Lucjan Janas
dr inż.
Politechnika Rzeszowska
Wydział Budownictwa, Inżynierii Środowiska i Architektury
ljanas@prz.edu.pl

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The acoustic specificity of steel-railway bridges

Abstract: In the paper, the acoustic effects in the vicinity of four railway bridges have been studied. One of the objects has a track fastened directly to the steel deck plate, another has a deck in the form of an open grillage. The other two objects have a track situated on the ballast and various types of girders. The influence of the bridge on the level of acoustic pressure in the neighborhood of railway roads has been analyzed. General recommendations for the design of silent bridges were discussed.

Keywords: Noise; Steel bridges; Railway

Introduction

Rail vehicles passing over bridges, viaducts or flyovers may have an impact on the environment to a much greater extent than vehicles passing along a track without such facilities. Engineering objects can contribute to the increase of noise level and the degree of increase depends mainly on the type of construction.

The threat to the environment may be steel objects built several or dozens of years ago, but also modern ones, designed in recent years [6, 8, 10]. Bridges made of prestressed concrete or composite steel and concrete generally cause much less acoustic problems, but such problems cannot be excluded [5, 7]. Bridge noise problem also occurs on high-speed lines [8].

Eurokod 3 draws attention to the noise problem of railway bridges [9]. In this standard, in the chapter on serviceability limit states, the general provisions stipulate that the natural frequency of construction should be limited, among others to reduce fatigue damage and excessive noise emission. In point 7.7 concerning the criteria for the use of railway bridges, it was stipulated that all noise emission requirements can be given in the design arrangements.

The noise problem of railway bridges has also been addressed in the document of the UIC International Railway Union, *Recommendations for the design of bridges to satisfy track requirements and reduce noise emissions* [11] which provides general recommendations for the design of structures that are characterized by low noise emission..

This article discusses the results of own research in the vicinity of four steel railway bridges with different types of girder and bridge structures. One of the objects has a track attached directly to the steel plate of the platform, the other has a bridge in the form of an open grate. The other two objects have a track laid on the ballast and various types of girder structures.

A research method

In order to determine the impact of bridges on noise, simultaneous measurements were made at a distance of 7.5 m from the center of the track on the bridge and at the same distance from the track on the section of the line off the bridge (usually 50 to 75 m before or after the bridge). In both cases, the microphones were 1.5 m above the level of the railhead. Additionally, at the same time noise was measured under the bridge, 1.5 m above ground level.

The article compares sound levels A, i.e. sound pressure levels corrected according to the frequency response according to the correction curve A:

$$L_A = 10\log\frac{p_A^2}{p_0^2}$$

where: p_A – effective value of sound pressure [Pa]
p_0 – reference threshold pressure, equal $2\cdot10^{-5}$ [Pa]

A set of microphones from Bruel & Kjaer and Pulse Reflex software were used for the tests. The acoustic phenomena were recorded during the passage of passenger trains, including long-distance trains, regional and rail buses and freight trains. Measurements were carried out at a temperature of 15 - 25 ° C, 50 - 70% air humidity and wind speed not exceeding 5 m / s. There were windscreens on the microphones. Prior to the tests, the measurement tracks were checked with the reference sound source.

Bridge construction type and sound level

A viaduct with a platform in the form of a steel plate without bedding

One of the analyzed objects was a 4-span steel viaduct with a length of 84.4 m and a static scheme of a continuous beam (Fig. **1**). The main girders of the viaduct are two plate girders with a web height of 1.38 m in a spacing of 4.4 m. The platform of the viaduct is made of steel sheet reinforced with crossbars and stringers. The rails were fixed directly to the steel structure. Outside the girders, business pavements, also made of steel sheets, have been designed. The object was located in a horizontal curve with a small radius of 250 m. The track on the object and beyond was non-contact. Inspection of the object showed its unsatisfactory condition. The main problem was the lack of vibroinsulation between the rails and the bridge (it was completely damaged) and incorrect curvature of the track. Next to the viaduct, at a distance of about 25 m, there was a multi-family residential building, whose residents complained about excessive noise.

1. Overhead gantry with steel platform without ballast

The object was intended only for the movement of freight trains and undesirable sounds were created despite the small, permissible speed of driving, i.e. 30 km / h. Sound levels recorded during three trips are shown in tab. **1**.

