Rolling Stock Analysis of Various Railway Bridges in Austria

Marko HEIDEN
Project Engineer
TDV GesmbH.
Graz, Austria

Martin PIRCHER
Research Associate
University of West. Sydney
Sydney, Australia

Heinz PIRCHER
Managing Director
TDV GesmbH.
Graz, Austria

Dorian JANJIC
Research & Development
TDV GesmbH.
Graz, Austria

Summary

The railway link between Vienna and Salzburg is currently upgraded to allow for a high-speed connection between these two Austrian cities. Initially the design speed has been be set to 160km/h but bridge structures are to be designed for speeds over 200km/h to allow for further upgrading in the future. Rolling stock analyses were performed for numerous different bridges along this planned railway link to ensure the compatibility of the design with the requirements of the draft for EUROCODE prEN 1990 and EUROCODE prEN 1991.

This paper presents the results of rolling stock analyses for several bridges including a pre-stressed hollow box bridge, composite girder bridges, an concrete slab bridge, a trough bridge, filler beams - composite (WiB) system. Most of these structures were found to come close or exceed the limits given by the EUROCODE prEN 1990. The experiences gained during the analyses of these bridges and the proposed improvements on the structural systems of these bridges in order to comply with the EUROCODE requirements will be described in this paper.

Keywords: rolling stock analysis, dynamic response, moving load, practical application

1. Introduction

A vehicle passing over a bridge comprises an intricate structural system. In many practical cases dynamic effects are negligible and a simplified static approach is deemed sufficient as a basis for bridge design. For high-speed railway bridges, where vehicles passing over a bridge have a comparatively high mass and travel at relatively high velocities, static analysis may proof insufficient and more sophisticated types of analyses are called for. The inclusion of dynamic effects are of interest to the bridge engineer for the following reasons:

1) Dynamic stresses are greater than static stresses.
2) Excessive bridge vibration must be controlled to design against fatigue.
3) Dynamic displacements and accelerations of bridge components must be limited to guarantee save and comfortable passage of the vehicle.

The existing railway link between Vienna and Salzburg in Austria was originally not designed for high-speed railway travel. Currently an upgrade of the railway corridor to two lanes is under way. At the same time, the bridges along this railway line will be investigated toward their suitability for travel with velocities up to 250km/h. A dynamic investigation of a number of representative bridges along this line according to EUROCODE [1,2,3] has been performed by TDV, Austria. This paper reports on some of the outcomes of this investigation.

2. Investigated Bridges

Table 1 gives some properties of the bridges reported on in this paper. The range of bridges analysed for this investigation includes steel-concrete composite systems and concrete bridges with one to four spans. The structural systems include box girders, slab bridges and filler-beams.

Table 1. Some properties of the investigated bridges.

#	Material	Spans [m]	Type	Lanes	Speed [km/h]	Damping [%]
1	concrete	33.5/50/33.5	hollow box	2	300	0.84
2	concrete/steel	19/20/19	filler beam	2*1	300	0.84
3	concrete/steel	15	filler beam	2	300	0.84,1-5
4	concrete/steel	23.5	filler beam	2*1	250	1.597
5	concrete	66/122/66	hollow box	2	300	0.76, 1-3
6	concrete	10/14/10	slab	2	300	0.76, 1-3
7	concrete	26/30/26	trough	1	300	0.76, 1-3
8	concrete/steel	33/41/41/36	composite	2*1	300	0.65, 1-3

3. Rolling Stock Analyses

The dynamic computer analysis for this project was carried out with the software system *RM2000* [4] including features described in [5,6]. Features for modal analysis as well as time integration [7] are implemented in this software system and have been used for this project. The investigation focused on four governing pieces of information for each bridge:

1) maximum vertical acceleration of any point on the bridge.
2) maximum variation of cant along the railway over the bridge.
3) maximum end rotation at the supports.
4) Horizontal displacements of the bridge.

