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DYNAMIC TESTING OF SOIL-STEEL COMPOSITE RAILWAY BRIDGE

DAMIAN BEBEN

Faculty of Civil Engineering, Opole University of Technology, Opole, Poland

The paper presents the results and conclusions of the field tests under service loads that were conducted on a soil-steel composite (SSC) railway bridge. Inductive gauges, extensometers and accelerometers were used to monitor displacements, strains and accelerations of this bridge, respectively. The maximum displacement and strain of the SSC bridge was -0.61×10^{-3} m and -54×10^{-6}, respectively. The maximum SSC bridge and ballast accelerations were equal to 0.67 and 1.23 m/s^2, respectively, and they did not exceed the Eurocode limit of 3.5 m/s^2. On the basis of the measured displacements, a Discrete Fourier Transform (DFT) method was implemented to determine the frequencies of SSC bridge (dominant frequencies were 0.1 (or 0.2) and 1.2 Hz). The natural frequencies of the bridge were 0.25 and 1.3 Hz, and they corresponded to approximately two first dominant frequencies extracted from the forced vibration tests.

Keywords: Displacement, Strain, Frequency, Service, Load, Acceleration.

1 INTRODUCTION

Steel-soil composite (SSC) bridges and culverts, typically ranging from 3 to 15 m, can be used as an effective alternative for short-span bridges. They can meet the design and safety requirements as for traditional bridges, at lower initial and long term maintenance costs (Janusz and Madaj 2007). Other benefits include a rapid construction time as the structure is assembled in the field using a number of corrugated structural plates. For these reasons, SSC bridges are increasingly being used in road and railway projects.

The main aim of this paper is to study the dynamic behavior of a SSC railway bridge under the service loads. The displacements and strains were measured during field load tests. The ballast and bridge accelerations were also monitored. On the basis of received displacements, the frequencies of this bridge were determined using the Discrete Fourier Transform (DFT) method. Displacements, strains and accelerations were measured for all trains which ran over the bridge during a 24-hour period.

2 BRIDGE DESCRIPTION AND INSTRUMENTATION

The tested SSC railway bridge in the cross section has two closed pipe-arches (Figure 1). The span of shells is L1 = L2 = 4.40 m that are placed directly on a special profiled layer of soil substructure, of about 0.20 m thickness, and compacted to reach the indicator density I_D = 0.98–0.95, in accordance with the Proctor Normal scale (CEN 2007). The height of shells is h = 2.80 m. The load-bearing structure was constructed as two shells assembled from corrugated steel plate sheets (Fig. 1). The individual sheets were connected together using high strength bolts. The soil cover over the steel shell structures (including ballast, blanket and backfill) equals hc = 2.40 m.

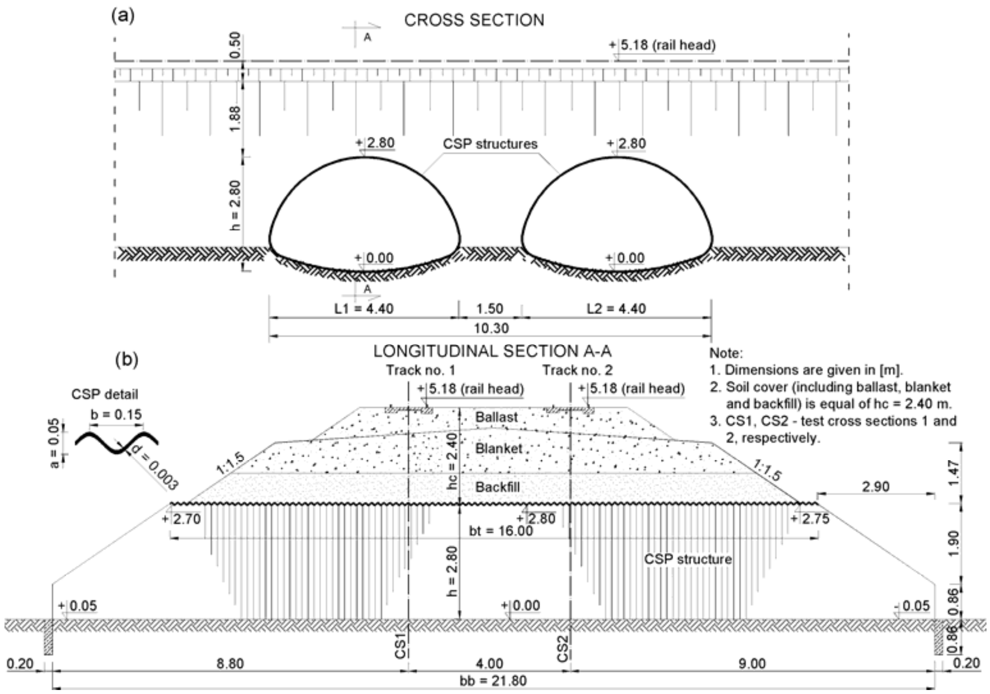

Figure 1. The SSC railway bridge: (a) cross section, (b) longitudinal section A-A.

