# Dynamics of a Train over a Flexible Bridge


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# Introducing the problem

- Up to now railway bridges on the network of DB AG have been designed only according to static analysis
- Actually, the maximum deflection of a railway bridge depends on:
  - Span length
  - Structure mass, stiffness, damping
  - Train axle loads
  - Train speed
- As for high speed trains a dynamic analysis is necessary because of resonance phenomena of the structures

# Introducing the problem

- For example, after introducing the TGV on the line Paris-Lyon, short bridges showed
  - Cracks and crumbles of concrete
  - High ballast attrition due to high accelerations
  - Big track irregularities

# Designing Railway Bridges (DS804)

- Checks have to be carried out regarding:

- Ultimate limit state
  - Load effects of the structure
  - Stability analysis
  - Impact behavior

- Serviceability limit state
  - Traffic safety (track twist, angular rotation at the end of deck)
  - Crack width control (concrete)
  - Riding comfort

# Resonance Phenomena on Railway Bridges

- Resonance phenomena occur due to:
  - High speeds
  - Regularly spaced axle groups of the train
- In case of resonance excessive bridge deck vibration can cause:
  - Loss of wheel/rail contact
  - Destabilisation of the ballast
  - Exceeding the stress limits
- Different trains lead to different Vcr
  - ICE 1 ($L_{vehicle}$ = 26,4m): +++
  - Thalys ($L_{vehicle}$ = 18,7m): ++
  - Talgo ($L_{vehicle}$ = 13,14m): +

# Resonance Phenomena on Railway Bridges

- Example: Bridge on the line Würzburg - Hannover
  - Steel beams encasted in concrete
  - L = 11,8m, $n_0$ = 10,35 Hz, $\zeta$ = 2%, $V_{max}$ = 280 km/h
- Trains:
  - ICE 1: $L_{vehicle}$ = 26,4m
  - Thalys: $L_{vehicle}$ = 18,7m
  - Talgo: $L_{vehicle}$ = 13,14m


| Vcr | Talgo | Thalys | ICE 1 |
|---|---|---|---|
| i=1 | 490 | 697 | 984 |
| i=2 | 245 | 348 | 492 |
| i=3 | 163 | 232 | 328 |
| i=4 | 122 | 174 | 246 |

# Vehicle/Bridge Interaction Model Using DB AG Internal Software

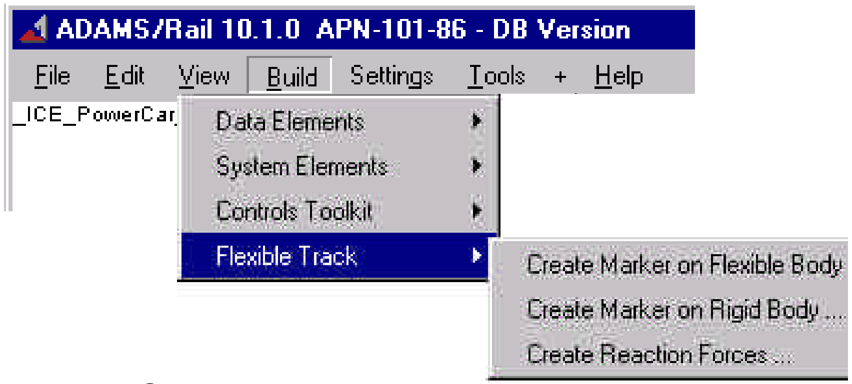
- Vehicle:
  - 2D Model with 10 DOF (only vertical behaviour)
  - Linear springs and damper in parallel
  - Wheel/Rail contact with a non linear spring (only compression)
- Bridge:
  - Finite Timoshenko Beam elements for rail and bridge
  - Linear springs and dampers in parallel
  - Sleeper and ballast as lumped masses (1 DOF)
  - First and last element of the rail are connected together

