18th International Conference
ENGINEERING MECHANICS 2012
Svratka, Czech Republic, May 14 – 17, 2012

pp. 109–116
Paper #141

SHORT-SPAN RAILWAY COMPOSITE BRIDGES:TEST AND RATING

J. Benčat*

Abstract: *This paper presents an overview of the in–service performance assessments of a steel–concrete composite (SCC) short–span railway bridge superstructure. A field load testing and visual inspections for the assessments of the SCC bridge durability under an actual service environment were conducted. The test result indicates that the SCC bridge superstructure has no structural problems and is structurally performing well in–service as expected. The results may provide a baseline data for future field SCC bridge load bearing capacity assessments and also serve as part of a long–term performance of SCC bridge superstructure.*

Keywords: *Dynamics of bridges, load bearing capacity assessments, bridges static and dynamic loading test, railway steel–concrete composite bridges, DLF, spectral analysis.*

1. Introduction

To investigate its in–service performance, field load testing was conducted under an actual service environment. Field load testing is an attractive tool for re–evaluating the capacity rating of bridges. For the first time, the capacity rating for an SCC railway bridge under in–service environment is calculated and discussed with various existing methods for the rating factors such as allowable stress and DLF (Baťa, et al.1994; Benčat, 2003). As the SCC railway bridge superstructure was instrumented, the real load test was conducted (Benčat, 2007) under similar loading and weather conditions as during initial field loading tests in the 2002 (Benčat, 2003). This was done to ensure the structure's integrity before opening it to the public, to establish base line conditions for a future in–service field load test program, and to compare actual performance with theoretical calculations. After the initial field load test, the follow–up field load test was conducted to ensure that the SCC railway bridge structure was behaving satisfactorily and to check out any signs of degradation. The SCC bridge superstructure was tested using conventional tractile locomotion E 662.2. The results of this test were later used to evaluate bridge in–service bearing capacity.

2. The bridge case – study

The short–span railway bridge on *ŽSR* (*Slovak Republic Railways*) line *Žilina – Čadca* (Fig. 1) was built in 2002. The bridge load bearing structure is created by one span two concrete plates reinforced by rolled **I** sections. Each line direction is supported by two single span plates which are shifted one another with distance 2,425 m. Length of the span is 13 m and width of structure is 9,8 m. Thicknesses of the plates are 0,82m and they are increased on the border to shape **Π** – Fig. 2. The soil conditions for foundations of the two abutments are very similar on both riversides the resistant substratum (gravel and sandy gravel). The bridge uppers structure creates continuous track with gravel bed (Bencat, 2002, 2007).

Foundations of the supports are reinforced concrete blocks on the same substratum as the both abutments. For both dilated bridge parts supports are reinforced concrete gravity abutments. Fig. 2 shows the bearing structure cross–section and Fig. 3 depictures schematic plan view of the bridge plates.

* Prof. Ing. Ján Benčat, CSc.: Structure Mechanics Dept., CEF,University of Žilina, University Street 8215/1; 010 26, Žilina; SK, e-mail: jan.bencat@gmail.com