The loading specifications given in [2] were used for the analyses. These specifications give axle-loads and axle-lay-outs for ten different norm-trains. The effects of the moving mass does not have to be considered in the numerical analysis since allowances for this effect are already made in the loading specifications. The computed values for the maximum cant and horizontal displacements never reached critical values but the values for maximum vertical acceleration and the maximum end rotations exceeded the limits given in the EUROCODE documents [1,2,3] in some cases. The time dependent response of discreet points on the bridge structure was computed (*Fig. 2*) and the extreme values were recorded.

Table 2 gives a summary of the extreme results for the eight bridges reported on in this paper. Some of these results and some details of the dynamic analysis will be discussed in this paper.

Table 2. Results for the investigated bridges.

#	maximum acceleration [m/s²]	allowable acceleration [m/s²]	end rotation v<250km/h [radian]	end rotation v>250km/h [radian]	allowable end rotation v>250km/h [radian]
1	1.625	3.5	ok	0.000355	0.000568
2	7.301	5.0	ok	0.002804	0.000820
3	6.211	3.5	ok	0.000668	0.000976
4	9.277	3.5	ok	n/a	n/a
5	0.683	3.5	ok	0.000818	0.000781
6	3.975	3.5	ok	0.000249	0.001360
7	4.144	3.5	ok	0.000627	0.00140
8	1.980	3.5	ok	0.00111	0.00122

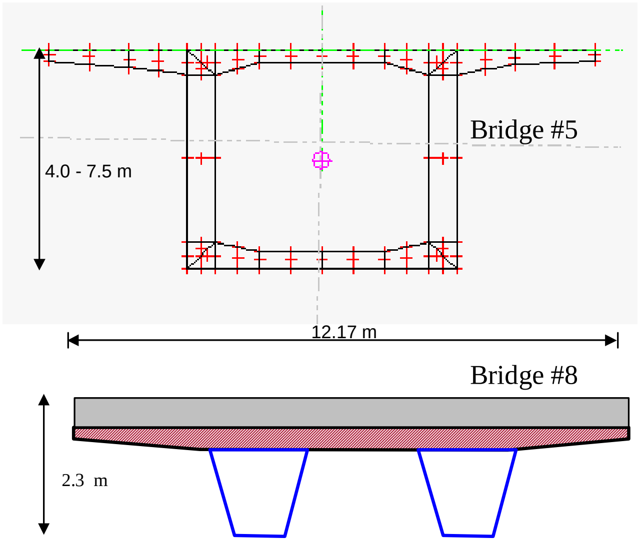

Fig. 1 Cross-sections of the main girders of bridge #5 and bridge # 8.

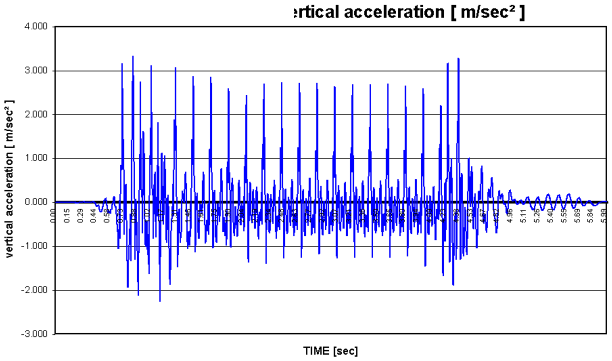

Fig. 2 Time-Acceleration diagram.

4. Maximum End Rotation

EUROCODE limits the rotation of the bridge girder about the lateral axis. For velocities of up to 250km/h fixed limits are given for the transition between two individual bridge structures and the transition between a bridge and the abutment for both, single and double railway line bridges. The formulations for these limits are different for velocities of less than 250km/h and over 250km/h. For the lower speed bracket constant values are given for the rotation limit. For design speeds of over 250km/h the rotation limit is a function of the height of the bridge girder.

For bridges with a high cross-section the limit for end-rotations is lower than for bridges with a small cross-section height. In the present study bridges #1, #5 and #8 had relatively high cross-sections and for #5 and #8 (Fig. 1) the design limits were exceeded for velocities over 250km/h. For bridges with relatively high main girders this requirement can obviously become a governing design factor and must be considered carefully when planning such a bridge for high-speed railway applications.