# Vehicle/Bridge Interaction Model Using DB AG Internal Software

- Advantages
  - Detailed knowledge of the mechanical background
  - Source code available
  - Shorter CPU times
- Disadvantages
  - 2D Model
  - Modelling of complex bridge structures not possible
  - Not very flexible
  - No animation
  - Can be used only by specialist

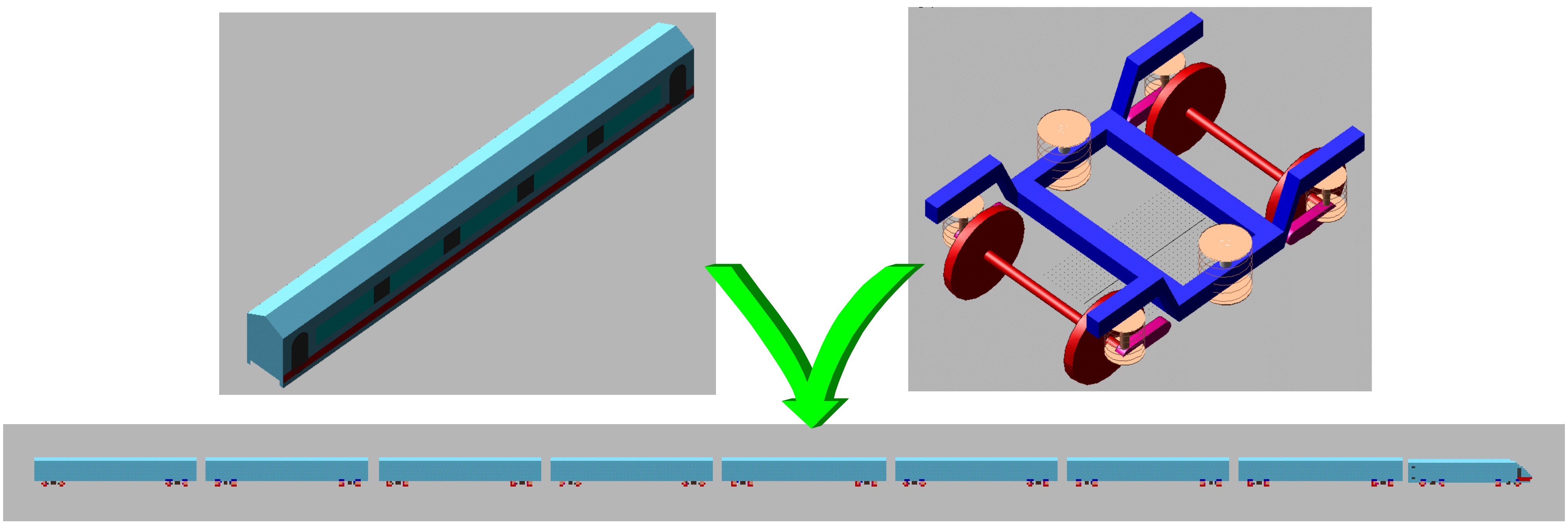
# Vehicle/Bridge Interaction Model Using ADAMS/Rail Environment

- Developed in cooperation with MDI a DB-customized version of ADAMS/Rail
- Advantages:
  - Coupling 3D vehicle models with 3D bridge models
  - Detailed modelling of complex bridge structures
  - High flexibility in modelling different types of vehicles
  - Exact calculation of the torsional behaviour
  - Meetings of train on double track bridges



