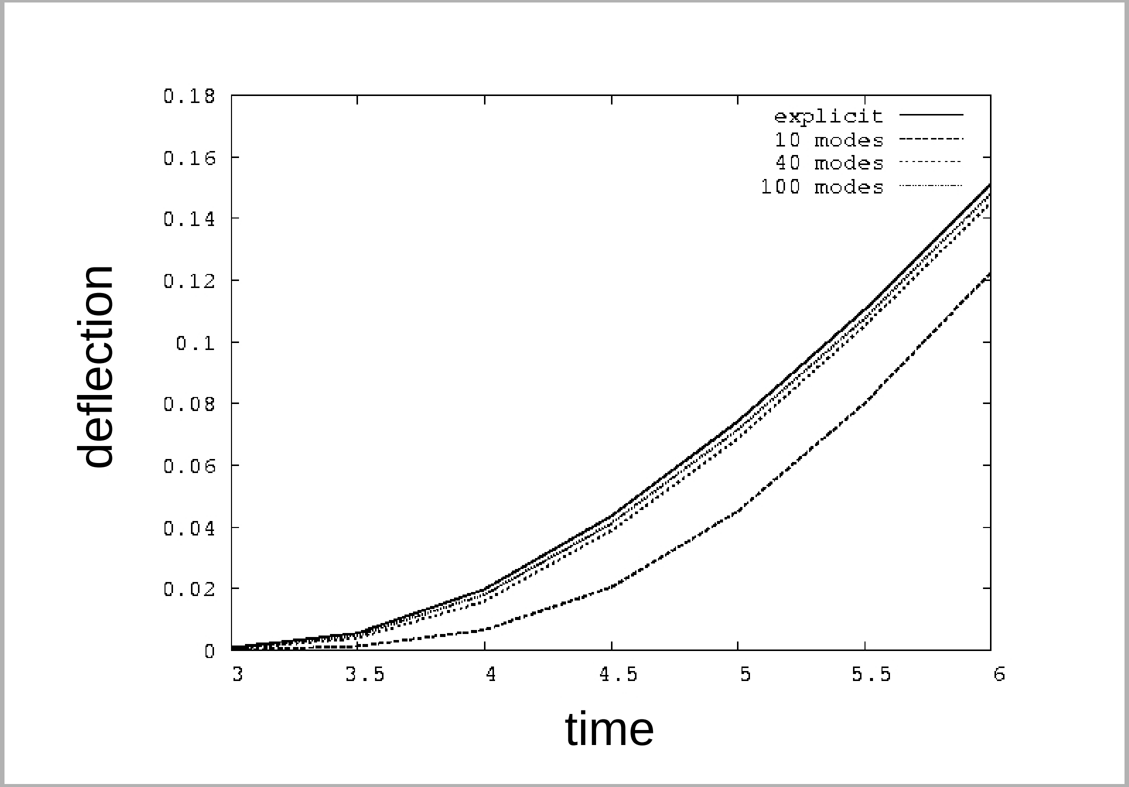


will be suppressed
by boundary parts

will dominantly take part in deformation
under impact

Head impact against a plate

- comparison of solution with fully explicit and modal method
- displacements of a typical node
  calculated with different number of modes



