Dynamic of Railway Bridges

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1. Introduction

The max. deflection of a railway bridge is dependent on

- speed of the train
- span length
- mass, stiffness and damping of the structure
- axle loads of the train

Up to now railway bridges on the network of DB AG have been designed only due to a static analysis.

As for high speed trains a dynamic analysis is necessary because of resonance phenomena of the structures.

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

Due to the work of ERRI D214 regulations for a dynamic bridge design should be introduced the Eurocode EC 1991-3.

2. Design of Railway Bridges due to DS 804

National code DS 804

Checks have to be carried out regarding
(Listing is not complete)

- ♦ Ultimate limit state
  - load effects of the structure
  - stability analysis
  - impact behaviour
- ♦ Serviceability limit state
  - traffic safety (twist of the track, angular rotation at end of deck)
  - crack width control (concrete)
  - riding comfort

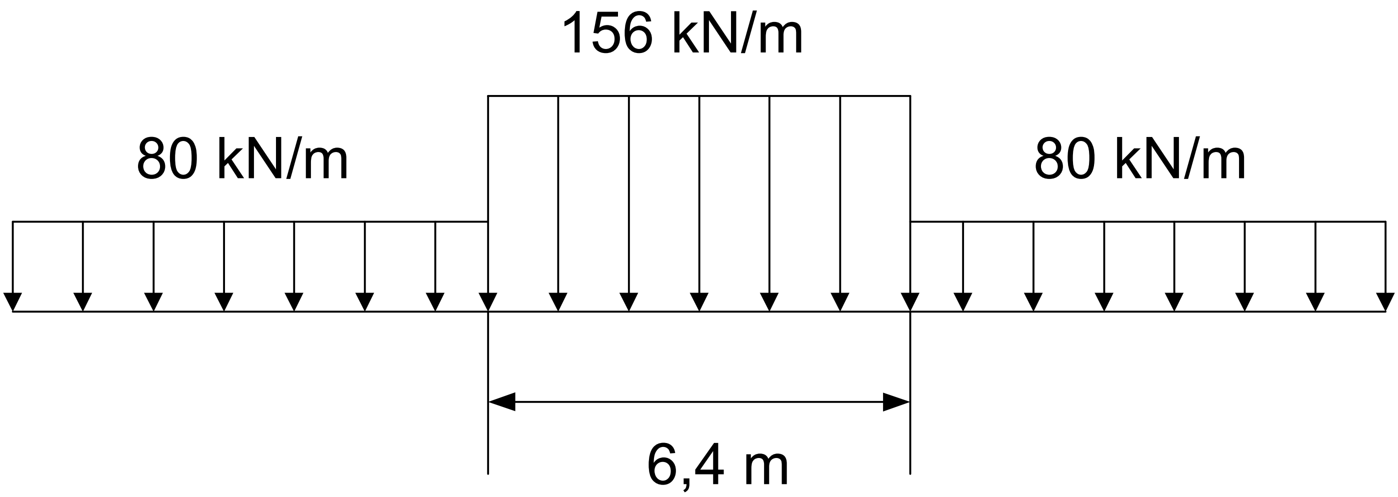
Riding comfort:

Limit values for deflection (L/f) dependent on span length and speed under Φ x LM UIC 71

Traffic loads on the structure:

only a static analysis with
- Loadmodel UIC 71 multiplied with dynamic factor Φ or
- service trains multiplied with $(1+\varphi'+0{,}5\ \varphi'')$
  φ' dynamic increment due to speed
  φ'' dynamic increment due to track irregularities

Load model UIC 71



$$\Phi = \frac{1{,}44}{\sqrt{L_\Phi} - 0{,}2} + 0{,}82$$

with the determinant L_Φ

Service trains are defined in DS 804

Dynamic increments can be calculated due to the formulae

$$\varphi'_{UIC} = \frac{K}{1-K+K^4}$$

with

$$K = \frac{v}{2L_\Phi n_0}$$

$$\varphi''_{UIC} = \frac{1}{100}\left[56e^{-\left(\frac{L_\Phi}{10}\right)^2} + 50\left(\frac{L_\Phi n_0}{80} - 1\right)e^{-\left(\frac{L_\Phi}{20}\right)^2}\right]$$