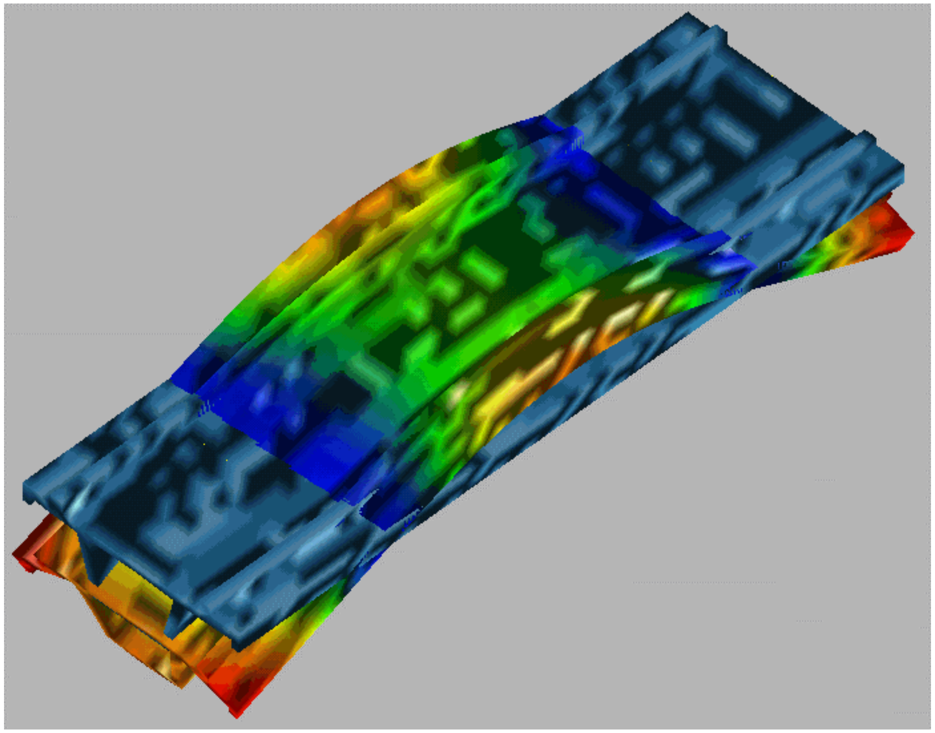
# Vehicle/Bridge Interaction Model Using ADAMS/Rail Environment

- Vehicle model:
  - Taken advantage of the Template-Builder structure to build up different ICE trainset assemblies by referencing to a ICE bogie and an ICE car body template



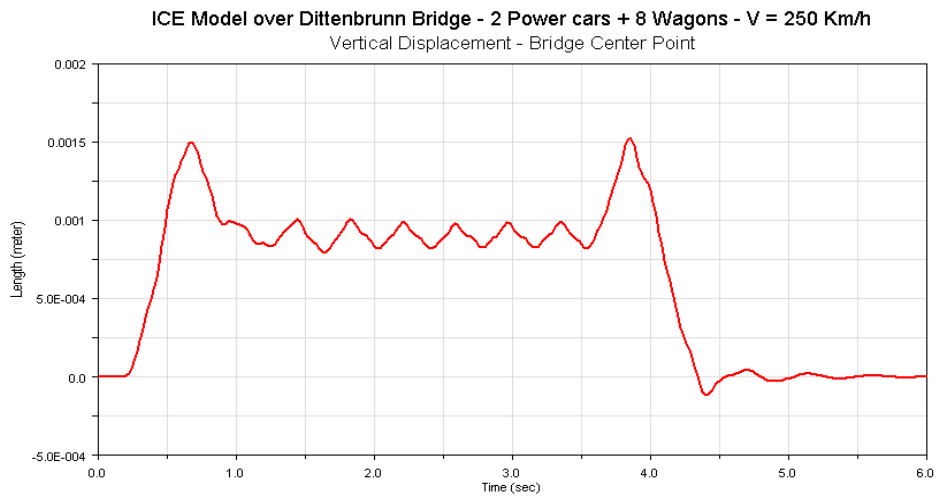
# Vehicle/Bridge Interaction Model Using ADAMS/Rail Environment