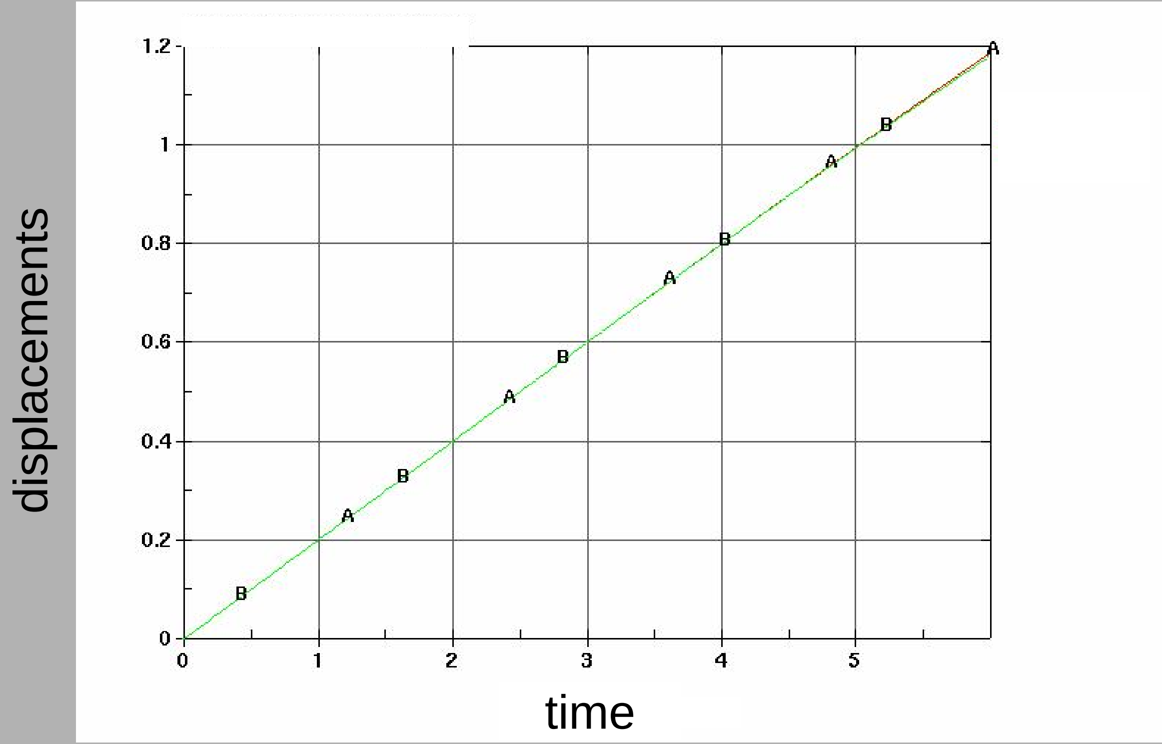
Results for displacements fully acceptable for low number of modes

Head impact against a plate

- relative error in displacements at t=6 ms using
  - 10 modes: 19.0 %
  - 40 modes: 4.2 %
  - 100 modes: 2.3 %
- computation time on an AMD Athlon 2200 machine
  - explicit time integration: 244 sec
  - computation of 100 modes: 8 sec
  - plate modeled with flexible rigid bodies, using
    - 10 modes: 237 sec
    - 40 modes: 246 sec
    - 100 modes: 258 sec
- *example is far too small to show computational savings*
- **but:** good agreement in displacements of plate compared to fully explicit solution with FE model

