Measurement and analysis of railway noise and vibration

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The acoustic environment, as well as the length and speed of the train, determine noise and vibration levels. The average intensity of the noise (assessing by SEL) varies from 83.9 to 104.1 dB/A: the highest intensity accompanies the passing of express (average 95.32 dB/A); the lowest intensity is measured during the passing of EMU (average 89.24 dB/A). Vibrations of the highest intensity are measured during the passing through free fields (0.750 $mm.sec^{-1}$). Regardless of the bridge type, the level of vibrations varies between 0.032 - 0.067 $mm.sec^{-1}$.

Key words: railway transport, noise, vibration, and environmental impact.

Railway transport has been used in Bulgaria for more than a hundred years. At present, the country is an important transportation zone between the East and the West and we are interested in the utilization and prospects of various means of transportation. Motor transport leads to increases of traffic noise (Beraha and Maximov, 1980) and environmental pollution. This is a serious problem, considering the country's small area and the intensive agricultural activity in its territory.

Railway transport can be used for the transportation of a significant number of goods. In these new conditions of freight traffic the main problem arises on the basis of the expected general levels of noise and vibration impact.

The purpose of the present investigation is to measure and record the actual noise and ground surface vibration generated by different sorts of trains under various operating conditions: passby through residential areas, free fields (rural land areas) in the countryside and over different bridge constructions.

Materials and methods

The noise-vibrations measurements have been taken 24 hours per day under normal conditions of motion and operation of the trains: express, fast trains, passenger trains, freight trains, and electric multiple units (EMUs); all relatively slow (top speed of express up to 100 km/h) in comparison with modern high speed trains, at a 12 km section with special attention to maximum and SEL values.

The section was chosen for two reasons:

1. This section accommodates two very busy railway routes, the first, Sofia – Plovdiv and the second Sofia – Karlovo, railroads, which have enabled us to collect sufficient data over the course of 72 hours.
2. This section is relatively short (12 km) and it presents the four different conditions determining the choice of the stations: # 1- residential areas, # 2- free fields in the countryside, # 3 – steel bridge and # 4 – concrete bridge.

In order not to change the usual speed of the trains, the serving train personnel were not warned ahead of time. This explains the spontaneous reaction of the machine-operators (hooters/horns) at the sight of the researchers (see figure 1 b).

The surrounding environment allowed free spreading of the noise and vibration. The measurement was made in still weather.

The points of the noise and vibration measurements were situated at a distance of 25 m perpendicular to the railway centerline. The measurement distance was 100 m but the passing time was different because of the different number of wagons and different speed of the trains.

The noise and vibration were measured using portable equipment: 1. For noise: Modular Precision Sound

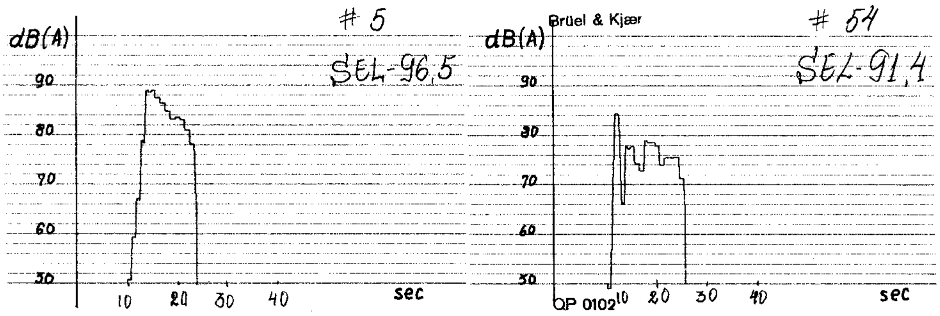

Figure 1. Noise profiles: (a)# 5-Express – passing through residential area; (b)# 54 Fast train – passing through countryside area – start horns

Level Meter Type 2231 with a Condensing Microphone Type 4149 and a Recording Device Type 2306. 2. For vibration: Accelerometer Type 4370, Vibration Meter Type 2511 and Recording Device Type 2317, all made by Brüel & Kjaer.