Fig. 1: View of the short–span bridge on ŽSR line Žilina – Čadca

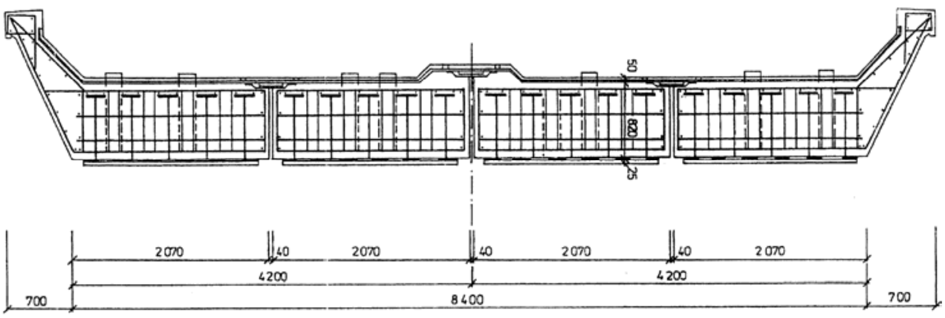


Fig. 2: Cross – section of the load bearing structure

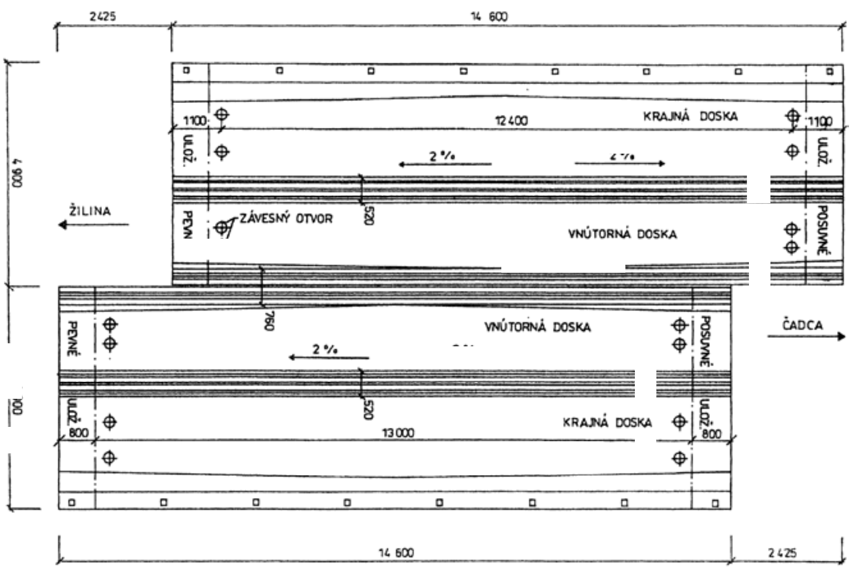


Fig. 3: Schematic plan view of the load bearing structure

3 Finite Element Model Analysis

3.1 Natural frequencies

Bridge static and dynamic numerical analysis was performed using the *IDA NEXIS software*. The 3D global model incorporated all primary and secondary load – carrying members in the bridge were excluded at this stage. Computing system enable to create slab – beam stiff connection. FE model of bridge structure was composed from two main plate using 2D elements stiff connected on beam elements with **I** shape cross section (reinforcement) respecting bridge load bearing structure geometry. Also supports were modelled respecting bridge bearings positions – one side stiff joints and other side slip joints (SUDOP Košice, 2001; The Steel Construction Inst., 20014; Slovak Standard 73 6203).

For the static and dynamic FEM computations the bridge superstructure (continuous track with gravel bed) is considered as a continuous distributed mass and locomotive type E 669.2 is considered as a singular mass. The simplified FE model consists of 1758 joints, 1904 beam elements and 1503 shell elements. Rendered computational model layout is presented on Fig. 4.

