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DYNAMIC BEHAVIOUR AND DAMPING OF STEEL RAILWAY BRIDGES AT A SPEED OF 200 KM/H

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Abstract

The subject of the paper is the comprehensive information on experiments carried out on a group of railway bridges near Břeclav, Vranovice and Soběslav, covering filler beams, steel girder bridges and composite bridges. The subject was to determine the behavior of bridges at higher speeds and to determine the value of damping as a basis for the preparation of HSR lines in the Czech Republic.

This paper describes the structures investigated and recapitulates selected findings, particularly related to the damping. Also, the general findings from a number of tests focusing on damping are also given.

Keywords

Dynamic tests, Damping, Modal analysis, Bridge

1 Introduction

The subject of the paper is a summary information about the experiments made on a group of railway bridges near Breclav, Vranovice and Sobeslav, both filler beams bridges, orthotropic steel girders and composite bridges. The aim was to investigate the behavior of the bridges at higher speeds and to determine the damping values as a basis for the preparation of HSR lines in the Czech Republic. This paper describes the structures under investigation and summarizes selected findings, especially those related to damping.

2 Overview of tested bridges

2.1 Filler beam bridges - Podivín

In 2019, the first measurements were carried out on two bridge structures (km 95.554 - one span L = 7.8 m and km 110.124 - one span L = 7.5 m) during a test run up to a speed of 200 km/h on the railway line between Břeclav - Vranovice in one track. In both cases, the beams were typologically filler beam bridges.

Figure 1 Filler beam bridge in km 95,554 in Podivín

2.2 Steel orthotropic bridges in Vranovice

The previous measurements in 2022 were followed in 2023 by dynamic tests on two bridge structures:

- km 116.129 with 3 spans L=11 + 18 + 11 m over the Svratka River (Figure 2)
- km 117.061 with 1 span L=30 m over the Šatava River

As in the previous case, the test train was running up to a speed of 200 km/h on the same railway line in the section Břeclav - Vranovice. In both cases, the bridges were made from steel with an upper orthotropic deck.

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Figure 2 View on the bridge in km 116,129 - 3 spans L=11 + 18 + 11 m over the Svratka River

2.3 Composite viaducts near Soběslav and Heřmanice

The previous measurements were followed up in 2023 with tests on three bridges:

- Bridge in km 67,130 - Soběslav (Figure 4)
- Bridge in km 106,108 - Radíč
- Bridge in km 108,939 - Heřmaničky

The test train was again running at speeds of up to 200 km/h on one track, see Figure 3.

Figure 3 The test train – Vectron locomotive

In all cases it was a composite steel-concrete structure with two I girders and a upper reinforced concrete slab deck.

Figure 4 The bridge in km 67,130 in Soběslav

3 Selected results from measurements

3.1 Filler beam bridges in Podivín

The superstructures of both tested bridges are similar. However, the evaluated modal characteristics show that the dynamic behavior of the two bridges is more different than would be expected on the basis of the similarity of the superstructures.

The superstructure of the bridge at km 95.554 is divided by a longitudinal thin gap into two parts, which however interact with each other. From this it can be estimated that in this longitudinal joint the slab is casted with mutual contact (i.e. as a kind of friction surface acting as a joint at low excitation). This behavior was also confirmed by the deflections measured during the dynamic load test.

The stiffness of the superstructure is lower in the transverse direction than that of the bridge at km 110.124; the girders oscillate to some extent independently with their own frequencies, which are slightly different from each other. This may be due to the fact that the bridge at km 95,554 is reinforced in lateral direction.

The evaluated results show that the magnitude of the dynamic coefficient more or less increases with the increase of the running speed of the test locomotive, but it is still significantly lower than the normatively defined value.

3.2 Steel orthotropic bridges in Vranovice

At both bridges, the damping values were always higher than the normative assumptions, by a factor of several times. It is likely that the level of damping is affected, among other things, by the interaction in the longitudinal joint between the bridges and the associated vertical movement in the track bed. This factor was observed on both bridges. Residual deformations of up to 1 mm remained on the bridge as a result of the interaction.