Tab. 1. Sound level measurement results in the vicinity of a viaduct with steel platform without ballast

Ordinal number	Type of train	Speed [km/h]	Sound level A in [dB]:			Difference in sound levels in [dB]	
			next to the track (1)	next to the viaduct (2)	under the viaduct (3)	(2) – (1)	(3) – (1)
1	freight	30	69.1	84.7	85.7	15.6	16.6
2	freight	20	72.7	88.4	88.9	15.7	16.2
3	freight	20	65.5	82.2	83.6	16.7	18.1

The noise near the flyover reached almost 89 dB (A) and was more than 15 dB higher than the noise next to the track outside the viaduct. The noise under the viaduct was even bigger by about 18 dB than the noise next to the track.

The reason for the large increase in noise next to the viaduct was excessive vibrations of the structural sheets (bridge plates, pavements, girders) causing the emission of sounds mainly in the range of low frequencies - this issue was discussed in detail in [3]. The sounds generated at the interface between the wheels and the rails and the loud operation of the rail joints resulting from the arc motion of a small radius have a large influence on the noise level next to the track.

A plate bridge with an open platform

Another analyzed object is a single-span plate bridge, supported by a crossbeam, with a transversal-string grate, i.e. open platform (Figure 2). The span length is 24.15 m. The rails have been fixed to wooden bridges by PM-60 washers and PKW under-rail spacers. The bridge was based on the Longitudinal stiffeners. The object was in good technical condition during the tests.

2. Overhead bridge viaduct with an open platform - longitudinal stiffeners-crosswise grate

Acoustic phenomena were recorded during passenger and freight train journeys - selected results of measurements were placed in tab. **2**.

Tab. 2. Sound level measurement results in the vicinity of a plate bridge with an open platform

Ordinal number	Type of train	Speed [km/h]	Sound level A in [dB]			Difference in sound levels in [dB]	
			next to the track (1)	next to the bridge (2)	under the bridge (3)	(2) – (1)	(3) – (1)
1	passenger - traction unit	50	80,3	83,8	96,2	3.5	15.9
2	passenger - long-distance	60	83,8	87,4	99,9	3.6	16.1
3	passenger - railbus	50	74,8	78,1	90,5	3.3	15.7
4	passenger - long-distance	70	84,7	89,2	102,0	4.5	17.3
5	passenger - long-distance	50	77,3	87,4	100,5	10.1	23.2
6	freight	50	84,3	88,9	100,7	4.6	16.4
7	freight	40	79,6	88,6	101,3	9.0	21.7

The noise near the bridge was 3.3 to 10.1 dB higher than the noise next to the track off the bridge. The noise under the bridge was even bigger by more than 20 dB from the noise next to the track. In a few cases, noise under the bridge exceeded 100 dB. The main reason for such a large noise is the type of construction. An open platform is not a barrier to sounds generated at the interface between wheels and rails. In addition, the vibration of the girders' web beams emits sounds in the low and medium frequency range. These issues are discussed in detail in the paper [1].

Due to the modernization works carried out during the tests on the railway line within which the facility was located, it was not possible to register an acoustic emission during the journeys at speeds greater than 70 km / h. It should be expected that such structures, at higher speeds, will have an even greater negative impact on the environment.

A steel plate bridge with a track arranged on a ballast

An example of a project that is often currently designed is a steel plate bridge with a steel orthotropic bridge and a track laid on a ballast (fig. **3**). The span of the tested bridge is 31.68 m, the height of girders 2.47 m. The ballast was placed in a ballast chute made of ribbed sheet metal. The facility was in very good condition, it was put into operation a few months before the tests.

3. A steel plate bridge with a track arranged on a ballast

In tab. **3**, the results of sound level measurements made during the passage of passenger and freight trains are listed. The noise next to the bridge does not differ much from the noise of both tracks off the bridge. In most cases, it is even slightly smaller, which results from the damping of sounds generated at the interface between wheels and rails through girders.