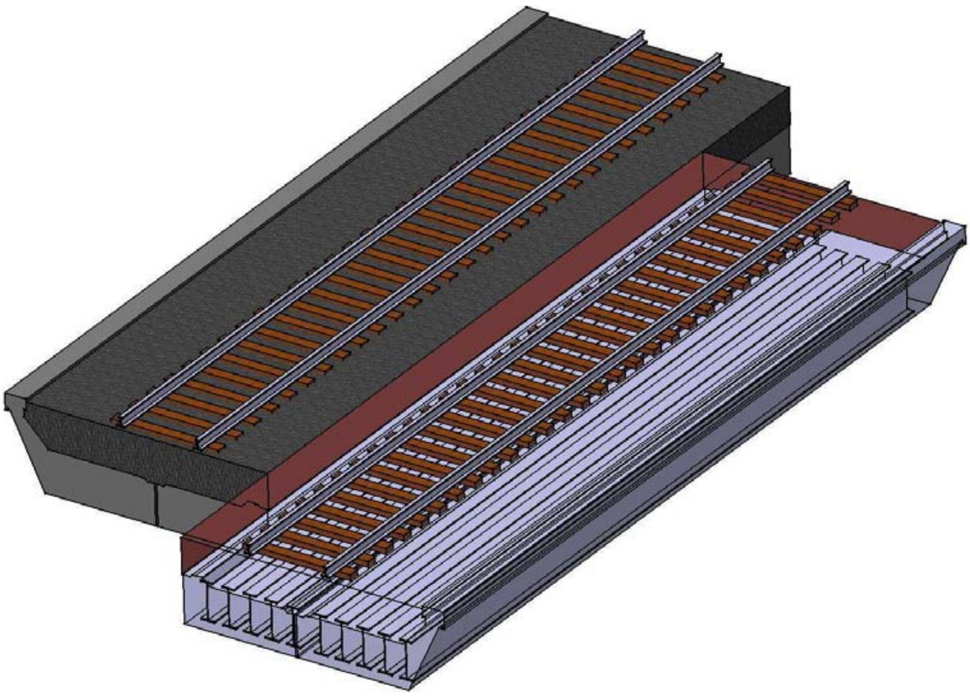


Fig. 4: Global FEM model layout

Using FE model of the bridge structure the first twenty natural frequencies and modes of natural bridge vibration were calculated to compare to their experimental values from the *Dynamic Loading Test* (DLT) measurements. As an example, some of them are shown in the Fig. 5. Comparison of the calculated and experimental natural frequencies values is explained in Tab. 2.

3.1. Bridge deflections calculation for SLT and DLT

The maximum static vertical deflections values in the middle of the spans, positions of measured points, load positions and the effectiveness of the testing loads (Locomotive type E 699.2 of 100 t mass) according to Slovak Standard 73 6203 for the Static Loading Test (SLT) were taking into account and also calculated via IDA Nexis software package. Results from the calculation of static deflections were also used for DLT testing load effectiveness. Fig. 6 shows an example of computed static deflection of bridge due to testing load. Comparison between FEM computed and measured static deflections in the years 2002 and 2007 is in Tab. 1.