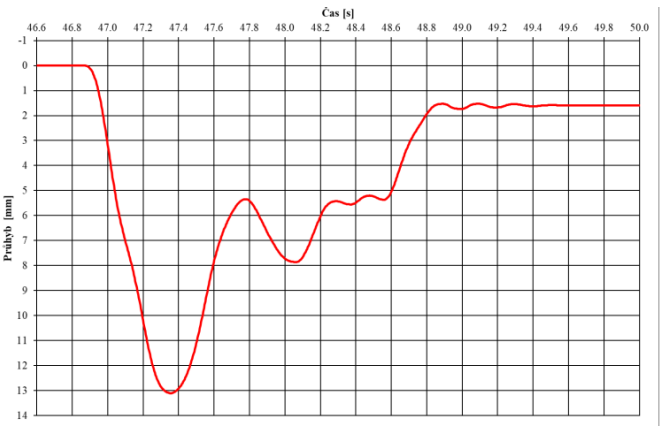

Figure 5 The deflection on the bridge in km 117,061 – the visible residual deflection after the train passed

In this case, the dynamic coefficients for service loads were close to or lower than the values considered for service loads. While this may be positive, it should be noted that the quality of the rolling stock was high. With higher imperfections of vehicle and track, it is possible that the real dynamic coefficients will be slightly exceeded compared to the coefficients for operational loads.

3.3 Composite viaducts on near Soběslav and Heřmanice

An interesting piece of information that is often discussed is the value of damping in relation to the type and level of excitation. As is generally known, the value of the damping

depends not only on the nature of the bridge, but also on the magnitude of the excitation force, the excitation level and the level of the induced vibrations, and possibly also the position and type of excitation. The following table provides a comparison of the results from the dynamic test with a shaker and the dynamic load test with passing train and subsequent free oscillation for the bridge at Soběslav. The shaker can surprisingly create higher vibration level on all frequencies, which leads to the higher damping.

Table 1 Comparison of the result from the informative load test with shaker and the dynamic load test with passing train on bridge in km 67,130

Modal analysis (shaker)		Dynamic load test	
Natural frequency [Hz]	Relative damping [%]	Natural frequency [Hz]	Relative damping [%]
3,46	2,12	3,50	0,46
3,64	1,21	3,69	0,64
4,82	1,24	4,92	1,00
5,01	-	5,07	0,79
5,39	0,97	5,52	0,82
5,70	2,26	5,78	0,80

Furthermore, data on the relative damping values from realized dynamic tests for individual natural frequencies are presented below. For comparison, the last column of the table gives the damping value determined according to EN 1991-2 ed. 2. Eurocode 1: Loading of structures - Part 2.

Table 2 The comparison of natural frequencies and damping evaluated from dynamic tests and Eurocode value

Bridge	Natural frequency [Hz]	Relative damping [%]	Relative damping EN [%]
Podivín, km 95,554, L=7,8m	22,50	3,20	2,55
	26,12	5,10	
	31,66	2,10	
	42,37	4,30	
Podivín, km 110,124 – L=7,5m	21,12	5,20	2,57
	34,25	3,00	
Vranovice, 3 spans L=11 + 18 + 11 m	6,91	1,42	1,23
	8,91	1,80	
Vranovice, 1 span L=30 m	5,08	1,46	0,5
	5,52	1,16	
	5,87	1,40	
Viaduct in km 67,130, Soběslav	3,50	0,46	0,5
	3,69	0,64	
	4,92	1,00	
	5,07	0,79	
	5,52	0,82	
	5,78	0,80	
Viaduct in km 106,108, Radíč	3,00	0,54	0,5
	3,22	0,73	
	4,16	0,64	
	4,63	0,51	
	4,78	0,64	
	4,93	0,55	
Viaduct in km 108,939, Heřmaničky	3,14	0,63	0,5
	3,56	0,72	
	3,75	0,79	
	3,94	0,65	
	4,56	0,57	
	4,69	0,54	

4 Damping analysis and comparison with other experiments

As a part of the analysis following the measurements, the damping of the bridge structures determined from other dynamic load tests was also investigated. Data were collected from various types of bridges such as road, railway bridges and footbridges. Trends in the value of the relative damping were studied depending on the type of material of which the structure was made (concrete, steel, composite), then depending on the type of structure (beam, arch, cable-stayed bridges etc.) and finally depending on the type of traffic. The trends of the relative damping values were compared with the limit values set by EN 1991-2.