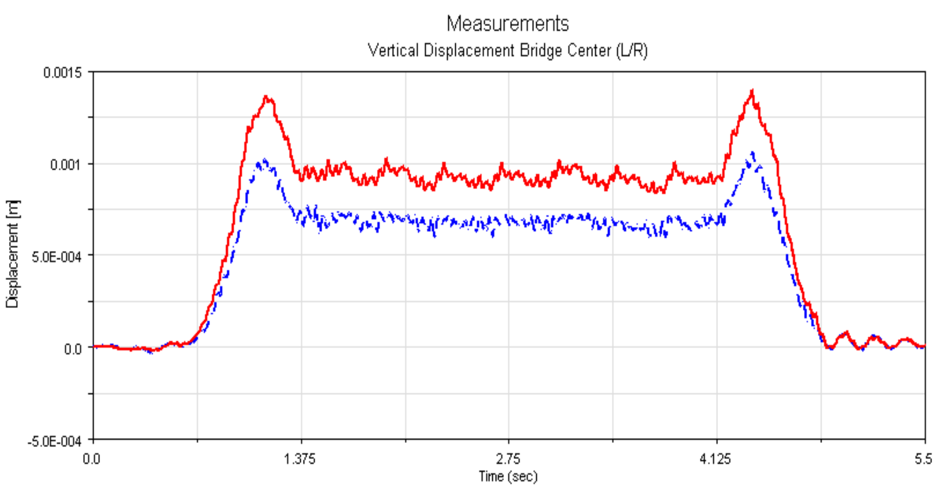
- Track model:
  - Including rigid track beams and ANSYS flexible body of the bridge
  - First free-free bridge bending frequency: ~10 Hz
- Contact model:
  - Development of Flexible-Point-to-Curve-Contact to model moving forces along a given line on a flexible body



# Vehicle/Bridge Interaction Model Using ADAMS/Rail Environment

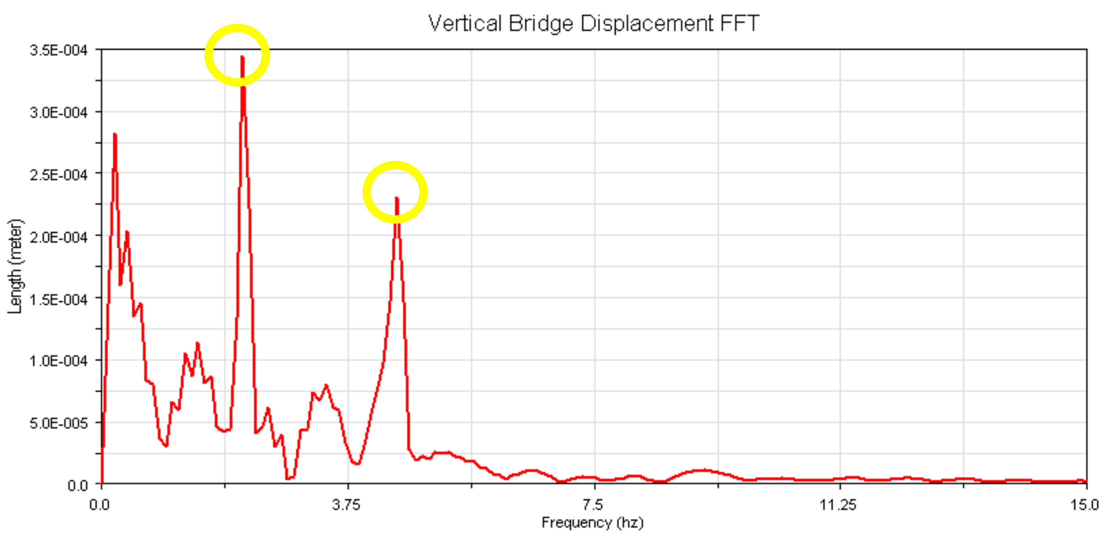
- Dynamic Analysis Reference Results:
  - ICE Trainset with 2 power cars and 8 wagons
  - Speed: 250 Km/h
  - Straight rigid track over a Dittenbrunn bridge L ~ 45 m
  - Observing the vertical deflection of bridge middle point