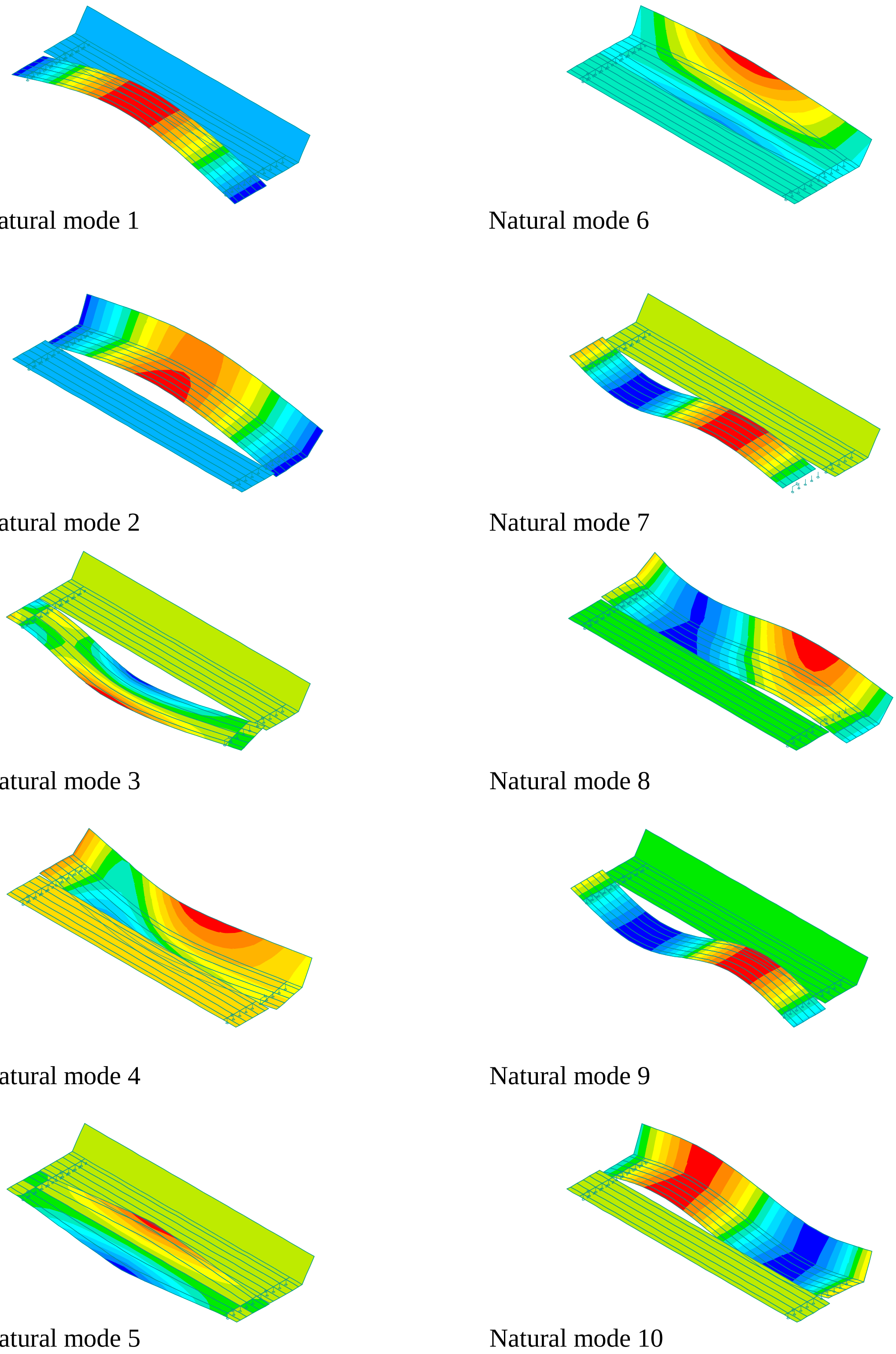


Fig. 5: Calculated modes of the bridge natural vibration

4. Dynamic Loading Test

To investigate bridge in–service performance for the two years, field load testing and visual inspections were conducted under an actual service environment in September 2007. Field load testing is an attractive tool for re–evaluating the capacity rating of bridges. Before the *bridge dynamic loading test* performance the *static loading test* was carried out using load locomotive type E699.2 with weight of 100 000 kg. The deflections values in the middle of the tested span were measured using LVTD inductive sensors *Bosh*.