Data from the following companies and from dynamic tests, done in last years, were used for this analysis and we would like to thank them for their kindness:

- Test laboratory of the Faculty of Civil Engineering, CTU in Prague,
- Klokner Institute, CTU in Prague, Department of Experimental and Measurement Methods
- Academy of Sciences, Institute of Theoretical and Applied Mechanics,
- INSET s.r.o.

Research papers from Portugal and Sweden, scientific literature and other research documents were also used.

Depending on the type of data source, it was possible to investigate the damping of the bridge structure in more detail. Some sources only provided graphs with the relative damping values depending on the span. Thus, for a given bridge structure that was not described in detail, one resulting value of relative damping was determined. Bridges from entities within the Czechia could be examined in more detail. Bridge types were distinguished in terms of material used, construction type and type of traffic. Different values of the relative damping for a given bridge were also observed depending on the natural frequency in the different forms of vibration (vertical bending, horizontal vibration and torsion).

The following graph shows the values of the relative damping versus span (for continuous beams, the main span was used). This graph shows all bridges of the analysis. Structures are not differentiated by material, construction type or type of traffic. If the damping information for a given bridge was represented by only one value of relative damping, this value is used. If there were more information for various types of frequencies, the relative damping value for the 1st vertical bending mode shape was used.

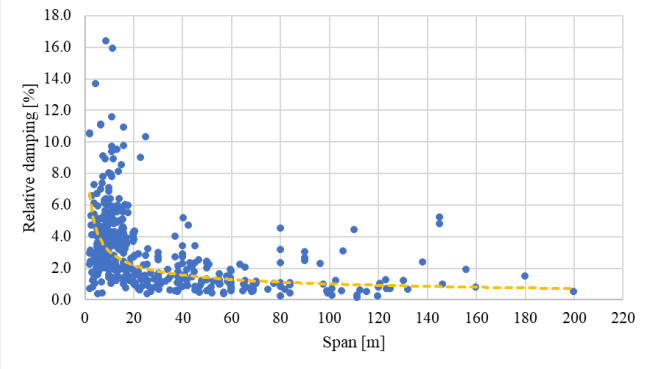

Figure 6 Summary analysis of the damping in the whole group of structures studied

In the Figure 6, it is possible to observe the trend of the relative damping values on the span. The dependence can be described as significant to very strong based on the Spearman correlation coefficient. In the Figure 7, the values of the relative damping versus span are presented only for the group of railway bridges. The relative damping values are not differentiated on the basis of material and structural type of the bridge. The green colour indicates the bridges that were measured in the presented campaign.

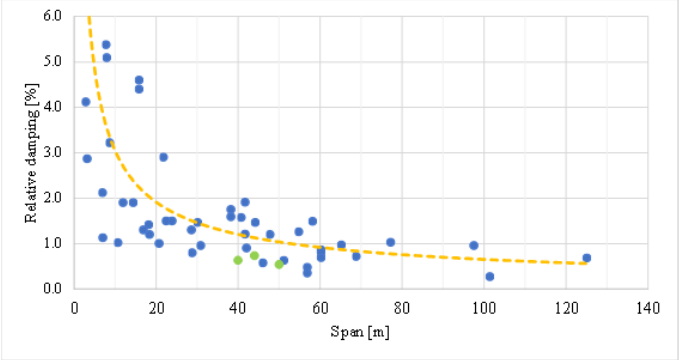

Figure 7 Summary analysis of damping in a group of railway bridges of the studied structures

The graph also shows the trend of the relative damping values. The degree of dependence here is higher than in the previous graph and can be described as very strong.

5 CONCLUSION

In conclusion, it can be stated that the obtained results will be an important basis for further development and construction of HSR lines, where they can help in design practice in dynamic calculations of response to moving loads.

6 Acknowledgement

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