Tab. 3. Sound level measurement results in the vicinity of the steel plate bridge with the track laid on the ballast

Ordinal numer	Type of train	Speed [km/h]	Sound level A in [dB]			Difference in sound levels in [dB]	
			next to the track (1)	next to the bridge (2)	under the bridge (3)	(2) – (1)	(3) – (1)
1	passenger - regional	80	76,9	75,9	84,7	-1.0	7.8
2	passenger - long-distance	60	80.8	76,7	85,6	-4.1	4.8
3	passenger - railbus	80	76,8	75,5	80,8	-1.3	4.0
4	freight	35	74,1	73,0	79,8	-1.1	5.7
5	freight	50	81,7	81,3	87,4	-0.4	5.7
6	freight	40	73,6	74,3	80,9	0.7	7.3

The noise under the bridge was bigger by 4 to 7.8 dB than the noise next to the track - the reason for the increased noise under the bridge was an excessive vibration of the steel platform slab. Because the analyzed object was located relatively low above the ground, the sounds were suppressed by the ground and did not spread. However, it should be noted that this type of construction used in an urbanized area, eg in a flyover on high sub-floors, can be troublesome for the environment.

Truss bridge with a track laid on a ballast

The last of the analyzed objects is a W-type truss bridge with a span of 49 m, with a bridge in the form of an orthotropic plate reinforced with cross-bars and a track laid on the ballast (Figure **4**). The trusses have box section elements and have been braced with wind tunnels. During the tests, the facility was in good technical condition.

4. Truss bridge with a track laid on a ballast

The sound level measurement results are summarized in tab. **4**.

Tab. 4. Results of sound level measurements in the vicinity of a truss bridge with a track laid on a ballast

Ordinal number	Type of train	Speed [km/h]	Sound level A in [dB]			Difference in sound levels in [dB]	
			next to the track (1)	next to the bridge (2)	under the bridge (3)	(2) – (1)	(3) – (1)
1	passenger - reginal	60	78.0	77.8	82.3	-0.2	4.3
2	passenger – long-distance	45	80.8	81.2	84.3	0.4	3.5
3	passenger - railbus	60	73.4	73.7	81.0	0.3	7.6
4	freight	30	79.1	82.2	89.1	3.1	10
5	freight	30	78,2	79,0	84,1	0.8	5.9
6	freight	40	78.1	81.1	87.4	3.0	9.3

The noise level next to the bridge is not much different from the noise next to the track off the bridge - the maximum recorded increase in sound level is 3 dB. Under the object, the noise was 3.5 to 10 dB higher than noise next to the track. The increase occurred mainly in the low-frequency range (up to 500 Hz) and was caused by vibration of the steel platform plate [2]. As in the case of sheet metal bridges with ballast, truss structures may pose a threat to the environment when located high above the site, in urbanized areas. In this type of constructions, the use of appropriate vibroinsulation is of great importance [4].

Summary and conclusions

Steel bridges made many years ago and those designed and built at present can pose a threat to the environment. They can facilitate the spread of noise generated at the interface of wheels and rails or emit undesirable sounds by themselves.

If you want to design quiet bridges, first of all, you should use the track on the ballast, but it is worth remembering that even such constructions can emit noise. If the frequency of excitation of vibration coincides with the natural frequency of large-surface elements of the bridge structure, unwanted emission of air sounds may occur. Because these sounds usually appear under the structure, objects with a track laid on a ballast can be a nuisance, if they are located high above the terrain, in urbanized areas. The improvement of acoustic properties can be obtained by using washers or vibration isolating mats.

Objects with open bridges belong to structures around which noise appears mainly as a result of the free spread of sounds generated at the interface between wheels and rails and as a result of vibrations of large-surface elements, eg webs of girders. Such objects should not be used in urbanized areas. If they occur, they should be replaced as far as possible with others with better acoustic parameters. Partial noise reduction around this type of bridges can be obtained by isolating the track from the supporting structure with vibration isolation and using horizontal screens absorbing sounds.

If it is necessary to use a track directly attached to the platform, the noise emission can be reduced by properly designed vibroinsulation. It is also possible to consider the introduction of additional stiffeners to change the natural frequencies of the large surface elements. In some cases, it is worth analyzing the possibility of increasing the weight of the platform or covering the elements emitting noise with a layer of material, providing additional damping.

Analysis of railway bridges in terms of noise emissions should be part of the investment preparation and design process. The recommendation applies not only to newly built facilities, but also to rebuilt and modernized facilities. Noise emission requirements should be determined by the investor. If such requirements are not defined by the investor, increasing the number and speed of travel, rebuilding or modernization of the railway line will not improve the acoustic climate but may even increase its environmental impact.

Source materials

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