Head impact against a plate

- displacements of center of mass of the head

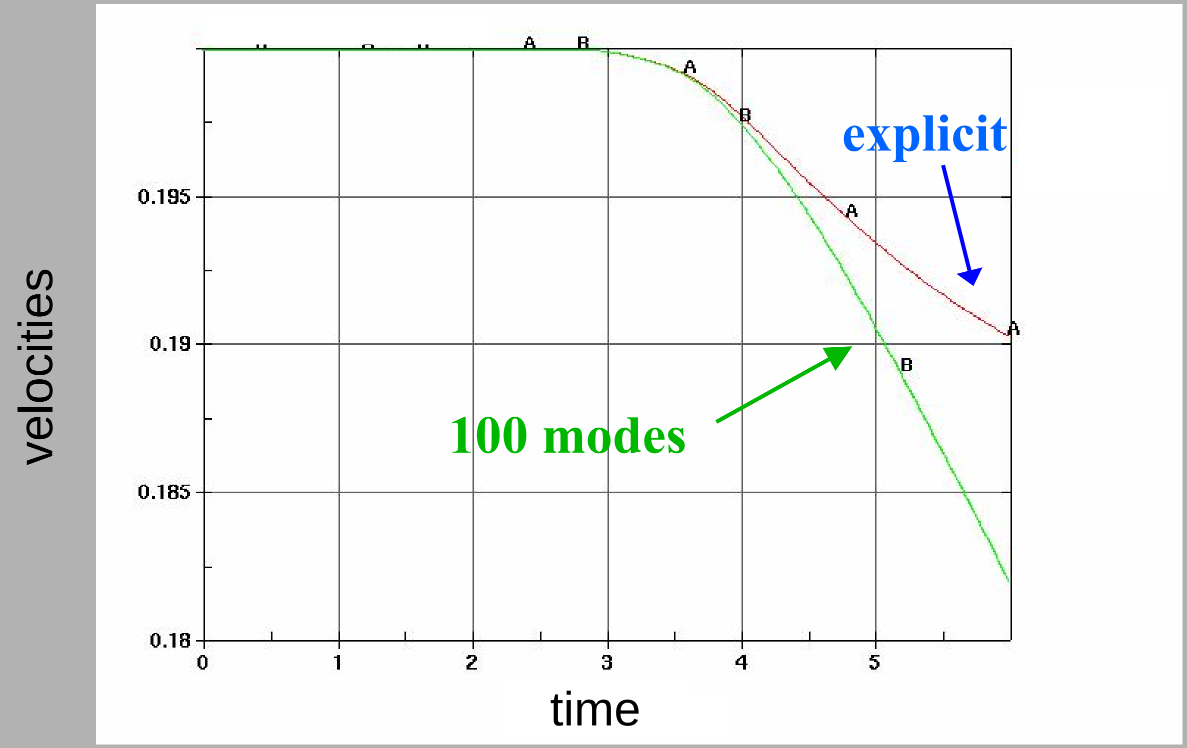


explicit and modal solution with 100 modes compared

- very good agreement in displacements as they are almost perfectly linear

Head impact against a plate

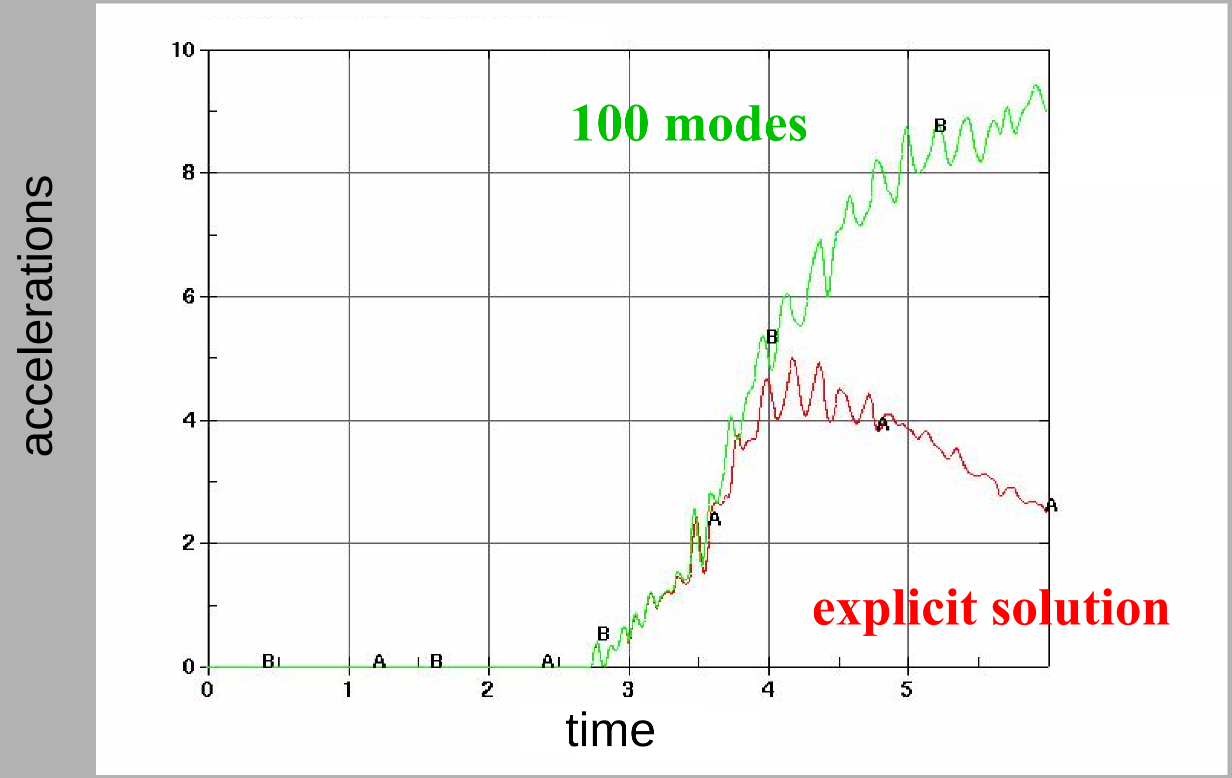
- velocities of center of mass of the head



