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Dynamic Response of the Short-Span Railway Composite Bridge

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Abstract

Full-scale dynamic testing of structures can provide valuable information on the service behavior and performance of structures. With the growing interest in the structural condition of railway bridges, dynamic testing can be used as a tool for assessing the integrity of bridges. From the measured dynamic response, induced by instructed passing trains, modal parameters (natural frequencies, mode shapes and modal damping values) and system parameters (stiffness, mass and damping matrices) are obtained. A field load testing and visual inspections for the assessment of the SCC bridge durability under an actual service environment were conducted. The results indicate that the SCC superstructure is structurally performing very well, and the capacity–rating evaluation for the SCC Bridge can use rating factor of the existing methods for the conventional materials such as the allowable stress and load–factor.

Keywords: bridges dynamic testing, spectral analysis DAF, natural frequencies, bridges monitoring.

1 Introduction

This paper presents an overview of the in-service performance assessments of a steel-concrete composite (SCC) short–span railway bridge superstructure. To investigate SCC bridge in–service performance, field load testing was conducted under an actual service environment in 2024. 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 (dynamic load factor). As the SCC railway bridge superstructure was instrumented, a real load test was conducted under similar loading and weather conditions as during initial field loading tests in the 2002. 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 Methods

The short–span railway bridge on ŽSR (Slovak Republic Railways) line Žilina – Čadca (Figure 1) was built in 2002. The bridge load–bearing structure is created by 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. The length of the span is 13 m and the width of the structure is 9.8 m. Thicknesses of the plates are 0.82 m and they are embedded on the border. 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 a continuous track with gravel beds [1, 2, 3]. Foundations of the supports are reinforced concrete blocks on the same substratum as both abutments. For both dilated bridge parts supports are reinforced concrete gravity abutments.

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

Bridge static and dynamic numerical analysis was performed using the IDA NEXIS software package. The 3D global model incorporated all primary and secondary load–carrying members in the bridge were excluded at this stage. FE model of the bridge structure was composed of 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 [5, 6, 7]. For 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 (Figure 2). Using the 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). Comparison of the bridge natural frequencies value is apparent from DLT measurements in Table1.

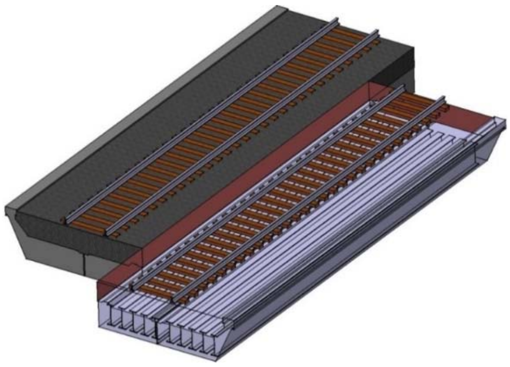

Figure 2: Global bridge FEM layout.

As an example, the first two basic bridge natural frequencies are shown in Figure 3.

Figure 3: First two calculated modes of the bridge natural vibration.

3 Results

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 2004. Before the bridge dynamic loading test performance the static loading test was carried out using load Locomotive type E699.2 with a weight of ≈100 000 kg. The deflections values in the middle of the tested span were measured using LVTD inductive displacement transducer Bosh. For static strains analysis Kistler 9232A (piezoelectric gauges instrumented on the steel part of the plate – I sectional bars) and M 502 (string strain gauges built into concrete part of the plate for static loading test– SLT) were installed on concrete and steel members surfaces (Figure 4). The experimental analysis has been carried out in the Laboratory of the University of Žilina, see also Figure 4. Natural frequencies of the bridge structure were obtained using spectral analysis [10, 11, 12] of the recorded bridge response dynamic components of the structure amplitude vibration, which are considered ergodic and stationary. Spectral analysis was performed via National Instruments software package NI LabVIEW. Vibration energy redistribution was observed via stress measuring on bridge steel and concrete surfaces of bearing elements. One of the most important parameters – the DLF was evaluated using stress and deflection time histories {σ(t) and w(t)} measured during DLT.

Figure 4: Example of the DLT instrumentation.