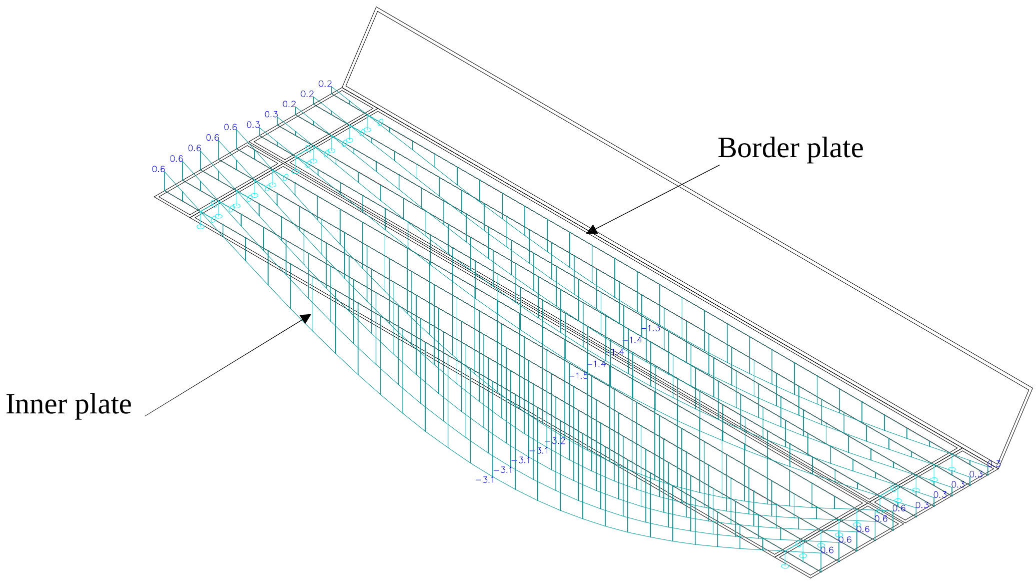


Fig. 6: Calculated deflection of bridge structure due to locomotive E 699.2

Tab. 1: FEM calculated and experimental static deflection values comparison

BRIDGE STATIC DEFLECTIONS	MAXIMAL VERTICAL DEFLECTION - MIDDLE SPAN (mm)							
	Track 1: Čadca–Žilina (2002)		Track 2: Žilina–Čadca (2002)		Track 1: Čadca–Žilina (2007)		Track 2: Žilina–Čadca (2007)	
	Border	Inner	Border	Inner	Border	Inner	Border	Inner
FEM (w_{CAL})	3,158	3,158	3,158	3,158	3,158	3,158	3,158	3,158
Measured el.(w_E)	1,84	1,86	1,88	1,82	1,71	1,70	1,78	1,79
Permanent (w_R)	0,05	0,05	0,00	0,05	0,05	0,05	0,05	0,05
w_E / w_{CAL} (α_1, β)	0,58	0,59	0,60	0,58	0,54	0,54	0,56	1,62
w_R / w_{TOT} (α_2)	0,03	0,03	0,00	0,03	0,03	0,03	0,03	0,03

For static strains analysis *Kistler* 9232A (piezoelectric gauges instrumented on steel part of the plate – **I** sectional bars) and M 502 (string strain gages built in to concrete part of the plate for SLT) were installed on concrete and steel members surfaces.

The dynamic response of the bridge was also induced by passing load locomotive type E 699.2 in the both directions with various speeds. The operating dynamic loading test (DLT) started with a load speed of v = 12 km/h (crawling) which increased up to the maximum achievable speed v = 72 km/h.

A computer – based measurement system (CBMS) was used to record the dynamic response of the bridge excitations induced by testing locomotive over DLT period. The investigated vibration acceleration, deflection and stress amplitudes were recorded at selected points with maximum calculated deflection in the middle of the span – Fig. 7. Output signals from the accelerometers (*Brüel–Kjaer*, BK4500), strains (*Kistler 9232A* – steel, *M 502* – concrete) and deflection sensors (*BOSCH*) were preamplified and recorded on two PC facilities with A/D converters software packages *DAS 16* and *DISYS*. The experimental analysis has been carried out in the *Laboratory of the Department of Structural Mechanics*, *University of Žilina*. Natural frequencies were obtained using spectral analysis (Bendat & Piersol, 1993) of the recorded bridge response dynamic components of the structure vibration, which are considered ergodic and stationary. The frequency response spectra have also been obtained by using two – channel real time analyzer BK–2032 in the frequency range 0 ÷10 Hz. Output signal in the form of *Fourier frequency spectrum* (power spectrum) was also recorded by computer and printed by laser printer and x – y plotter. Spectral analysis was performed via *National Instruments* software package *NI LabVIE*. Vibration energy redistribution was observed via stress measuring on steel and concrete surfaces. One of the most important parameter – the *Dynamic Load Factor* (DLF) were evaluated using stress and deflection time histories measured during DLT.

There are presented below (Fig. 9) first of all the values of *dynamic load factor* – δ_{OBS} of the bridge (right bridge, line *Žilina – Čadca*), as an illustrative results example. The bridge vibration forcing was assumed by the run of the locomotive moving with various velocities in the tested parts of the bridge. The function δ_{OBS} against speed of the locomotive motion is plotted in Fig. 9. As an example, Fig. 8 also shows a part of the experimental analysis procedure results of the dynamic components structure vibration from the bridge DLT. Fig. 8 also shows: (a) *deflection time history* – $w(t)$ due to in–service slow train, (b) *stress time history* – $\sigma(t)$, (c) *acceleration time history* – $a(t)$, (d) *stress time history* – $\sigma(t)$ due to locomotive and (e) corresponding *power spectrum* – $S_D(f)$.

Fig. 7: Accelerometers with amplifiers – a part of CBMS

Tab. 2: Calculated and measured natural frequencies

Natural mode	NATURAL FREQUENCY $f_{(j)}$ [Hz]				
	FEM RESULTS	EXPERIMENTAL VALUES (DLT - 2002)		EXPERIMENTAL VALUES (DLT - 2007)	
		Track 1	Track 2	Track 1	Track 2
1	1,918	1,950	1,945	1,995	1,986
2	2,785	2,795	2,790	2,803	2,816
3	5,910	6,054	6,102	6,121	6,152
4	7,534	7,356	7,326	7,359	7,336
5	13,090	12,859	12,891	12,889	12,901
6	13,677	13,206	13,873	13,287	13,804