- acceptable agreement in velocities, relative error to full FE model with explicit time integration less than 5%
  REASON: *Accelerations are rather small*

Head impact against a plate

- ➢ **accelerations of center of mass of the head**



- ➢ **accelerations** **partially poorly approximated**

Head Impact against a Side Part – 1st Example

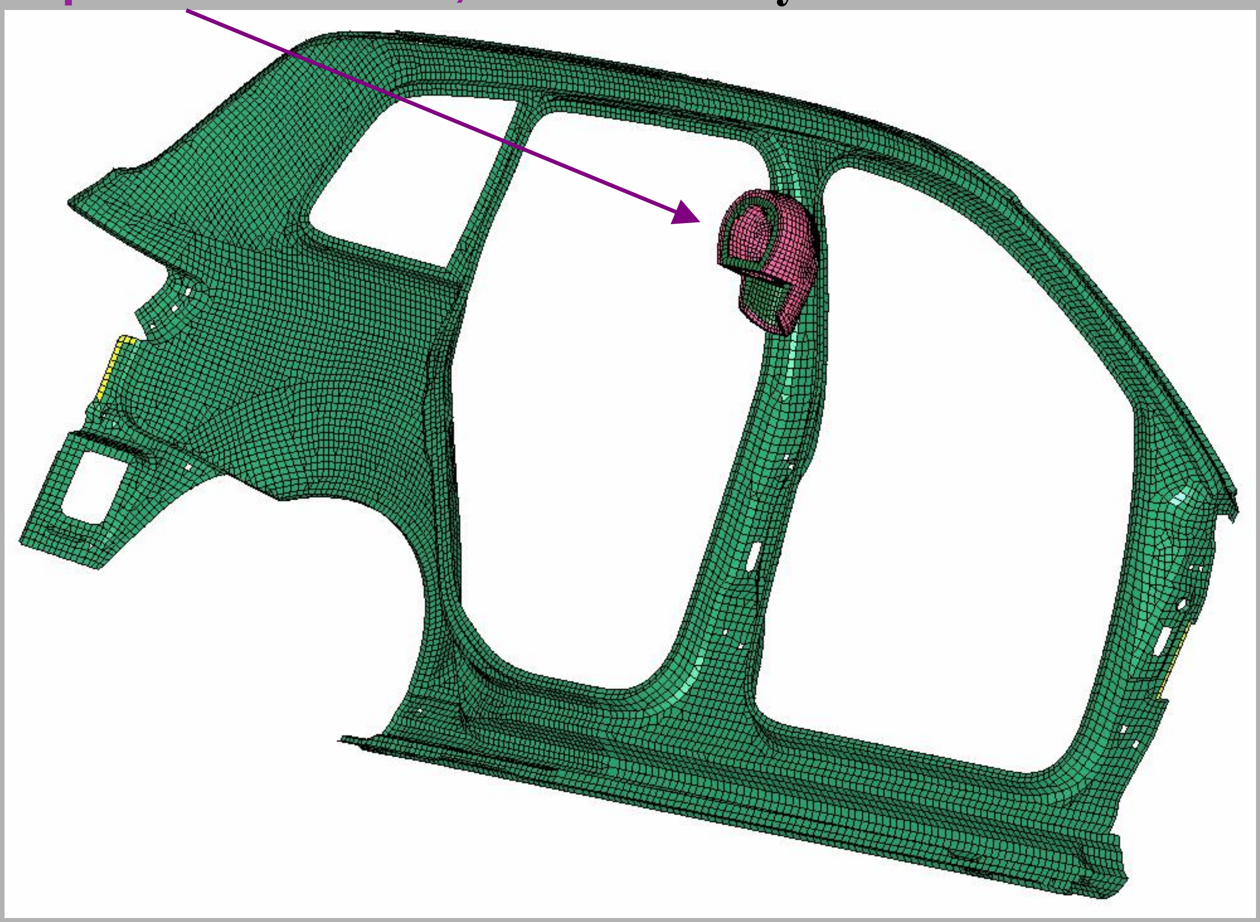
- **LS-DYNA Model of a side part of an Audi car:**
  - **13289 nodes and 12893 shell elements**
  - **yellow elements are excluded to incorporate geometrical bc**