with the 1st bending frequency n_0 of the structure and L_Φ like above

Range of validity für Φ, φ‘ und φ“

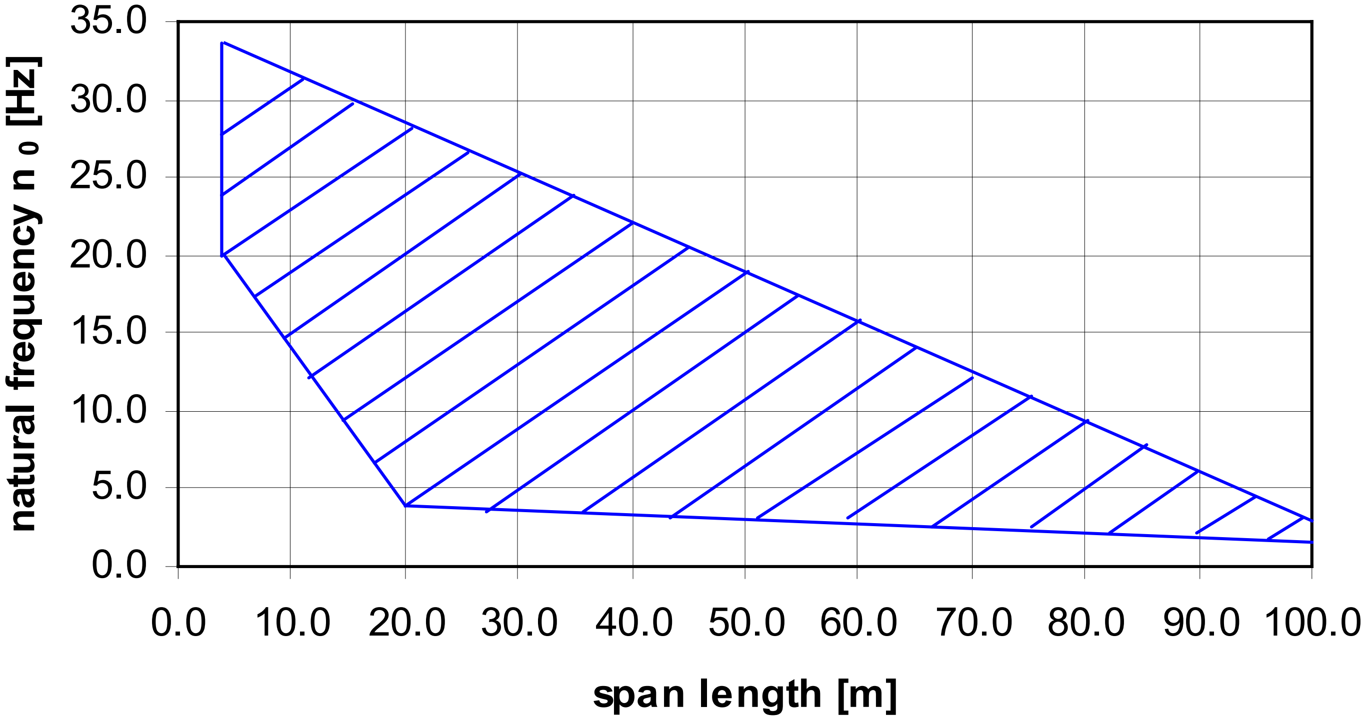


Figure 6.9 from ENV 1991-3

Φ, φ‘ and φ“ are results of parametric studies, carried out by ORE D23 and ORE D128.

3. Resonance Phenomena on Railway Bridges

Resonance Phenomena occur due to
- high speeds and
- 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.

Resonance is given, if

$$n_{Bridge} = i \cdot f_{excit} \qquad i = 1,2,3,4$$

with f_{excit} = v/$L_{vehicle}$ and the first natural frequency for bending n_0 the critical speeds can be calculated with the formula