All the requirements of the current regulations and standards of the Ministry of Health and ISO have been taken into consideration in the examination of the noise and vibration. (BSS: # 12.1.012-80; # 14478-82; # 16798-88; ISO 2631).

The exact hour of passing of the composition, as well as the time for passing through the particular 100 m section, were registered in each measurement. The following indicators have been used for the analysis and

Table 1. Railway noise levels dB (A) 25 m from track centerline

Fixed location /Type of train	Number of passing trains	Average passing time(sec)	Average SEL (dB(A))	Min.SEL (dB(A))	Max.SEL (dB(A))	Lmax (dB(A))
Residential area						
Express	7	12.6	96.2	92.7	98.2	96.5
Fast train	14	13.8	95.0	93.6	96.1	90.0
Passenger train	3	18.5	90.6	87.0*	95.1 *	83.0
EMU	10	15.5	87.6	83.6	93.4	81.0
Freight train	7	26.2	95.0	87.8	97.7	87.0
Countryside						
Express	8	13.5	93.8	85.5	95.0	91.5
Fast train	8	13.7	92.9	90.4	95.6	88.0
Passenger train	3	12.0	95.8	94.4	96.7	88.0
EMU	8	9.6	83.9	68.1	95.0	83.0
Freight train	5	26.6	94.1	90.2	97.4	87.0
Steel bridge						
Express	4	15.1	104.1	98.5	115.0	95.0
Fast train	8	16.8	98.7	97.4	103.9	96.5
Passenger train	3	19.5	101.2	99.8	102.5	94.5
EMU	7	10.6	96.5	95.1	98.9	93.0
Freight train	8	47.1	100.1	97.9	106.7	96.0
Concrete bridge						
Express	4	16.0	87.9	86.6*	89.3	77.0
Fast train	6	18.7	86.5	84.2	88.4	79.0
Passenger train	4	15.9	87.4	86.5 *	89.1	79.0
EMU	5	12.9	84.7	82.3	86.7	77.0
Freight train	4	33.0	85.6	85.3	92.0	76.0

* - Hooters/horns

Actual day-time L_{Aeq}: 55.7 dB/A - residential area; 50.4 dB/A - country side; 52.6 dB/A-bridges;

Actual night-time L_{Aeq} - 44.5 dB/A - residential area; 40.3 dB/A - country side; 42.6 dB/A - bridges.

evaluation of the noise and vibrations: peak particle velocity (PPV) in mm.s^{-1}; maximum level of noise (L_{max}) in dB (A); equivalent levels during day time and night time (L_{Aeq}) in dB (A); SEL (single event level) in dB (A)- the noise, continuous for one second, giving the same energy as a specific noise event over its whole period.

All the results from the measurement of the noise and vibration have been statistically systematized using SPSS statistical programs.

Results and discussion

The summarized results of all taken measurements (241 altogether: 127 noise profiles and 114 vibration profiles) are presented in tables 1 and 2. The time of passing through the 100 m section is different for each rolling stock, depending on the type of the trains, their length and speed. The choice of the stations has allowed the measuring and evaluating of the noise and vibrations during the various regimes of operation: varying speeds of the trains in and outside residential areas and on bridges; different terrain and varying acoustic environment (building area, free field in countryside, steel and concrete bridges), over 24 hours.

As already mentioned, the method of measuring has been unified to the highest degree, according to the requirements of the national standards and ISO with special attention to Lmax and SEL. The longer-term noise level, such as L_{Aeq}, has been calculated for a residential area according to well-known dependence (Carpenter, 1994; EHC 12, 1980):

$$L_{Aeq} = \frac{10 \log \sum (10^{SEL/10} \times \text{number of trains})}{(\text{total period (seconds)}) \text{ dB (A)}}$$