nodes fixed

nodes fixed

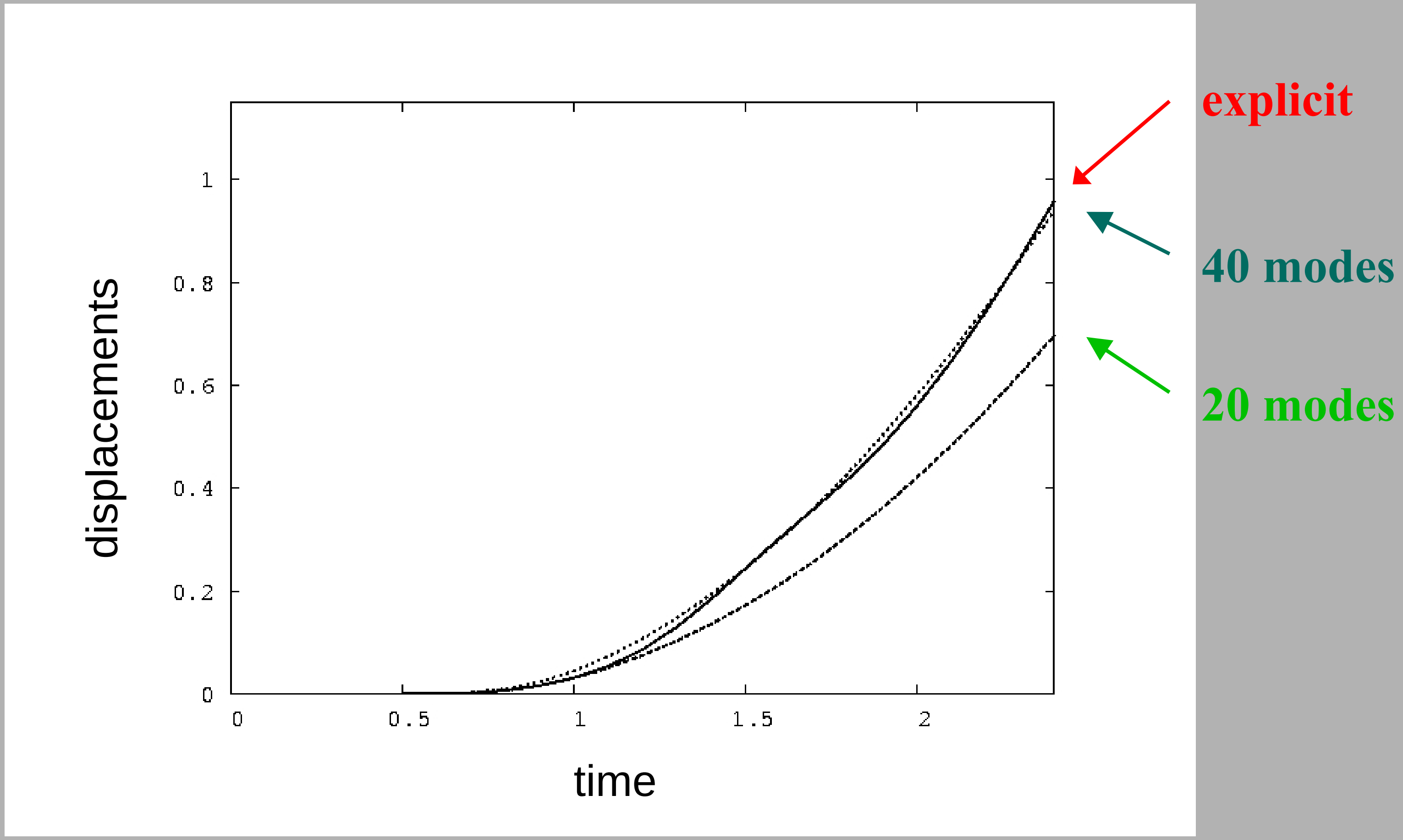
Head Impact against a Side Part – 1st Example

