Comparison of acoustic phenomena in the vicinity of two types of steel plate girder bridges

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Abstract. This paper discusses the results of own research of acoustic phenomena in the surrounding of two railway bridges of different type of decks. One of the objects has an open deck with cross girders and stringers, next has an orthotropic deck and track laid on ballast. The biggest threat for the environment is posed by objects with open deck. The extent of increase in noise reaches as much as 20 dB. Objects with ballast may also affect worsening of acoustic climate around the bridge, in particular under the bridge.

Reasons for an increase of noise when a train crosses the bridge in general split into two groups:
- vibrations coming from vehicle wheels, transmitted through rails to a bridge structure make its components vibrate; large surface of structure may act as membranes of a loudspeaker and emit unwanted sounds;
- for bridges with open platform the lack of attenuation by the deck (ballast) make the sounds at point-to-point contact of wheels with a rails freely disseminate.

1. Introduction
Railway bridges may affect the environment to much greater extent than railway lines on sections between bridges. This impact may be manifested as the excessive emission of noise which is significantly important within agglomeration areas.

The problem of railway bridges generating noise is discussed for example in [1, 2]. In Eurocode 3 [3], in a chapter relating serviceability limit states, in general provisions, states that one should limit the frequencies of own vibrations, among others to limit the fatigue damages and the excessive noise emission. In point 7.7 regarding the criteria of use of railway bridges it was written, that any requirements regarding the noise emission may be specified in design objectives. Some recommendations for noise reduction are given in [4].

2. Method of research
In order to establish an impact of bridge objects on noise, simultaneous measurements from a distance of 7.5 m from the axis of track at the bridge were conducted, and at the same distance from the track on a track section beyond the bridge (usually 50 to 75 meters before or after the bridge). In both cases, microphones were placed 1.5 m above the head of rail. At the same time, noise was measured additionally under the bridge, 1.5 m above the ground. The research used Bruel&Kjaer microphone set and Pulse Reflex software. The acoustic phenomenon was registered during the passage of passenger trains, including long-distance trains, regional trains and railbuses, as well as cargo trains. Measurements
were conducted at a temperature of 15 – 25 °C and relative humidity of 50 - 70 % and wind speed not exceeding 5 m/sec. Microphones were covered with anti-wind covers. Prior to tests, the measurements tracks were checked using the reference sound source.

In order to determine the magnitude of the noise exposure, measurements were taken at the following points (figure 1): near the track beyond the bridge (measuring point [m.p.] #1), near the bridge (m.p. #2) and under the bridge (m.p. #3).

![Figure 1. Distribution of noise measurement points](image)

The recorded signals were analysed in one-third octave bands. The analysis included a comparison of the levels of acoustic pressure and determination of the summary levels. The values represent the total sound level (noise) with the characteristic (A) taken into account. The narrow frequency band analysis included a detailed identification of the frequency composition of the generated sounds are presented in [5].

3. A plate girder bridge with open deck
First object under analysis was one-span plate girder bridge, with free supported beam and stringer-traverse grid, i.e. the so-called open platform - figure 2. The span length is 24.15 m. Rails were affixed to wooden bridge sleepers using PM-60 washers and PKW-type spacers. Wooden sleepers were supported on stringers. The object technical condition during the test was good.

![Figure 2. A plate girder bridge with an open deck: a) front view, b) bottom view.](image)

The acoustic phenomenon was registered during passages of cargo and passenger trains - selected results of measurements are presented in table 1.

The noise beside the bridge was higher by 3.3 to 10.1 dB than the noise beside the track beyond the bridge. The noise under the bridge was even higher by approx. 20 dB than the noise beside the track. In few instances the noise under the bridge exceeded 100 dB. Figure 2 shows the typical characteristics of sound pressure levels as a function of time recorded simultaneously in three points (showed in figure 1)
during the passage of the cargo and passenger trains. Comparison of acoustic pressure levels in one-
third octave frequency bands is shown in figure 4.

**Table 1.** Sound levels in the surrounding of plate girder bridge with an open deck.

| No. | Type of train                  | Speed of passage [km/h] | A sound level in [dB (A)]: |
|-----|--------------------------------|-------------------------|----------------------------|
|     |                                |                         | beside the track (1)       |
|     |                                |                         | beside the bridge (2)      |
|     |                                |                         | under the bridge (3)       |
| 1   | passenger train (traction unit)| 50                      | 80.3                       |
|     |                                |                         | 83.8                       |
|     |                                |                         | 96.2                       |
| 2   | passenger train (long-distance)| 60                      | 83.8                       |
|     |                                |                         | 87.4                       |
|     |                                |                         | 99.9                       |
| 3   | passenger train (light suburban)| 50                      | 74.8                       |
|     |                                |                         | 78.1                       |
|     |                                |                         | 90.5                       |
| 4   | passenger train (long-distance)| 70                      | 84.7                       |
|     |                                |                         | 89.2                       |
|     |                                |                         | 102.0                      |
| 5   | passenger train (long-distance)| 50                      | 77.3                       |
|     |                                |                         | 87.4                       |
|     |                                |                         | 100.5                      |
| 6   | cargo train                    | 50                      | 84.3                       |
|     |                                |                         | 88.9                       |
|     |                                |                         | 100.7                      |
| 7   | cargo train                    | 40                      | 79.6                       |
|     |                                |                         | 88.6                       |
|     |                                |                         | 101.3                      |

**Figure 3.** Sound levels as a function of time in the vicinity of a bridge with an open deck during passage: a) cargo train – 50 km/h, b) passenger train – 60 km/h.