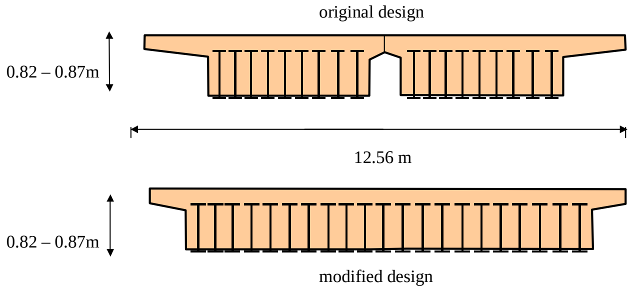

Fig. 3 Design modifications for bridge #3.

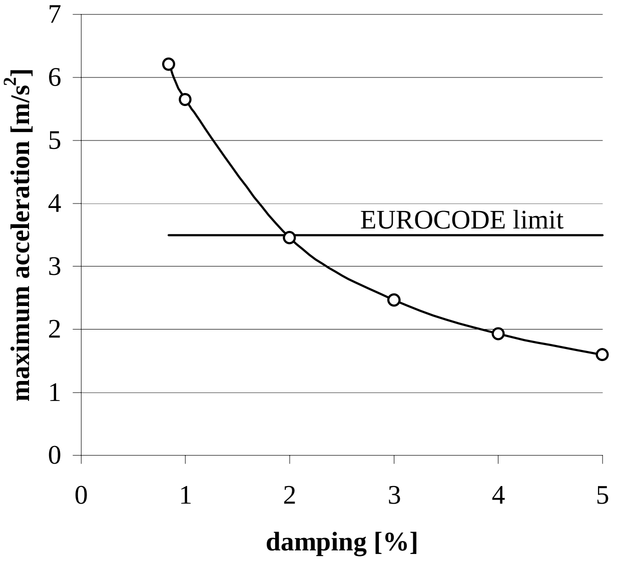

Fig. 4 Influence of damping on the maximum acceleration of bridge #3.

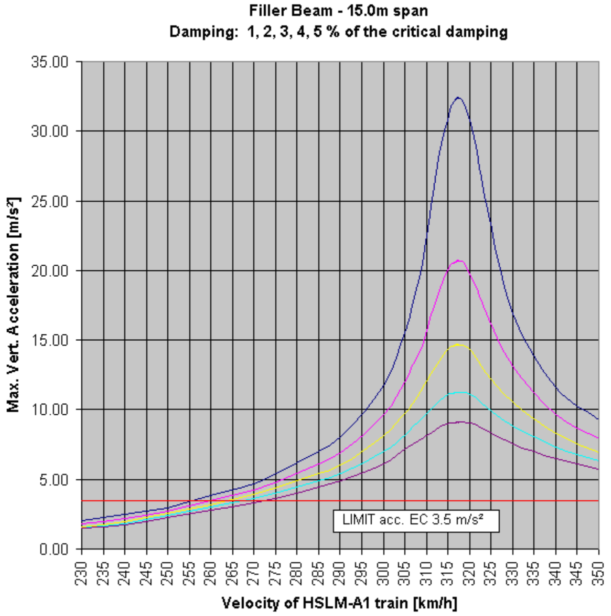

Fig. 5 Filler Beam Bridge before modification – maximum acceleration for different damping values.

5. Filler Beam Bridges

Bridge #3 represented an interesting case as the bridge deck was constructed from steel I-beams cast into a concrete slab. The originals design had two separate parallel structures for each of the two railway lines. The structural system consisted of a simply supported beam of 15m length. The initial design was checked for a damping value of 0.84% after [8] and clearly showed, that the bridge exceeded the limits for maximum accelerations and end rotations by a large degree. The design for this bridge was then modified. Since the girder height could not be increased the two structures for each train line were connected and one steel beam was added on each side of the cross-section as shown in Fig. 3. Table 3 gives the respective values for the two designs. The increased mass of the bridge due to the modified design resulted in greatly reduced values for the maximum acceleration and also for the end rotation. However, the maximum acceleration was still found to be in excess of the limits given by the EUROCODE. A detailed analysis showed that resonance effects were still likely for train velocities of over 200km/h. Further studies were performed to determine the influence of the damping properties and it was found that a damping value of just under 2% would bring the maximum acceleration below the required limit of 3.5m/s^2 (*Fig. 4*). The damping values proposed in [3] are much higher than those given in [8]. For the given structure a modal damping of 2.25% can be assumed according to [3] (as opposed to the 0.84% according to [8]). With the damping set to this value the structure was found to comply with the requirements of the EUROCODE.