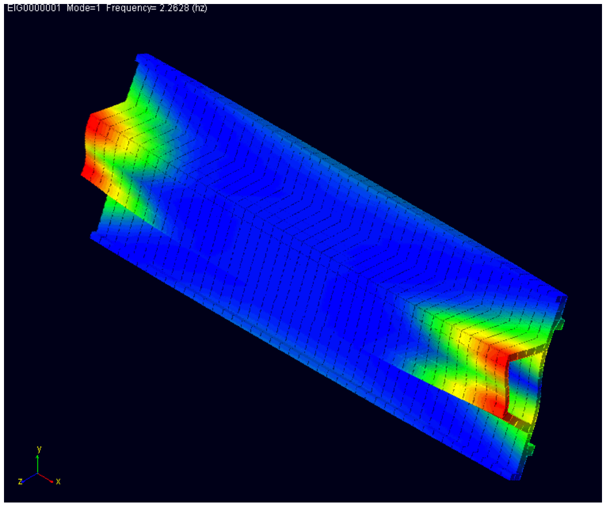


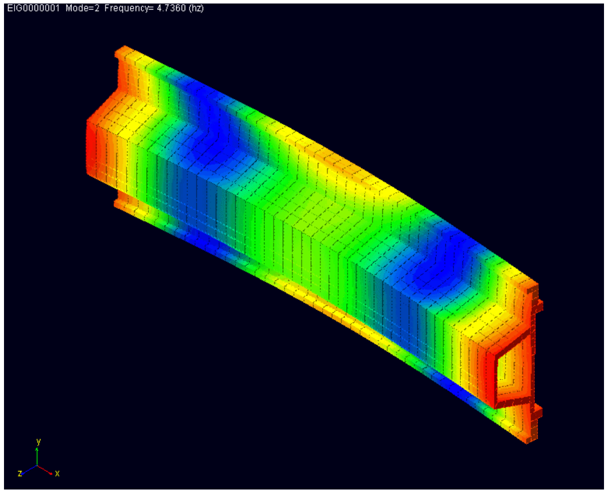



# Vehicle/Bridge Interaction Model Using ADAMS/Rail Environment

- For high train travelling speeds, the bridge oscillates vertically with frequencies corresponding to the 1st and 2nd natural frequencies (torsion and bending)