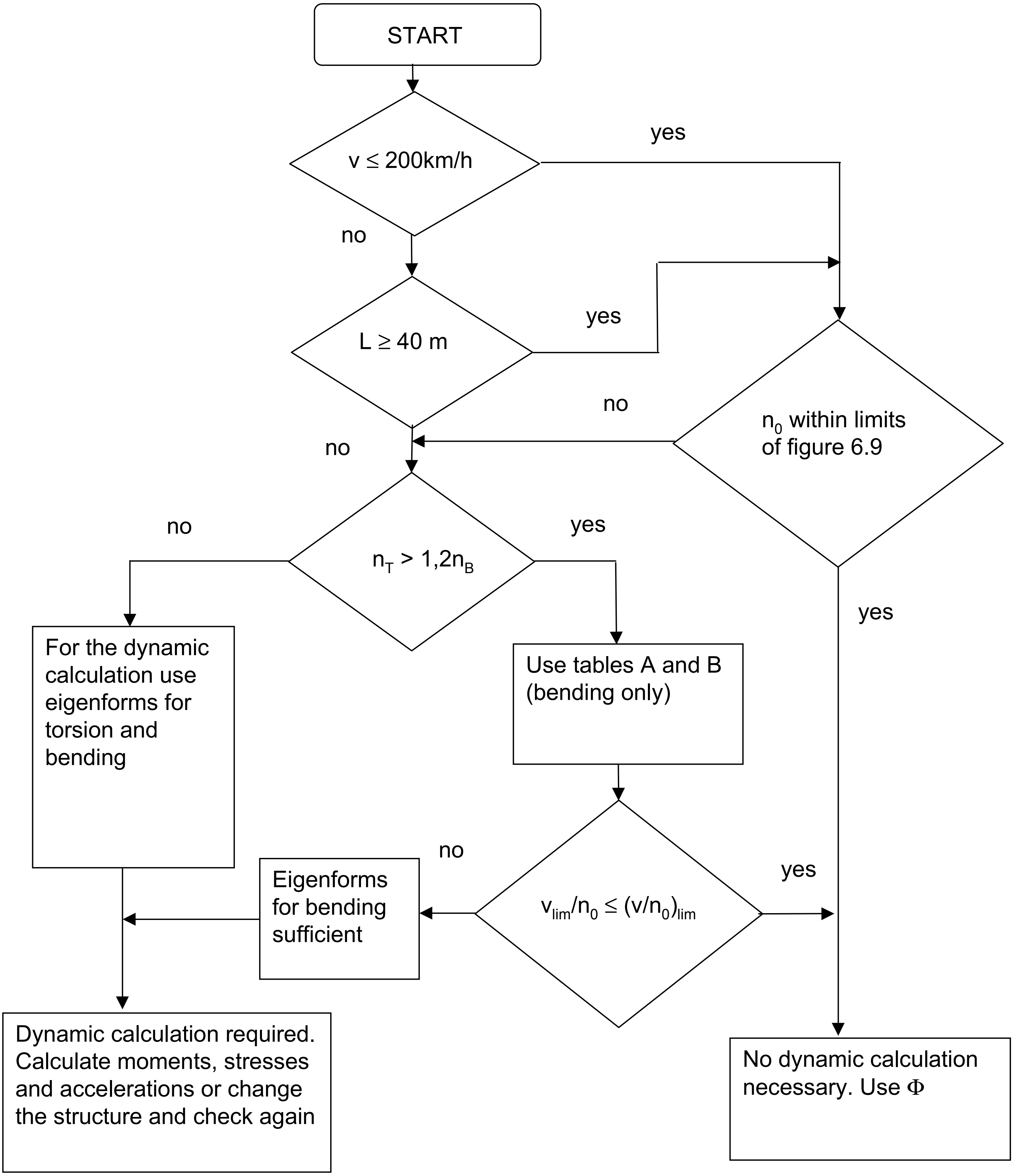
$$v_{crit} = \frac{n_0 \cdot L_{vehicle}}{i} \qquad i = 1,2,3,4$$

Dynamic Bridge Design

- When is a dynamic analysis required?
- What limits have to be checked?

A draft has been worked out for a proposed revision of Eurocode clauses on dynamic effects including resonance. As for simply supported bridges the results of ERRI D214 showed that

- resonance is unlikely for spans longer then 40 m.
- a dynamic analysis is not necessary if the given limit values (Table A and B in the flow chart diagram on the next page) are satisfied.


START
v ≤ 200km/h
yes
no
L ≥ 40 m
yes
n0 within limits of figure 6.9
no
no
nT > 1,2nB
no
yes
yes
For the dynamic calculation use eigenforms for torsion and bending
Use tables A and B (bending only)
no
Eigenforms for bending sufficient
vlim/n0 ≤ (v/n0)lim
yes
Dynamic calculation required. Calculate moments, stresses and accelerations or change the structure and check again
No dynamic calculation necessary. Use Φ

Limits that have to be checked in a dynamic analysis

- Bridge deck acceleration

  for ballasted track: $a_{max} \leq 0,35g$

  for unballasted track: $a_{max} \leq 0,5g$

- Load effects

  If a dynamic investigation is required, the results have to be compared with the static analysis.
  (Φ x LM UIC 71)

  The most unfavourable values of moments, stresses, etc. shall be used for the bridge design.