Displacements and strains of the bridge caused by dynamic service rail loads were measured with using inductive and strain gauges, respectively. Location of gauges in the bridge has been shown in Figure 2. Two main testing sections were chosen for the bridge (CS1 and CS2) at a distance of 4.0 m from each other. In plan, the CS1 and CS2

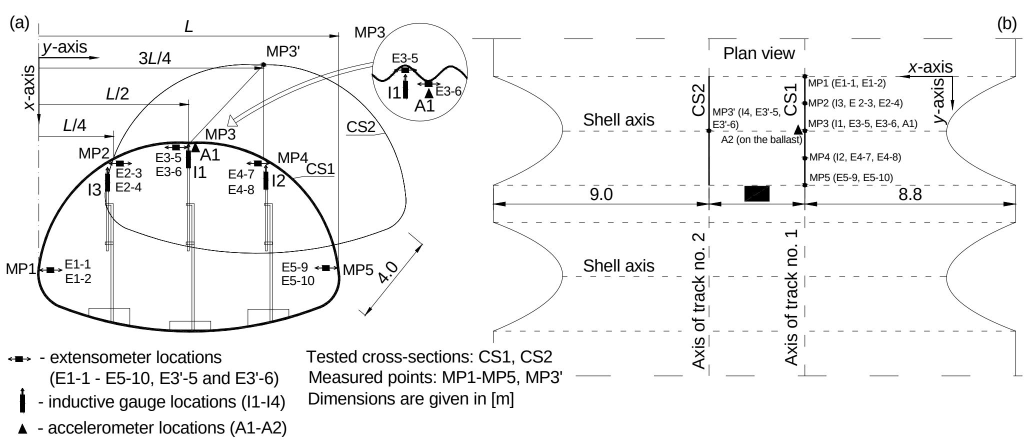

Figure 2. Arrangement of sensors on the shell bridge: (a) cross section, (b) plan view.

sections were located underneath the track axes (Fig. 2b). Two extensometers were placed in each of the points to measure strains in longitudinal direction (*y*-axis) of the shell (at the top and at the bottom of the corrugation), which gives 10 extensometers E1-1–E5-10 for cross section CS1 and 2 extensometers E3'-5–E3'-6 for cross section CS2 (Fig. 2).

Additionally, at measurement points MP2, MP3 and MP4 (section CS1), three inductive gauges (I1, I2 and I3) were installed to measure vertical displacements (Fig. 2). In section CS2 (measurement point MP3'), one inductive gauge (I4) was also installed. In addition, two accelerometers (A1 and A2) were used to monitor the acceleration of the ballast and the SSC bridge. Accelerometers were positioned both on the bridge crown (A1) and on the railway embankment – ballast (A2 – between the sleepers of track no. 1 directly over the bridge crown, Fig. 2).

3 RESULTS OF MEASUREMENTS AND THEIR ANALYSES

3.1 Bridge Displacements

The maximum displacements do not exceed -0.61×10^{-3} m. Figure 3 presents the example of displacement course of the bridge crown (gauge I1) and quarter point (gauge I2) during passage of freight train (no. 18) at a speed of 35 km/h. The effect of each axle of the freight train can also be observed from the displacement versus time plots. During train rides, three main phases of displacements were emphasized. The first phase represents impact of the locomotive and first heavy wagon, and the maximum displacements amounted to -0.48×10^{-3} m. The second phase relates to the passage of eleven lighter wagons. At this stage, the maximum displacements equaled almost -0.20×10^{-3} m. The third phase relates to vibration reduction (damping) after the passage of the freight train. As it can be seen, the displacements at the quarter point are smaller than at the crown, and they do not exceed -0.25×10^{-3} m. Taking into account the whole test period, the largest displacements of the SSC bridge are related to the impact of locomotives (mainly for freight trains). The impact of wagons is quite small in comparison to the loco impact. It is undoubtedly related to the weight of the locomotives.