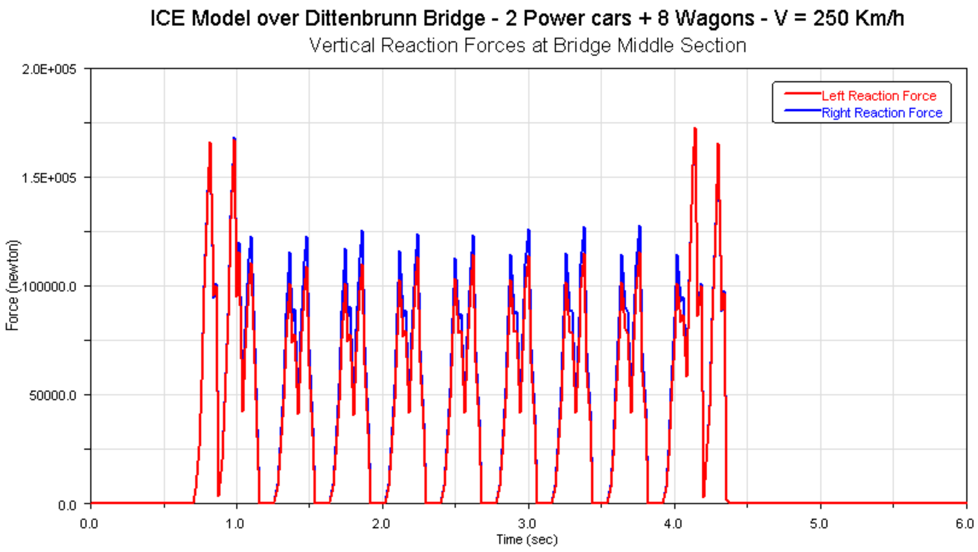


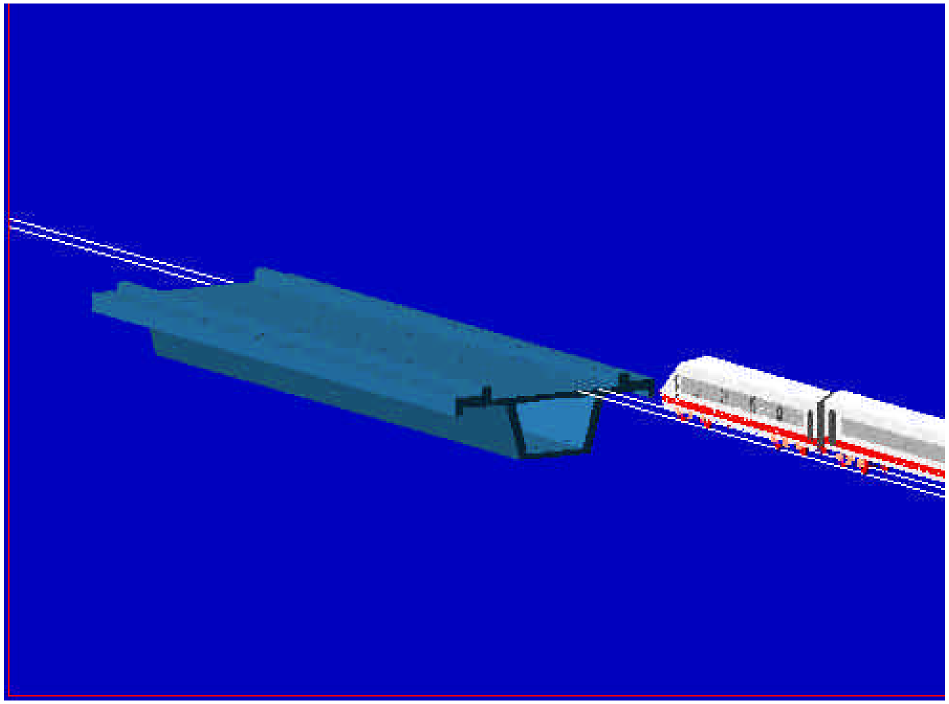



# Vehicle/Bridge Interaction Model Using ADAMS/Rail Environment

- Results and animation of dynamic analysis



# Vehicle/Bridge Interaction Model Using ADAMS/Rail Environment

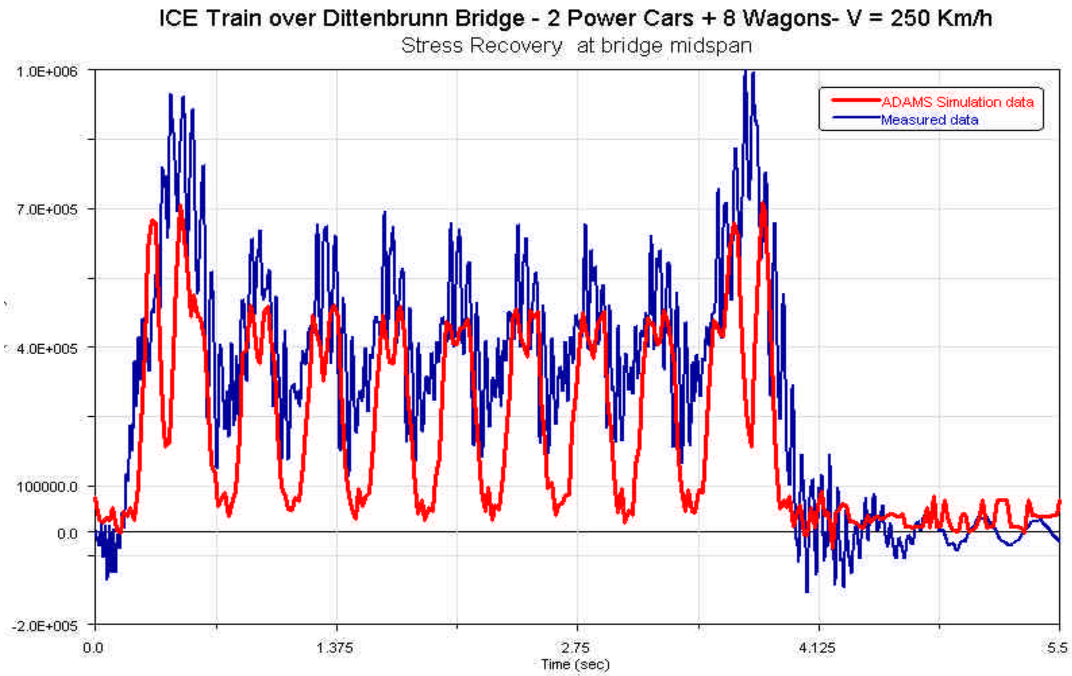
- Followed the Modal Stress Recovery approach used to calculate the stresses and strains in the relevant bridge points, by using:
  - The Ansys RST file (corresponding to the MNF file generation) containing all the FEA results associated to the modal forms
  - The ADAMS RES file containing the modal coordinates (participation factors) for every time step of the analysis
- These data are combined in Ansys to obtain stresses and strains corresponding to the calculated time history