**Figure 4.** Level of acoustic pressure versus one-third octave frequency bands in the vicinity of a bridge with an open deck during passage: a) cargo train – 50 km/h, b) passenger train – 60 km/h.
The main reason of such big noise was the type of structure - the open platform is not a barrier for sounds generated at point-to-point contact of wheels with a rails. In addition, vibrations of large surface plate girder’s web emit sounds within the range of low and medium frequencies - this question was discussed in details in [5].

The increase in the sound pressure level is observed throughout the entire frequency range – figure 4. The highest acoustic pressure level was observed in low frequencies (around 31.5 Hz) and between 200 and 2000 Hz.

4. A plate girder bridge with a track laid on ballast

The example of currently designed objects is a plate girder bridge with steel orthotropic platform and a track laid on ballast (figure 5). The length of span of the bridge is 31.68 m, height of girders 2.47 m. The ballast was laid in a deck made of ribbed metal plate. The thickness of the ballast layer under the concrete sleepers was at least 0.35 m. There was no vibroisolation under the ballast.

The bridge was in a very good technical condition and was opened to public just few months before the test.

![Figure 5. A plate girder bridge with a steel orthotropic deck and a track laid on ballast: a) front view, b) bottom view.](image)

The table 2 presents the results of measurements of sound level made during the passage of passenger and cargo trains. Figure 6 shows sound pressure levels as a function of time recorded simultaneously during the passage of the two trains.

| No. | Type of train          | Speed of passage [km/h] | A sound level in [dB (A)] beside the track (1) | beside the bridge (2) | under the bridge (3) |
|-----|------------------------|-------------------------|-----------------------------------------------|-----------------------|----------------------|
| 1   | passenger train (regional) | 80                      | 76.9                                         | 75.9                  | 84.7                 |
| 2   | passenger train (regional) | 60                      | 80.8                                         | 76.7                  | 85.6                 |
| 3   | passenger train (suburban) | 80                      | 76.8                                         | 75.5                  | 80.8                 |
| 4   | cargo train             | 35                      | 74.1                                         | 73.0                  | 79.8                 |
| 5   | cargo train             | 50                      | 81.7                                         | 81.3                  | 87.4                 |
| 6   | cargo train             | 40                      | 73.6                                         | 74.3                  | 80.9                 |

The noise beside the bridge does not differ significantly from the noise beside the track beyond the bridge. In most instances it is even smaller, which results from the fact that sounds generated at point-to-point contact of wheels with a rails are damped by plate girders. The noise under the bridge was higher from 4 to 7.8 dB than the noise beside the track. Since the object analysed was low over the ground, sounds were damped by the ground and did not disseminate. However, it must be noted that this
type of structure used on populated areas e.g. in fly-over on high supports may be inconvenient for the environment. Exemplary comparison of acoustic pressure levels in one-third octave frequency bands is shown in figure 7.

![Figure 6](image6.png) ![Figure 7](image7.png)

**Figure 6.** Sound levels as a function of time in the vicinity of a plate girder bridge with track laid on ballast during passage: a) cargo train – 50 km/h, b) passenger train – 60 km/h.

**Figure 7.** Level of acoustic pressure versus one-third octave frequency bands in the vicinity of a bridge with track laid on ballast during passage: a) cargo train – 50 km/h, b) passenger train – 60km/h.

The increase in the acoustic pressure level under the bridge was observed in frequencies range up to approx. 800 Hz. The main reason of noise increase was excessive vibrations of steel plate of the deck. Above 800 Hz the acoustic pressure under the bridge was lower than the acoustic pressure beside the track – sounds in this range were dumped mainly by ballast.

The acoustic pressure beside the bridge was lower than the acoustic pressure beside the track up to approx. 315 Hz. In this case, plate girder beams were a type of acoustic screens.

5. **Conclusion**

Steel bridges may pose a threat to environment. They may contribute to the dissemination of noise generated at point-to-point contact of wheels with a rail or independently emit the unwanted sounds.
Objects with open deck belong to type of structures in which noise is mainly due to free dissemination of sounds generated at contact of wheels with rails and as a result of vibrations of large-surface elements. These types of bridges and viaducts should not be used on urbanized areas. If they are present there, they should be replaced if possible with others, with better acoustic properties. The partial reduction of noise be obtained by separating the track from the bridge structure using vibroisolation and application of horizontal sound barriers.

If one wishes to design the silent bridges, a track should be laid on ballast, but this type of structures may also emit noise. If the frequency of excitation of vibrations matches the frequency of own vibrations of large-surface elements of structures, then the emission of air sounds may occur. Since these sounds will appear most often under the structure, objects with a track laid on ballast may present an inconvenience if they are situated high above the ground on urbanized areas. Acoustic properties may be improved by using vibroisolation pads or matts.

The analysis of railway bridges for the emission of noise should be the important element in the process of preparation of investment projects. This recommendation applies not only to newly constructed objects but also to reconstructed and modernised bridges and viaducts.

References
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