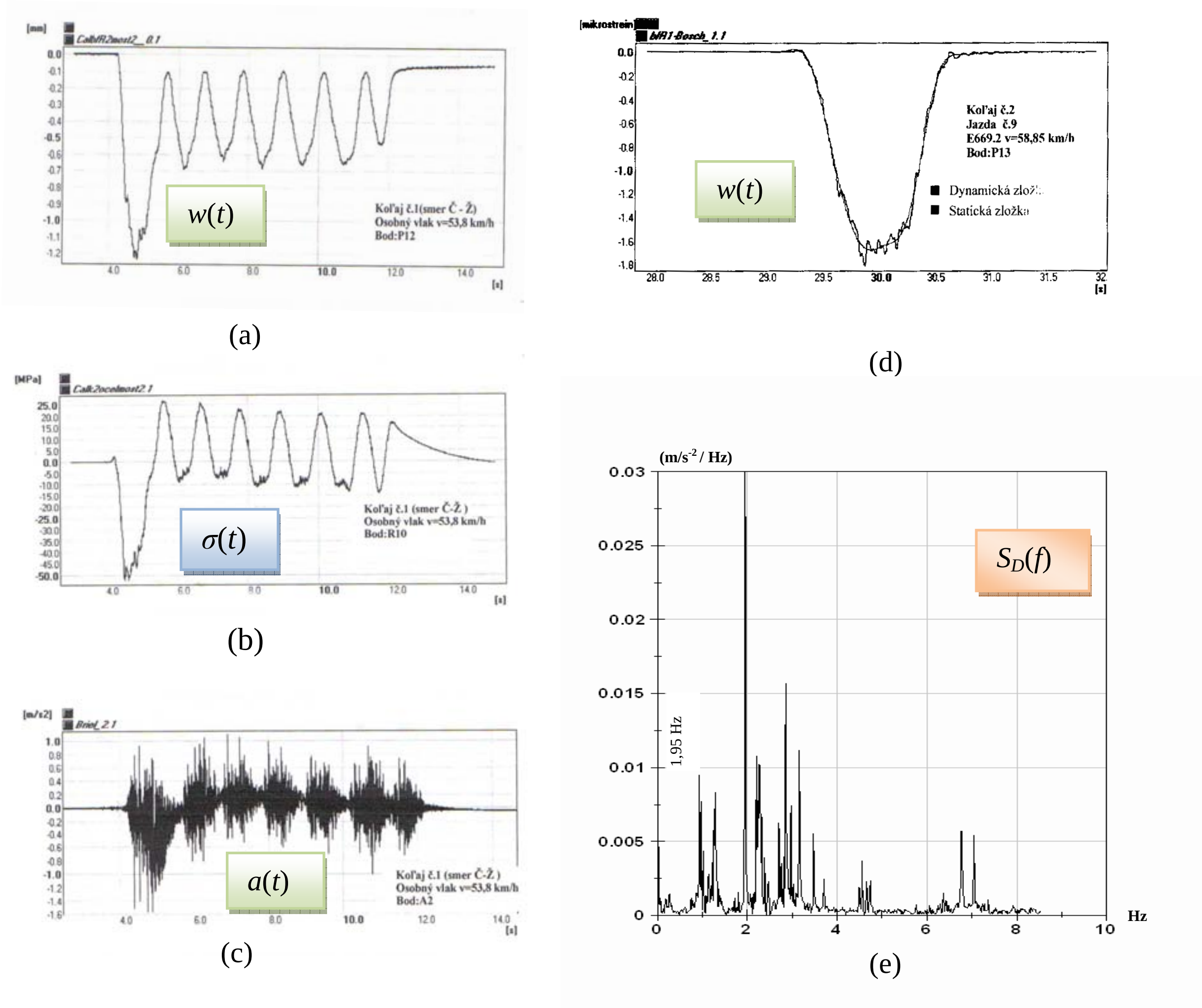
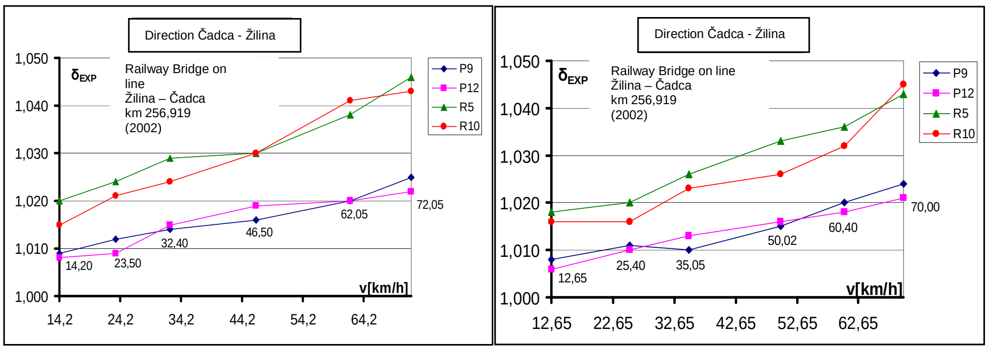
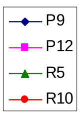