Demonstration of the experimental analysis procedure results of the dynamic components structure vibration from the bridge DLT are as an example depictured on Figures 5, 6. In Table 1 is presented the comparison of the calculated and experimental measured natural frequencies value.

Natural mode (*j*)	**Natural frequencies value $f_{(j)}$ [Hz]**				
	FEM model	**Experimental values (DLT)** (2002)		**Experimental values (DLT)** (2004)	
		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

Table 1: FEM calculated and experimental natural frequencies value comparison.

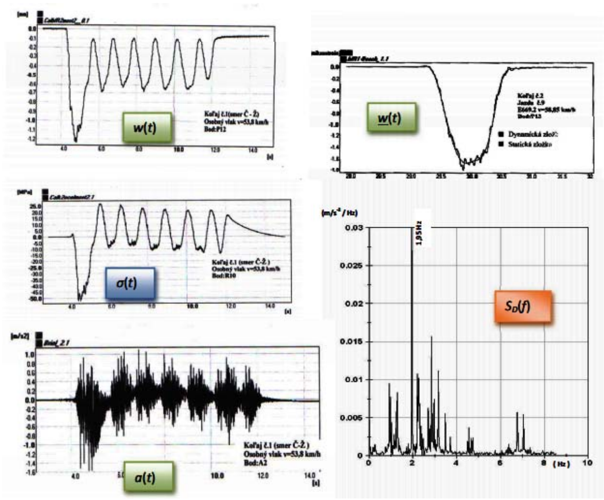

Figure 5: Bridge structure amplitude vibration experimental analysis results example.

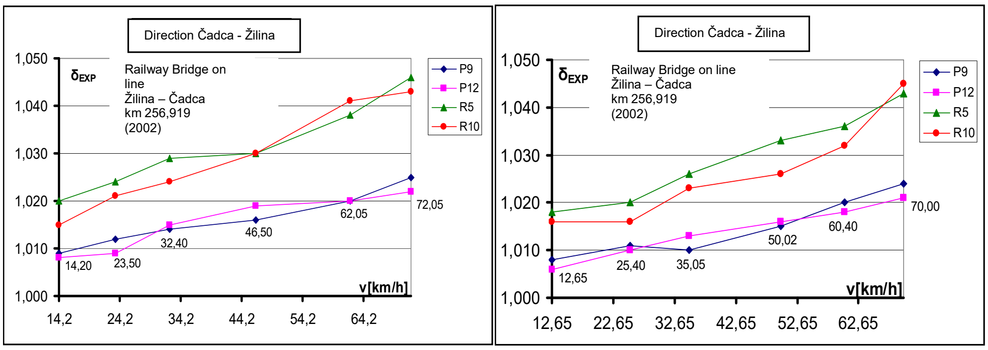

Figure 6: Dynamic load factor δ_{obs} against speed of the testing locomotive motion (LVTD sensors Bosh, Kistler 9232A piezoelectric gauges).

4 Conclusions and Contributions

A field load testing and visual inspections for the assessment of the SCC bridge durability under an actual service environment were conducted. Based on the results presented in this paper the following conclusions can be drawn:

i) After two years of service, values DLF of the ŽSR SCC Bridge is well compared with values DLT measured in the initial tests (2002). All experimental DLF values were lower than prescription DLF values by the Slovak standards [8], see also Figure 6. Therefore there is no need to post the load limit. The results indicate that the SCC superstructure is structurally performing very well, and the capacity–rating evaluation for the SCC Bridge can use rating factor of the existing methods for the conventional materials such as the allowable stress and load–factor [8], [9].

ii) The predicted dynamic behaviour of the bridge by a simplified FEM analysis calculation was compared to the measured one. Despite both the complex structural

layout of the bridge and simplifying assumptions of the FEM (Figure 2), results showed good agreement for all experimentally identified (2002, 2004) damped natural frequencies in the basic frequency range 0 – 11 Hz and that is well compared with the theoretical values, (Table 1).
iii) Although the data on the in–service performance of SCC ŽSR Bridge is now 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 (monitoring) of the bridge superstructure.

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