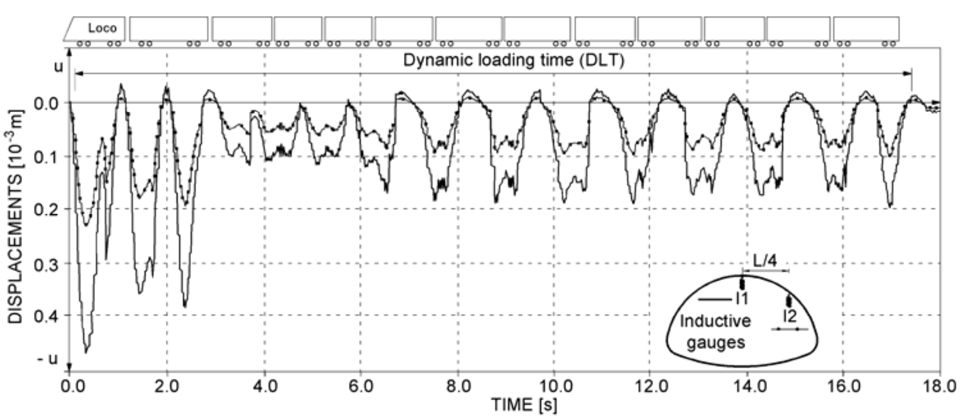

Figure 3. The courses of displacements of the bridge crown and quarter point during passage of the national freight train no. 18 (11866 kN) at the speed of 35 km/h.

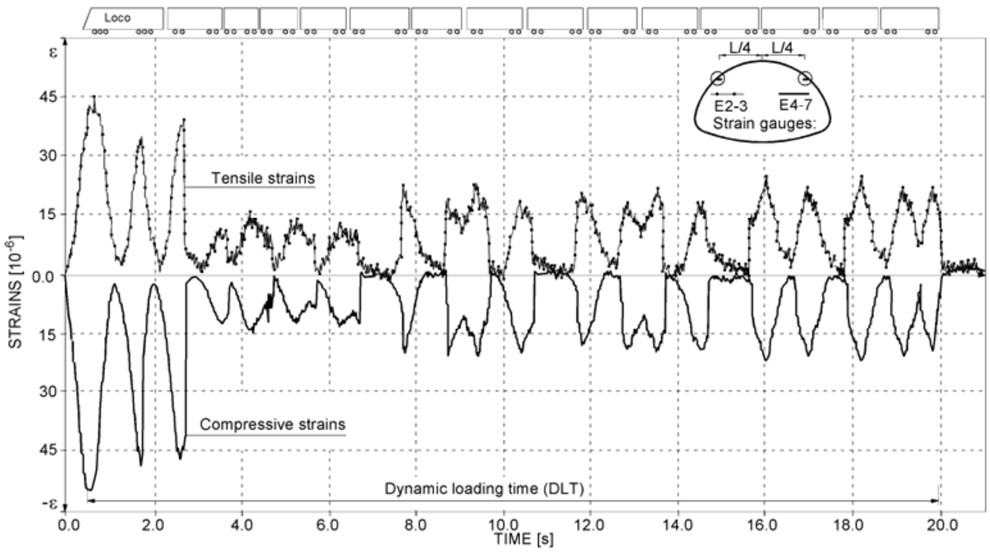

Figure 4. The strain courses (compressive and tensile) of SSC Bridge (in the quarter points) during passage of the international freight train no. 5 at the speed of 35 km/h.

The displacements peaks are situated directly under the axles of locos and wagons. Dynamic loading time (DLT) depends on the train lengths, however as it can be seen the impact of wagons in comparison to locos is insignificant.

3.2 Bridge Strains

The highest values of bridge strains were measured at the quarter points of the structure (measurement points MP2 and MP4, strain gauges E2-3 and E4-7 are situated on the top of corrugation, respectively): $\varepsilon_{2\text{-}3} = 45\times10^{-6}$, $\varepsilon_{4\text{-}7} = -54\times10^{-6}$ (Figure 4). They were observed during passage of an international freight train weighing over 16500 kN with a speed of 35 km/h. Strains in other measurement points are smallest (did not exceed 20×10^{-6}). As it can be seen, the bridge sides (quarter points) are in the state of compression and tensile. This indicates uneven distribution of loads on the circumference of the shell. It may be related to different soil stiffness (various indicator densities) around the steel shell. In some cases, values of compressive strains at the top of corrugation (gauge E4-7, $\varepsilon = -29\times10^{-6}$) and the tensile strains at the bottom of the wave (gauge E4-8, $\varepsilon = 15\times10^{-6}$) are not the same. This indicates that the neutral axis is not situated in the middle of the corrugation and distribution of loads on the structure perimeter is uneven. This effect can also be observed during typical static and dynamic tests (Sezen *et al.* 2008, Beben and Manko 2010, Beben 2013). This is mainly due to the combined effect of thrust and bending as well as curvilinear shape of the bridge, and it causes shift of the neutral axis of corrugation.

3.3 Bridge and Ballast Accelerations

The European bridge design code (CEN 2002) specifies a limit of 3.5 m/s^2 for the maximal vertical deck acceleration. It is to ensure safety against ballast instability.