Fig. 5 shows the influence of the damping properties on the initial design for various train velocities. The limit for the maximum acceleration was exceeded by almost a factor of three even for a damping value of 5% of the critical damping.

Table 3. Dynamic analysis results for the two designs for bridge #3.

design	maximum acceleration [m/s²]	allowable acceleration [m/s²]	maximum end rotation [radian]	allowable end rotation [radian]
original	12.462	3.5	0.002304	0.000976
modified	6.211		0.000668	

6. Lateral Vibration modes

For a number of bridges within this study great care in the computer modelling had to be taken in order to account for all the possible vibration modes. Cross-sectional distortion had to be allowed for in the bridge girders in order to pick up such lateral vibration modes. Especially for the trough cross-section of bridge #7 this was of great importance as such a mode occurred at a critical frequency (*Fig. 6*). The main girder could not be approximated by a series of beam elements but had to be modelled in greater detail. The loading path is not simply longitudinal as in other, much simpler bridge systems. Local and global effects interact in such structures and it becomes very complicated to predict the governing modes and the critical points in a structure. The numerical model must allow for these effects to be represented. Similar modelling considerations had to be made for the box-girder bridges.

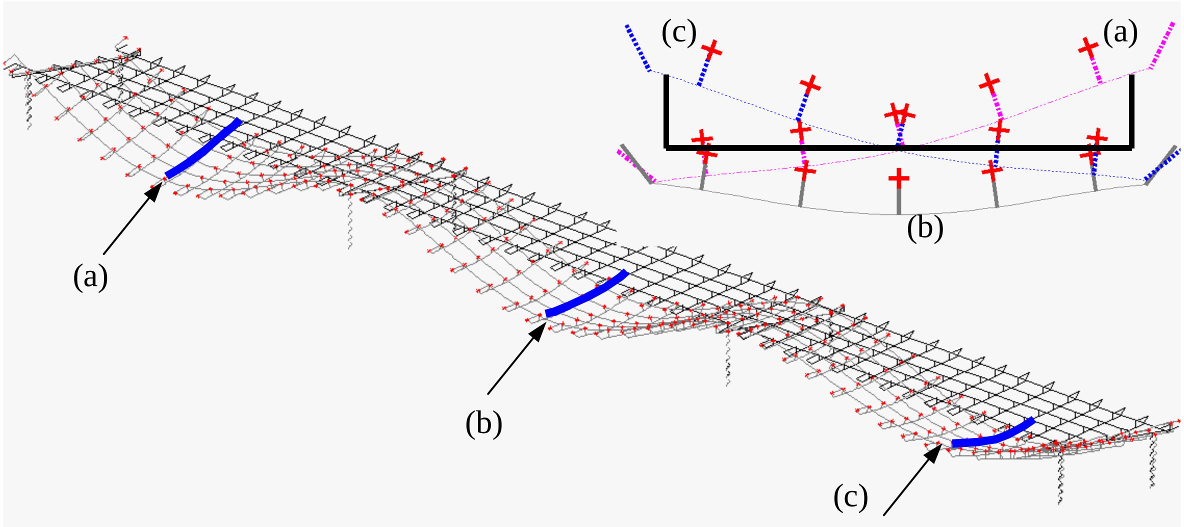

Fig. 6 Vibration mode with cross-sectional distortion intaeracting with bending and torsional displacements.