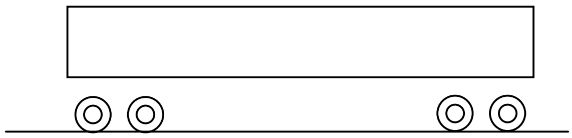
The speed range is from 40m/s up to 1.2 times of the envisaged line speed.

Example

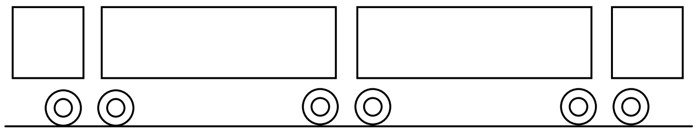
Bridge on the line Würzburg - Hannover
Steel beams encasted in concrete
L = 11,8m, n_0 = 10,35 Hz, ζ = 2%, v_{max} = 280 km/h,

Trains:

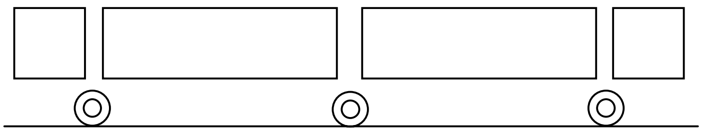
- ICE 1: $L_{vehicle}$ = 26,4m



- Thalys: $L_{vehicle}$ = 18,7m



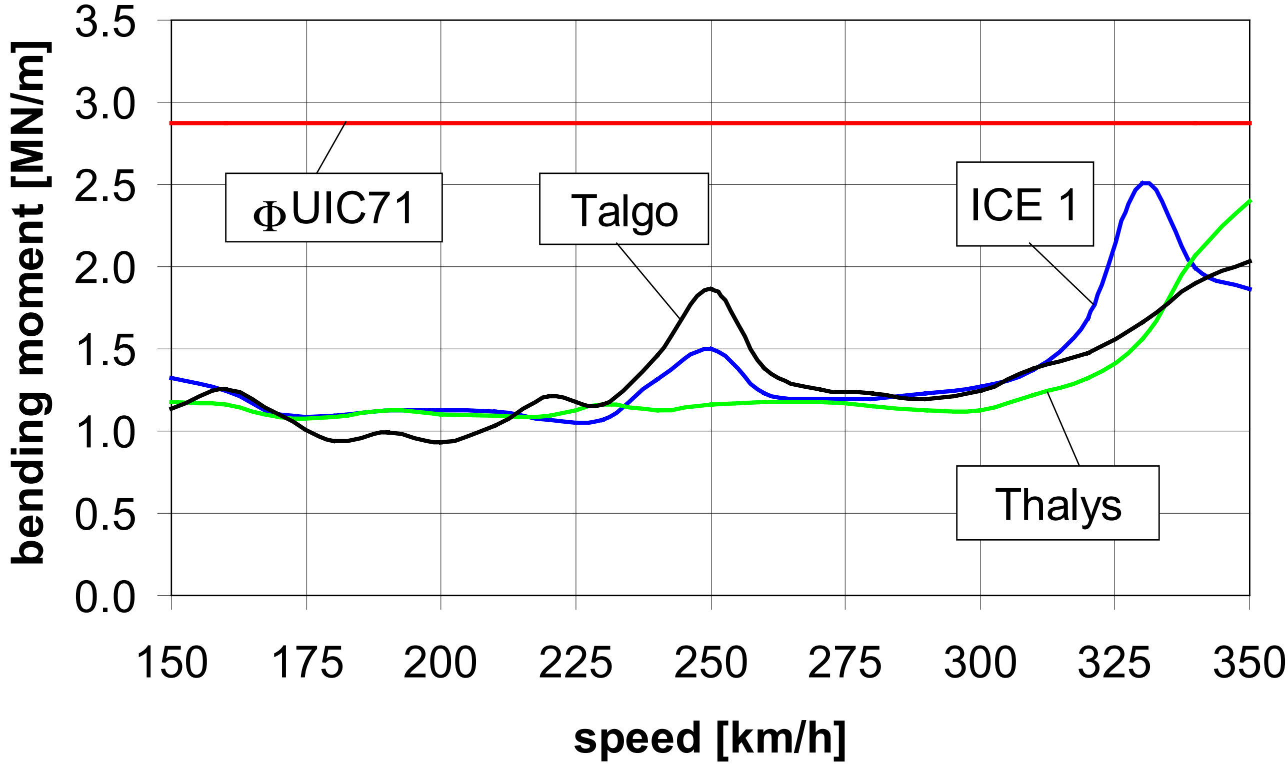
- Talgo: $L_{vehicle}$ = 13,14m

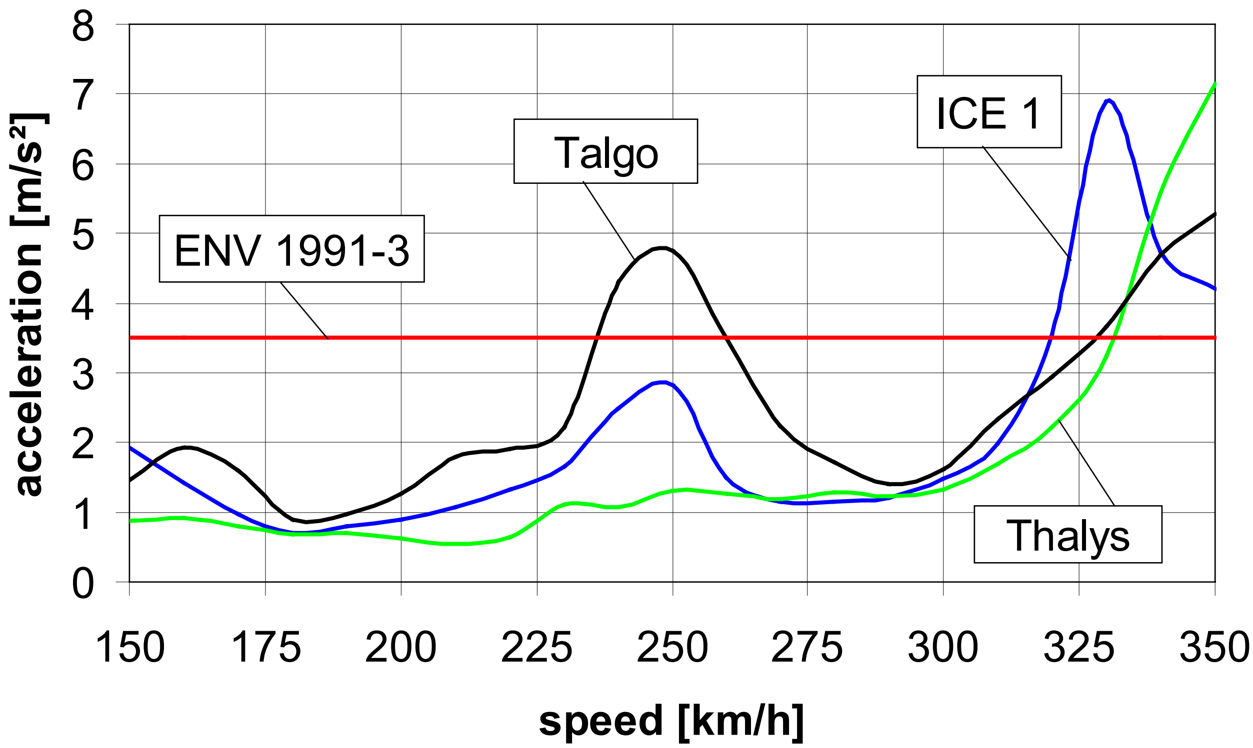


Critical Speeds [km/h]