Table 2. Railway vibration levels (PPV-mm.sec^{-1}) 25 m from track centerline

Fixed location /Type of train	Number of passing trains	Average passing time(sec)	Average level of PPV (mm.sec-1)	Min. PPV (mm.sec-1)	Max. PPV (mm.sec-1)
Residential area					
Express	3	12.6	0.152	0.140	0.175
Fast train	5	13.8	0.128	0.115	0.140
Passenger train	3	18.5	0.130	0.100	0.155
EMU	5	17.3	0.107	0.090	0.140
Freight train	6	23.4	0.142	0.130	0.160
Countryside					
Express	8	13.6	0.403	0.280	0.750
Fast train	7	12.8	0.387	0.280	0.690
Passenger train	3	13.6	0.500	0.500	0.500
EMU	7	9.5	0.304	0.280	0.400
Freight train	6	25.0	0.385	0.210	0.550
Steel bridge					
Express		15.1	0.056	0.045	0.064
Fast train	7	16.8	0.052	0.032	0.080
Passenger train	3	19.3	0.041	0.035	0.045
EMU	9	13.1	0.038	0.025	0.050
Freight train	6	52.1	0.032	0.016	0.055
Concrete bridge					
Express	5	19.4	0.067	0.048	0.100
Fast train	5	21.2	0.055	0.035	0.090
Passenger train	5	20.4	0.042	0.033	0.055
EMU	9	16.7	0.043	0.025	0.055
Freight train	6	46.2	0.045	0.025	0.062

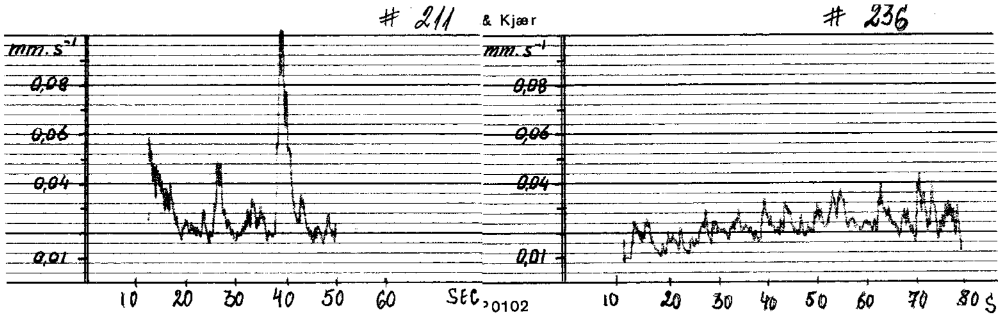

Figure 2. Vibration profiles: (a)# 211 – Freight train – passing through steel bridge; (b)# 236 – Freight train – passing through concrete bridge.

The summarized data (Table 1, 2) and noise and vibration profiles (figures 1, 2) show that the measurements have been taken during the passing of different number of a rolling stocks (consisting of different number of units and at different speed). This does not allow for a comparison of the time or any other indicators, except for the ones mentioned already.

Table 3 shows the processed statistical data for the noise, generated by the different types of trains. As it can be seen from table 2, there is a statistically significant difference ($p< 0.05$; confirmed by a non-parametrical analysis) between the level of noise of EMUs and all other trains. The difference in the average values of SEL for all the remaining trains is insignificant. In accordance with the well-known data from other publications, the results show that the level of the noise depends on the length of the train (Bender et al., 1974; Spenser, 1974). Usually the EMUs are short (including 2 – 4 wagons), relatively slow and much quieter (Carpenter, 1994). The lack of statistically significant difference among the different types of trains (with the exception of EMUs) allows the observations to be grouped in paragraphs, according to the difference in the acoustic environment (table. 4).

Table 3. Average noise levels according to type of train

Type of train	Noise level (SEL dB(A)) X–SD	P
Express	95.32 ± 6.28	
Fasttrain	93.92 ± 5.29	
Passengertrain	93.27 ± 5.85	
EMU	89.24 + 5.14	p<0.05
Freight train	93.36 ± 5.13	

Table 4. Average noise levels according to fixed location of measurement

Fixed location	Noise level (SEL dB(A)) X–SD	p
Residential area "Slatina"	93.09 ± 4.40	
Free field (Countryside area)	93.42 ± 6.34	
Steelbridge	97.63 ± 4.84	p<0.05
Concretebridge	86.76 ± 2.09	p<0.05