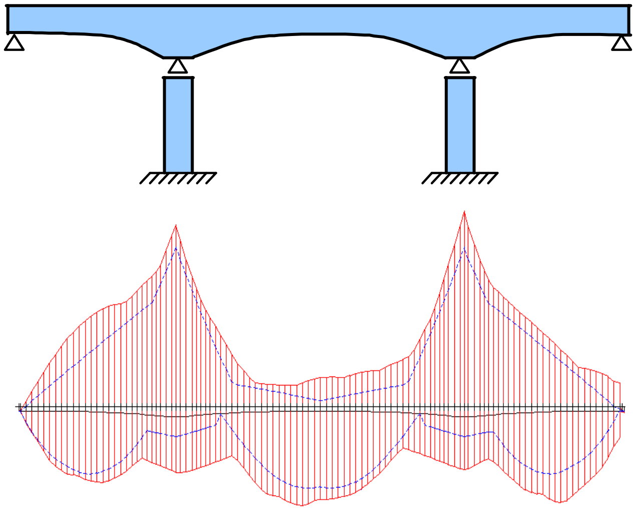

Fig. 7 Comparison static and dynamic loading.

7. Comparison Static and Dynamic Loading

Comparisons of the section forces generated by static loading with dynamic loading was made for the composite bridge #5. A static traffic load evaluation was performed for all ten train constellations given in the EUROCODE to determine a reference envelope. The blue line in Fig. 7 shows the bending moments for this three-span bridge. This reference envelope was then plotted against the maximum bending moments in each point extracted from a large series of rolling stock analyses covering a great number of train velocities and all ten trains specified in the EUROCODE. The hatched area in Fig. 5 shows the result for the dynamic analyses. As could be expected, the section forces gained from the dynamic analysis exceeded those from the static analyses by up to 30% at the governing cross-sections.

8. Conlusions

The upgrade of an existing railway line to accommodate high-speed usage in Austria resulted in a series of dynamic analyses for a number of bridges. These analyses were performed according to EUROCODE. In some cases the existing structures exceeded limits imposed by the EUROCODE for maximum accelerations of the bridge deck and displacements within the bridge. This paper reports on a number of findings resulting from this project.

As a general rule, it was found that simply supported systems were most likely to exceed dynamic limits. The governing natural vibration frequencies of these structures commonly fell within a range that was close to the excitation frequencies of the loading models for high-speed trains in the EUROCODE. This general rule has been confirmed in other analyses not elaborated in this paper.

Since the load exerted by a moving train is never constant additional studies were performed to investigate oscillating loading by passing trains for some of the bridges. An oscillating load with an amplitude of 10% of the load given for the respective critical train constellation and a frequency equal to the first two natural frequencies were superimposed onto the constant load components. It was found that accelerations and displacements within the bridge were increased by only a small amount. It is noted that dynamic loading effects are already accounted for in the EUROCODE specifications.

9. Acknowledgements

The authors gratefully acknowledge that the work for this paper was funded by the F.F.F. on behalf of the Austrian Government as part of the research project FEMBRIDGE.

10. References

[1] prEN 1990-Draft, *Annex A2: Application for bridges*, August 2001

[2] prEN 1991-2 *EUROCODE 1 – Part 2: Traffic loads on bridges*, July 2002 (Conversion of ENV-1991-3 into 1991-2) (final draft)

[3] ENV 1991-3 *Anhang G – Grundlagen für Entwurf, Berechnung und Bemessung – zusätzliche Regelungen zu ENV 1991-1 für Eisenbahnbrücken einschließlich Gebrauchstauglichkeitskriterien*, 1995

[4] TDV GesmbH. (2001) *RM200 – Technical Description*, Graz, Austria

[5] PIRCHER H., JANJIC D., *FEMBRIDGE – Technical Project Description*, 2001, TDV-Austria

[6] PIRCHER M., JANJIC D., PIRCHER H., BRIDGE R.Q. "Towards a Wholistic Approach to Bridge Design", *Proceedings: IABSE-Symposium 2002*, Melbourne, pp. 236-237

[7] ZIENKIEWICZ O.C., TAYLOR R.L. *The Finite Element Method*, Fifth Edition, McGraw-Hill Book Company, London, 2001

[8] PETERSEN C., *Dynamik der Baukonstruktionen*, Vieweg Verlag, München, 1996