- **LS-DYNA Model of a side part of an Audi car:**
  impact position of head, initial velocity 10 m/s



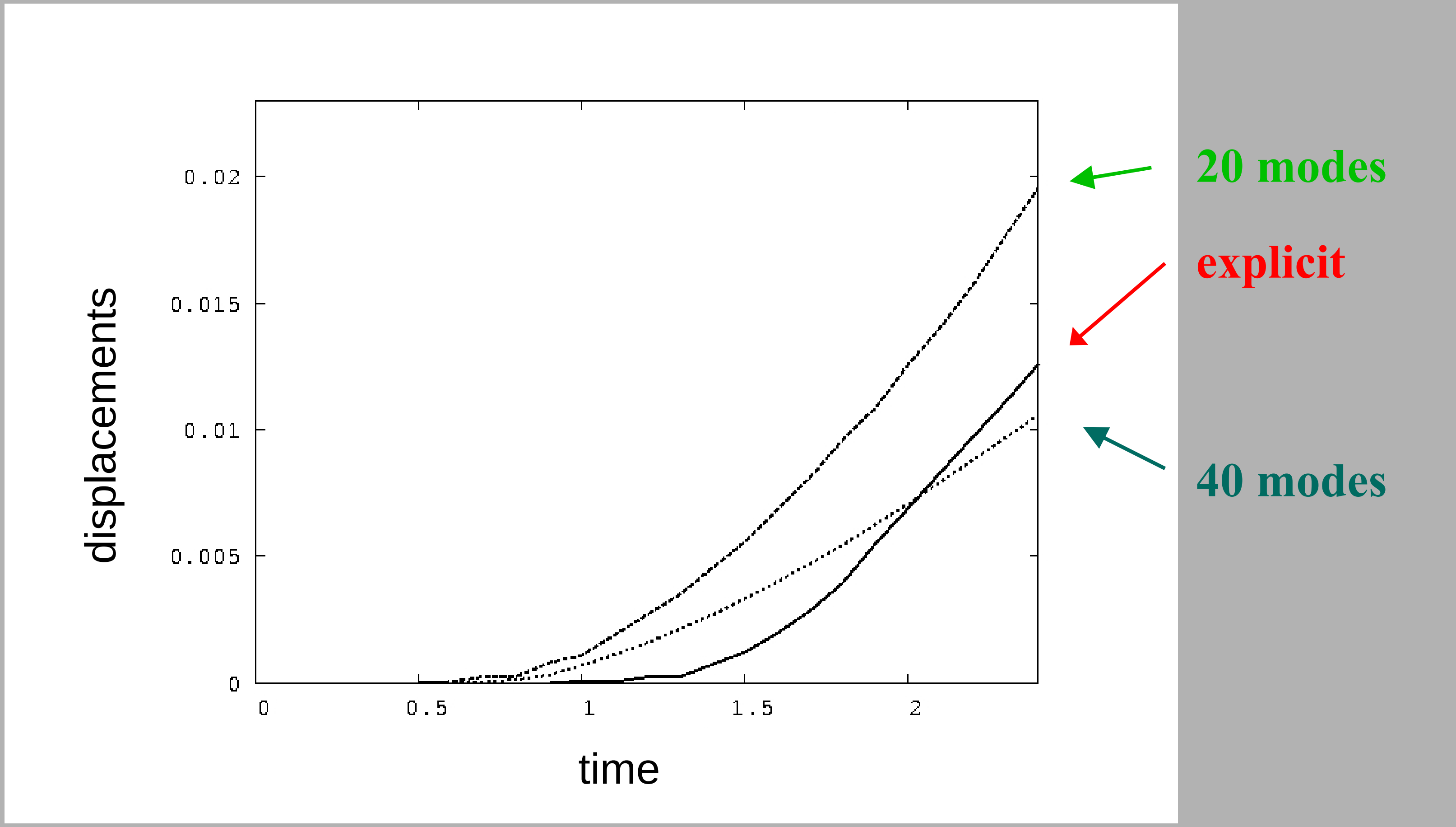
Head Impact against a Side Part – 1st Example