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

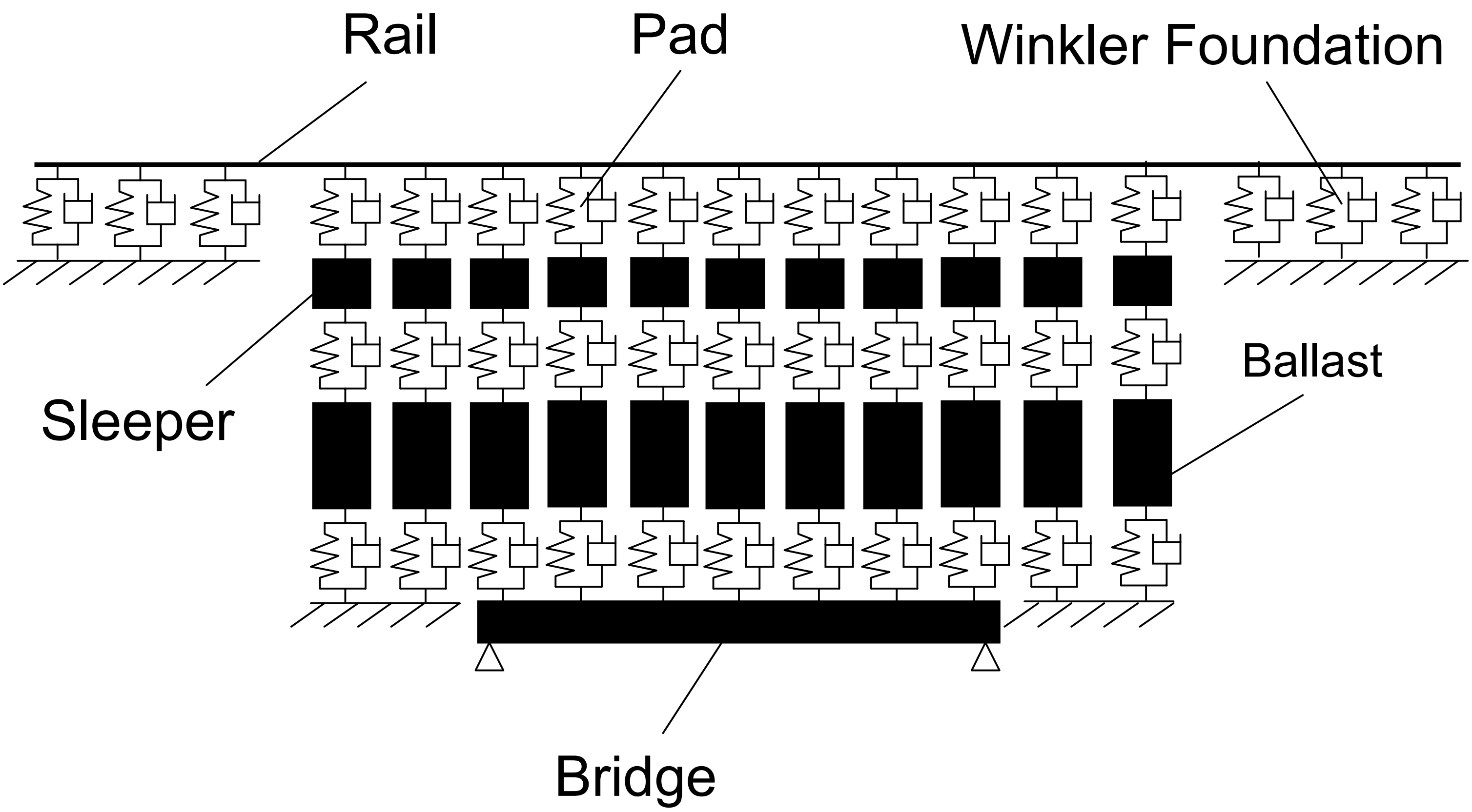
Results


bending moment [MN/m]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ΦUIC71
Talgo
ICE 1
Thalys
150
175
200
225
250
275
300
325
350
speed [km/h]


acceleration [m/s²]
8
7
6
5
4
3
2
1
0
ENV 1991-3
Talgo
ICE 1
Thalys
150
175
200
225
250
275
300
325
350
speed [km/h]