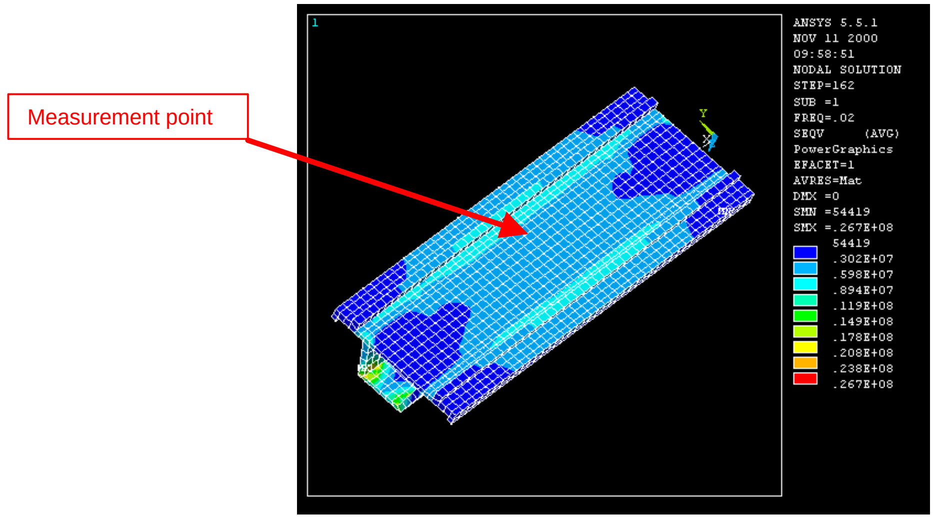
# Vehicle/Bridge Interaction Model Using ADAMS/Rail Environment