- **displacements of a typical node in B-column**



Head Impact against a Side Part – 1st Example

- **displacements of a typical node in C-column**

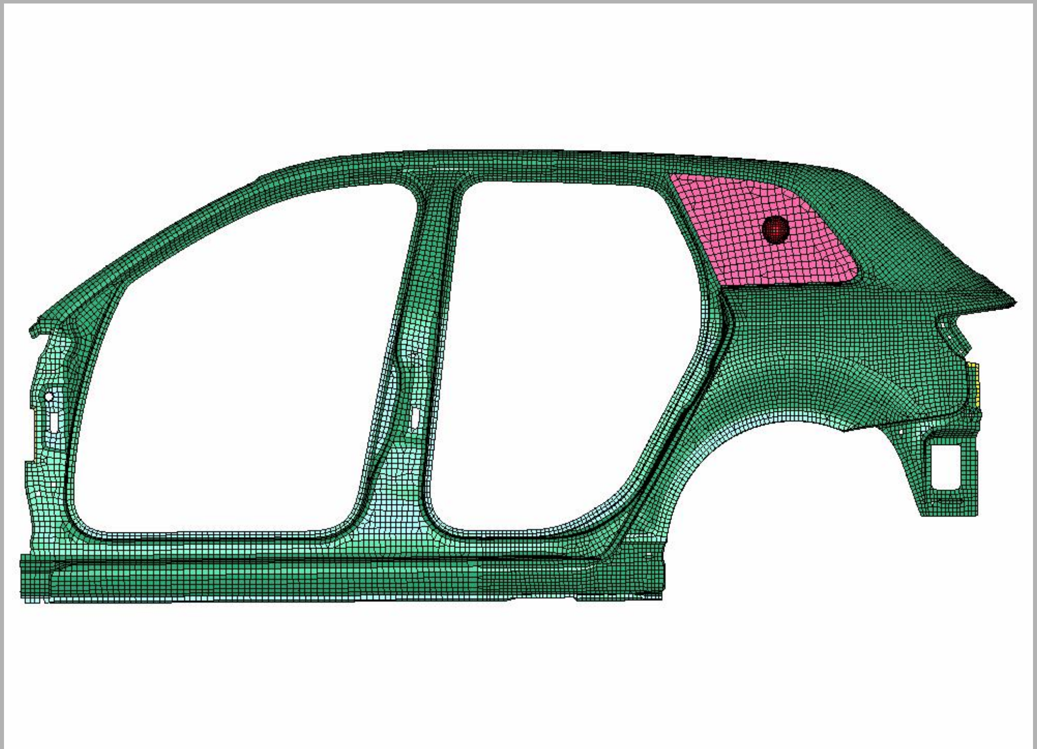


Head Impact against a Side Part – 1st Example

- deflections in B-column (close to impact location) with low number of modes very good approximated
- deflections in C-column (far away from impact location) with low number of modes not at all approximated
- **usage of a reduced set of modes leads to neglecting parts of the wave propagation effects**
- example is still too small to show gain in computation time:
  - explicit time integration: 1186 sec
  - computation of 40 modes: 78 sec
  - side part modeled with flexible rigid bodies, using
    - 20 modes: 998 sec
    - 40 modes: 1163 sec

Current Work

- **Additional parts added to model, connected with spotweld beams**
- **Impact on fully discretized part, remaining structure modeled with flexible rigid bodies**
- **Problem: How to handle spotweld contact between rigid bodies**



Conclusions

Modal Methods

- offer the possibility to superimpose linear deformations onto a rigid body
- work with high accuracy for originally small numbers of DOF
- get an approximate procedure with orig. large numbers of DOF
- require a special treatment of constraints + boundary conditions
- work well in replacing parts of structures with global deformations of minor interest → efficiency can be considerably improved

Useful applications:

Metalforming, die models as flexible rigid bodies
Head impact for basic response

Conclusions

Modal Methods

- need very high effort to capture local response
- parts of a structure can be modeled by modal methods, while others are treated
  - with fully nonlinear FE discretization
  - with locally refined meshes
- displacements and velocities are well captured
- limit: accelerations usually not well approximated

  Way out: If local quantities are of interest, use full discretization there and modal methods further away → *to be done*