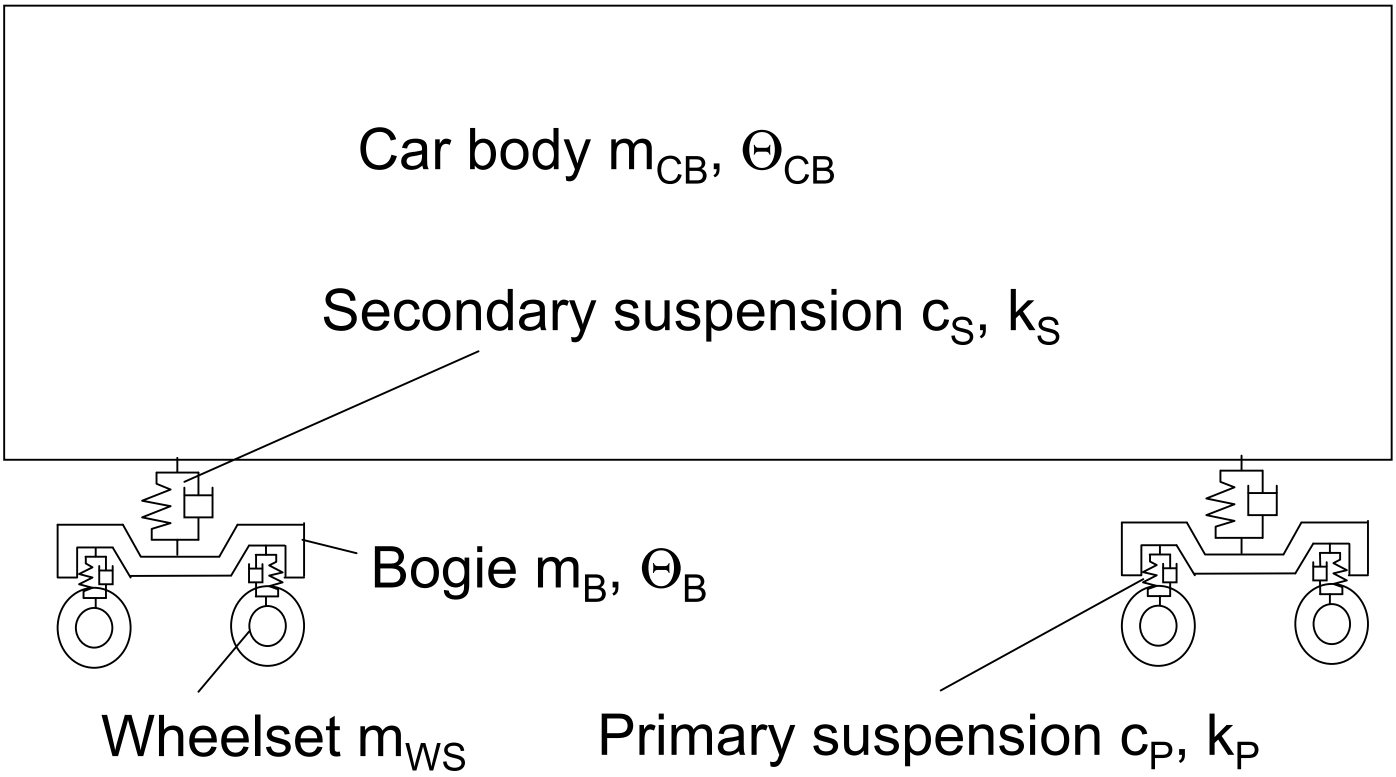
4. Vehicle/Bridge-Interaction Model used by DB AG

Track-Bridge-Model of DB AG



- 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 Model of DB AG



- 2D Model with 10 DOF (only vertical behaviour)
- linear springs and damper in parallel
- Wheel/Rail contact with a non linear spring (only compression forces)
- Train consists of a finite number of vehicles

Advantages:

- detailed knowledge of the mechanical background
- source code available
- short CPU times

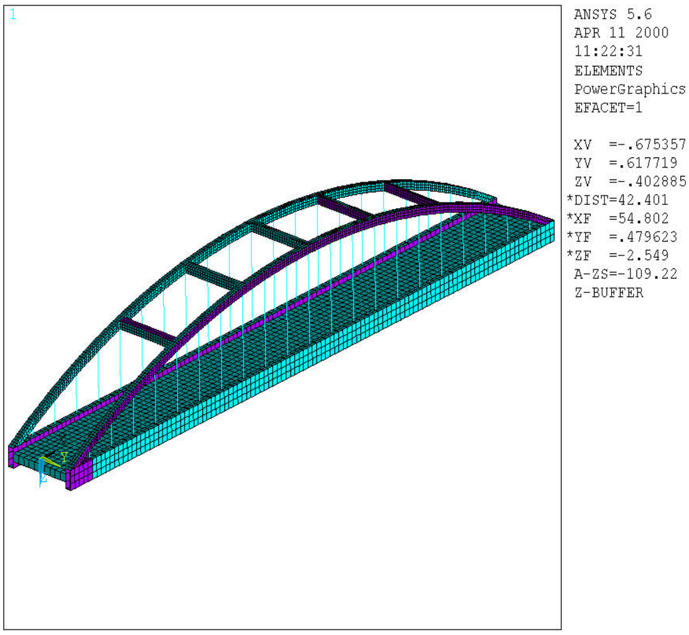
Disadvantages

- 2D Model
- modelling of complex bridge structures not possible
- not very flexible
- no animation
- can be used only by specialist
- poor documention

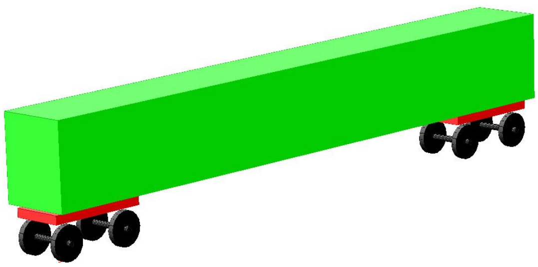
Goal: Coupling of 3D vehicle models with 3D bridge models

- 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

Bridge model



Vehicle model



Co-operation DB AG - MDI

Setup a project divided in 4 phases

- Phase A:

  Development of Flexible-Point-to-Curve-Contact for moving forces along a given line on a flexible body.