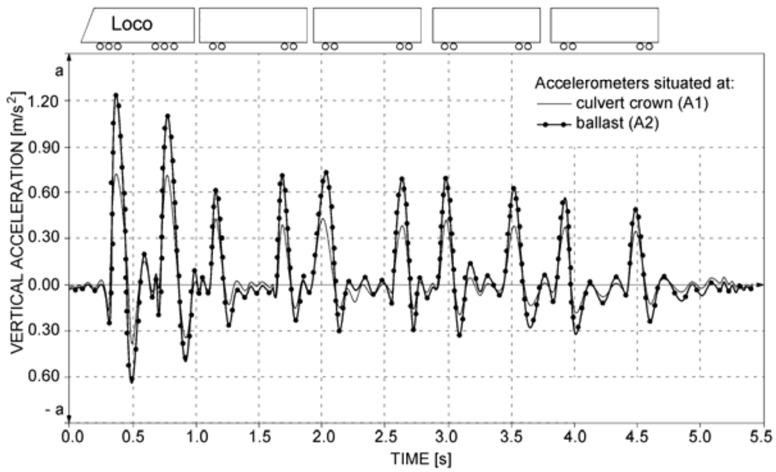

Figure 5. Vertical acceleration of the bridge crown and ballast during passing the express train with the speed of 120 km/h.

Therefore, the vertical ballast and bridge accelerations were also monitored during the test at two points. The obtained results show very low acceleration levels, much lower than the code limit of 3.5 m/s^2. The results clearly indicate that there are no ballast instability problems for this bridge.

Figure 5 shows the comparison of the maximum acceleration (A1) of the bridge crown to the maximum ballast acceleration (A2) for passing express train with the speed of 120 km/h. The maximum peak acceleration is 0.67 m/s^2 in the steel and 1.23 m/s^2 in the ballast. Other train rides caused smaller acceleration values. It can be seen that the vertical acceleration of the bridge crown is strongly lower (about 45%) than the ballast acceleration. The reduced energy level at the bridge crown may be caused by a decrease of the wave speed in the backfill and a significant soil height at the crown. The energy reduction (about 38%) was also obtained by Mellat *et al.* (2014). It should be noted that in this case, the height of the soil cover at the bridge crown amounted to 1.90 m. Thus, it follows that the increase of the soil cover depth causes the acceleration decrease.

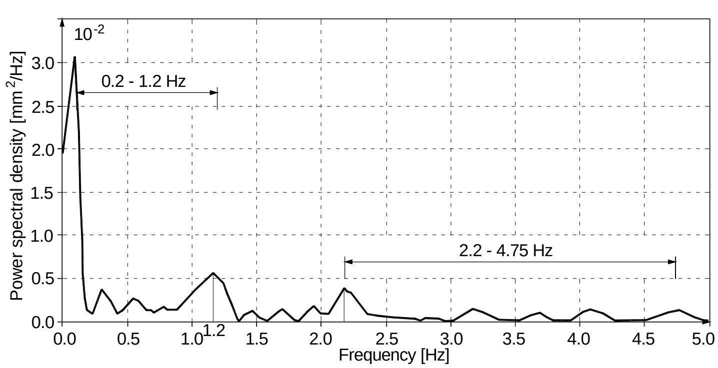

Figure 6. Power spectral density of measured displacements for the passing express train.

3.4 Bridge Frequencies

In order to extract the frequencies of the SSC bridge, all datasets were performed using the Discrete Fourier Transform (DFT) method. Figure 6 shows the DFT of the recorded displacements from which the peaks associated with the dominant frequencies of the bridge are identified. Generally, the dominant frequency of the SSC bridge is in the range of 0.2–1.2 Hz, which corresponds to an angular frequency ranging from 1.26 to 7.54 rad/s and a vibration period of 0.83 to 5 s.

4 CONCLUSIONS

Based on the practical experience gained from this study, the following general conclusions can be drawn:

1. During experimental tests under service loads, the maximum displacements did not exceed -0.61×10^{-3} m, and strains -54×10^{-6}, at loading by a train weighing almost 17000 kN and driving at 35 km/h. The impact of trains weighing less than 2000 kN on SSC bridge deformations is very low and it can be ignored. The biggest displacements and strains were recorded in the bridge crown and quarter points, respectively. The dominant frequencies of the bridge were 0.2 and 1.2 Hz, which correspond to angular frequencies of 1.26 and 7.54 rad/s and vibration periods of 0.83 and 5 s, respectively.
2. The obtained results of the ballast and bridge accelerations do not exceed the Eurocode condition i.e., 3.5 m/s^2. The bridge crown accelerations were in each case smaller than the ballast accelerations (about 45%). The results clearly show that if the train speed increases, the bridge and ballast accelerations also increase.
3. As a result of dynamic loads, greater values of strains (compressive) were mainly recorded at the top of corrugation and lower at the bottom (tensile). This is related with the combined effect of thrust and bending, and also uneven distribution of loads on the circumference of the shell (probably, the neutral axis of the shell structure is not located at the middle of corrugation).

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