DB

Mechanic Dynamics

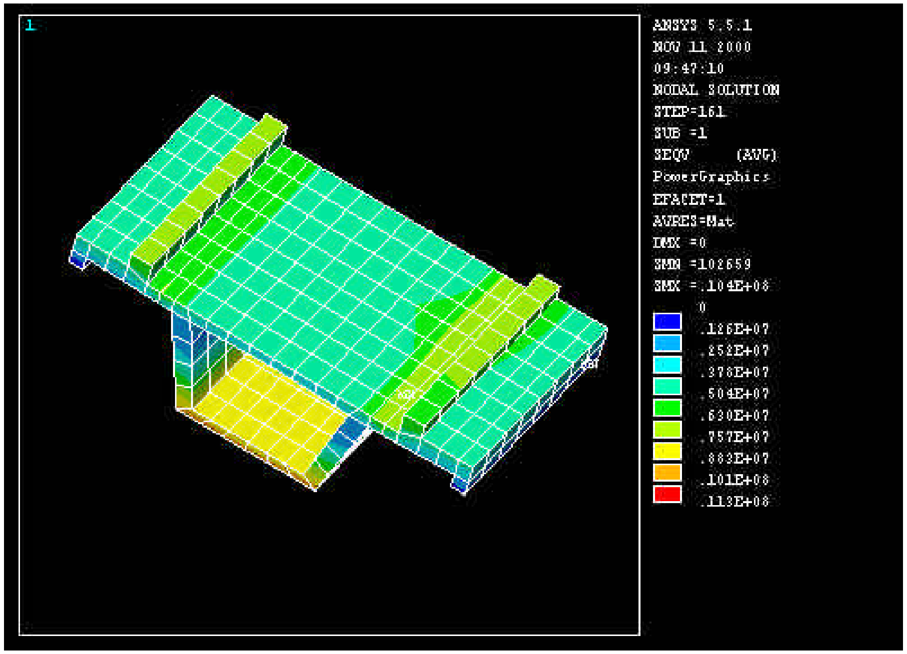
- Sample results of modal stress recovery calculation:
  Stresses in a measurement point in the bridge middle section

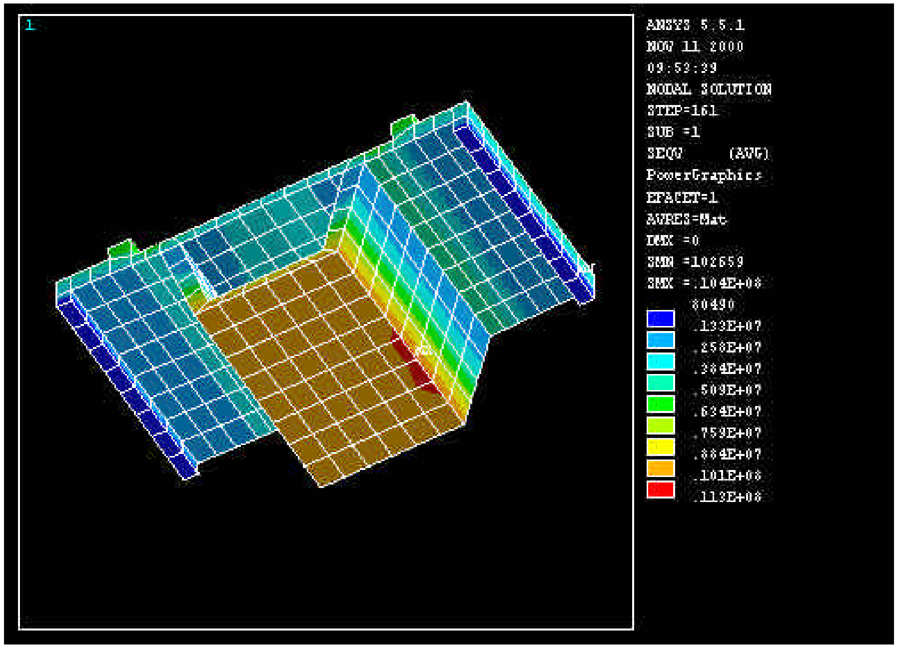


# Vehicle/Bridge Interaction Model Using ADAMS/Rail Environment

- Sample animation of modal stress recovery (on the middle section of the bridge)



# Conclusions and future work

- Conclusions:
  - Implemented a tool to investigate bridge resonance phenomena due to high-speed trains
  - The tool has been validated with a typical train over a typical bridge, travelling at typical velocity, against corresponding available measurements
  - The tool allows further investigation of the resonance phenomena for other trains and other bridge models
- Future work:
  - Proceed with validation against measurements to further tune model parameters
  - Use of more sophisticated wheel/rail contact methods
  - Intensive testing on a series of bridges