Fig. 8: Experimental analysis procedure results examples



Legend:



Bosh LVTD sensors

Kistler 9232A piezoelectric gauges

Fig. 9: Dynamic load factor δ_{OBS} against speed of the testing locomotive motion

5. Conclusions

This paper presents an overview of the in–service performance assessments of an SCC short–span bridge superstructure. A field load testing and visual inspections for the assessments of the SCC bridge durability under an actual service environment were conducted. Based on the presented results the following conclusions can be drawn:

- The maximum deflection from two SLT (2002, 2007) was *max* w = 1.88 mm from both SLT. The maximum value of SLT is 59.53 % lower than the maximum theoretical value of FEM. It means that the SCC bridge superstructure may be designed with a less restrictive design deflection.
- The dynamic responses in 2002, 2007 (monitoring) also show that the passage of the trains produces insignificant vibrations, the maximum dynamic deflection effective value w_{rms} = 0.48 mm (2002) and w_{rms} = 0.32 mm (2007). This is attributed to the difference between the natural frequency of the SCC bridge superstructure and the forcing frequency of the passing locomotive and trains.
- After five years of bridge service, DLF values of the SCC bridge are well compared with values DLT measured in the initial tests (2002). All experimental DLF values are lower than prescription by the *Slovak standards* DLF values. Therefore there is no need to post the load limit and the capacity–rating evaluation and for the SCC bridges can use rating factor of the existing methods for the conventional materials such as the allowable stress and load–factor.
- The predicted dynamic behavior of the bridge by a simplified FEM analysis calculation was compared to the measured one. Despite both the complex structural layout of the bridge (Fig. 2,3) and simplifying assumptions of the model (Fig. 4), obtained results showed good agreement for all experimentally identified damped natural frequencies in the basic frequency range 0 – 11 Hz (2002, 2007) and these are well compared with the theoretical values, Tab. 2.
- Although the data on the in–service performance of SCC Bridge are not enough, the results may provide a baseline data for the future capacity rating assessments and also serve as part of a long-term performance of the examined SCC bridge superstructure.

Acknowledgement

We kindly acknowledge the research project *VEGA*, Nr.G1/0169/12 granted by *Scientific Grant Agency of the Slovak Republic Ministry of Education.* We should also like to thank the *Civil Engineering Faculty – University of Žilina* for additional feed in this field research activity.

References

Baťa, M., Plachý, V., Sýkora, J., Bílý, V. & Polák, M. (1994) Static and dynamic tests of bridges, in: *Proc. of Czech – US Bridge Conference*, Praha.

Benčat, J. et al. (2007) *Report on dynamic monitoring results of the bridge on railway Žilina – Dětmarovice v km 256,919*, Report No. 6 – 3 – 42/SvF/07, ŽU/Žilina.

Benčat, J. et al. (2003) *Report on static and dynamic test results of the bridge on railway Žilina – Dětmarovice v km 256,919*, Report No. 6 – 3 – 19/SvF/03, ŽU/Žilina.

Bendat, J. S. & Piersol A. G. (1993) *Engineering applications of correlation and spectral analysis*, (2nd edition), Wiley Interscience, New York.

Design documentation. (2001), SUDOP Košice.

Slovak Standard No.73 6209 – *Loading test of bridges*.

Slovak Standard No.73 6203 – *Loading of bridges.*

The Steel Construction Institute. (2001) *Structural design of stainless steel*, SCI Publication P291, Ascot, UK.