- Phase B:

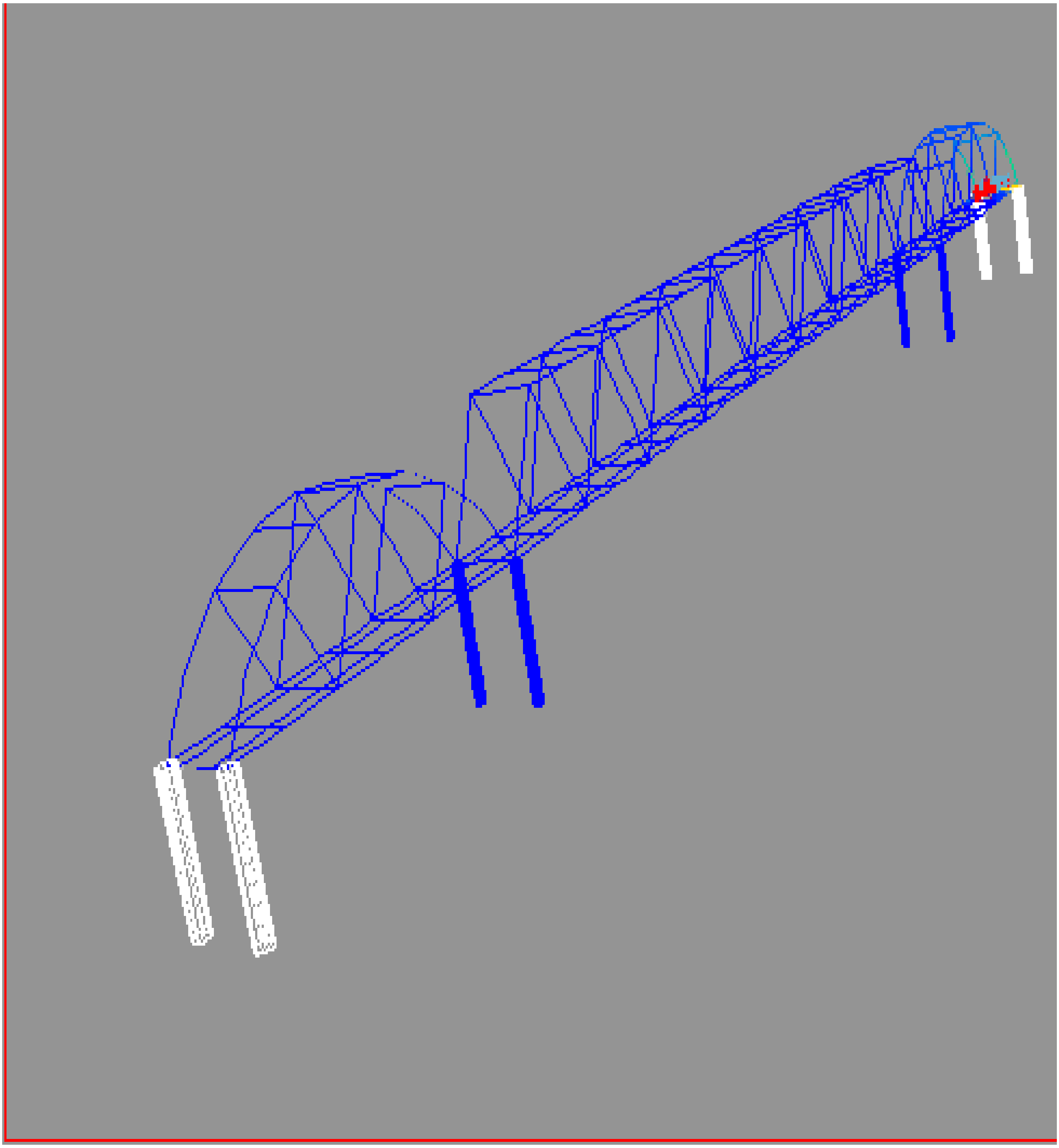
  Setup of wheel/rail contact on independent wheels

- Phase C:

  Setup of non-linear wheel/rail contact over a flexible rail

- Phase D:

  Modelling in ADAMS all non-linear elements needed for a detailed analysis



6. Future work

1) Validation of the algorithm with

- measured data
- calculated result with the DB model

2) Start Phase C & D

3) Intensive testing on a series of bridges