It is evident from table 4 that the most intensive noise accompanies the passing of the trains across bridges with metal constructions. The speed of the passing trains, which is of greatest importance according to other authors (Carpenter, 1994) in residential areas and free fields, is probably equal. Moreover the speed of the trains (according to the passing time by the bridges-the measuring station 3 and 4) is slower and also equal, but the acoustic environment is very different. Aside from vibration absorbing effects, a concrete bridge has also noise absorbing effects. The side walls of concrete bridges, although not very tall, produce a screening effect, sufficient for a statistical decrease in the noise levels.

The calculated level of noise in a residential area (L_{Aeq} = 99.22 dB (A)) exceeds the hygienic noise limits in the national standard (BSS # 16798-88) and thus shows an acoustic environment negatively changed in proximity to the railway lines.

As mentioned above, this is only the first step in the investigation of railway noise and vibration in Bulgaria. Maybe this data is not sufficient for predictions of the noise impact of future traffic, but at this moment it is necessary to think about the measurements needed to achieve noise reduction.

The measured vibrations are of low intensity. The peak particle velocity of measured vibration in residential areas is far below 0.3-2.0 mm.sec^{-1} (table 2), pointed out as acceptability criteria by other authors (Carpenter, 1994).

Vibrations of the highest intensity are measured during the passing of express and fast trains in rural land areas: 0.750 mm.sec-1 and 0.690 mm.sec^{-1} (table 2). It is possible that the different kinds of ground, its composition and structure influence the intensity and spreading of vibration the most. The bridge structures are secured by means of vibration consuming devices that lower the whole line of vibrations produced by the movement of the trains over the bridge.

Conclusion

Noise and ground surface vibrations arise when railway transport is used. The average intensity of the noise (assessing by SEL) varies from 83.9 to 104.1 dB/A. Noise of the highest intensity accompanies the passing of express trains (up to 104.1 dB/A, average 95.32 dB/A). Noise of the lowest intensity is measured during the passing of electric multiple units trains (average 89.24 dB/A) which have 2 to 4 wagons on average. The acoustic environment, as well as the length and speed of train, determine the noise levels. The highest noise is measured during the passing over steel bridges (97.63 dB/A). The lowest noise is measured during the passing over concrete bridges (86.76 dB/A). Supposedly, the construction of concrete bridges absorbs the noise.

The calculated noise level (L_{Aeq}) exceeds the hygienic noise limit in the national standards and shows an acoustic environment changed in proximity to the railway lines in residential areas.

Mostly the type and the structure of the ground determine the intensity of the infrasound and the ground surface vibration. Vibrations of the highest intensity are measured during the passing through free fields (0.750 mm.sec^{-1}). In residential areas, the measured vibrations are around 0.130 mm.sec^{-1}. The constructions of the bridges absorb the vibrations. Regardless of the bridge type, the level of vibrations is lowered 5-10 times in comparison to the recommended value (0.3 mm.sec^{-1}) and varies between 0.032 – 0.067 mm.sec^{-1}.

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Roads and annoyance

Thousands of people are trapped in run-down areas afflicted by city roads that are motorways "in all but name", a study by the UK Noise Association says. The association, whose researchers tested the noise and annoyance levels of dozens of roads, found that the North Circular Road in London was the most infuriating in Britain. Researchers said living near the road, which runs through north London for more than 15 miles, was akin to "being assaulted by a torrent of noise". "It is a motorway that roars through residential areas. Thousands of people live within yards of the North Circular but many of them have no protection form the unremitting noise," the survey found. In second place was Parkfield Road/Lewisham Way in south-east London, which has to cope with traffic heading into the centre of London. Residents complained of a 24-hour drone that was loudest at 5.30am when heavy lorries started heading into the city. In joint third place were the A4 in west London and the A102 northern approach to the Blackwall Tunnel in east London. The association said these roads had the characteristics of motorways but none of the protection. One person living near the A4 said people could only cope with the noise by using a "cocktail of sleeping pills".

noise notes