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INFLUENCE OF LOW NOISE BARRIER HEIGHT ON SOUND INSERTION LOSS

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Abstract. Ensuring the best possible quality of the living environment is the worldwide aim. One of the very important factors strongly affecting people's health is the traffic produced noise, the reduction of which to permissible values can significantly improve the well-being of those living and working near traffic areas. On railway lines where rolling stock does not exceed 250 km/h, low noise barriers may be used. The aim of the study is to determine which low noise barriers are the most effective in Lithuanian conditions. This article analyses the insertion loss of low noise barriers of different heights installed at different distances. The obtained results show that the highest loss insertion in all 45 m long low sound barriers at a distance of 45 m from the track axis was found for the 1.2 m high straight sound barrier located 2.6 m from the track axis and the 1.3 m high and inverted L-shaped (bracket length – 0.65 m) noise barriers located at a distance of 3.1 m from the track axis. Their insertion loss is 2.9–4.6 dBa, depending on the running speed (slightly) and the level of the microphone.

Keywords: traffic noise, railway, low noise barrier, insertion loss.

Introduction

The environment and its protection from the negative effects caused by human activities are increaingly gaining a global importance, which is why travel and freight transportation by rail are encouraged. This mode of transport takes up less land, emits less CO_2, causes less congestion, etc. than other types of transport. However, railways also pollute the environment. The most obvious negative impact is caused by noise emitted by rail transport, especially freight trains (Oertli & Hubner, 2010; Wiebe et al., 2011). The main identified health disorders caused by noise are nervousness, sleep and hearing disorders. The longer residents live next to traffic that emits high levels of noise, the greater the health problems that can occur (Louen et al., 2014).

Licitra et al. (2016) found that people are most irritated by whistling and screeching sounds. The greater negative impact is experienced at night, when train traffic is heavier, i.e., at 20 trains/night, 1.2 wake-ups were established, at 100 trains/night – 5.7 wake-ups (Möhler et al., 2018).

The number of severe cases of sleep disturbances due to exposure to railway noise increases with inreasing night-time equivalent sound pressure level, peak sound pressure level and increasing intensity of trains (Schreckenberg et al., 2018). Railway noise can lead to hypertension – noise ≥60 dB was found to be 8% more likely to lead to hypertension than noise <60 dB (Sørensen et al., 2011). Another study found that a 10 dB increase in the level of rail transport noise increases the number of hypertension diagnoses by 5.4% (Zeeb et al., 2017). However, no association was observed between diabetes and exposure to noise emitted by rail transport in residential areas (although this association was observed with exposure to noise emitted by motor transport) (Roswall et al., 2018).

The costs incurred due to noise exposure, mainly divided into annoyance costs and health care costs, are 1 euro per 1000 tkm for a conventional railway (Siciliano et al., 2016). Moreover, it was found that the costs depend on the noise level (Andersson et al., 2013). Noise limits the ability to hear announcements, especially if the listener has a hearing impairment (Le Prell & Clavier, 2017).

In order to reduce the noise emitted and its negative impact on the environment, various noise abatment measures are available for implementation along the railways, which can be applied in the rolling stock (for example, wheel dampers, hoods), in the track structure and bed (for example, rail dampers, continuous welded rails, rail grinding), in the sound path (for example, noise barriers, vegetation) and in adjacent buildings (for example, soundproof windows, insulation of the building façade).

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In Lithuania, one of the most widely used measures is a high noise barrier, which suppresses noise very effectively, but also has negative aspects. Difficulties arise due to traffic safety (restricted visibility, more complicated evacuation works), higher installation and maintenance costs, etc. (Oertli & Scossa-Romano, 2012). Therefore, low noise barriers installed right next to the railway tracks are also used worldwide, which quite effectively suppress the noise emitted by the wheel-rail interaction (Fitzgerald, 1996; Jolibois, 2013, 2014; Čižkova & Štulikova, 2014; Nilsson et al., 2014; Čižkova, 2016; Vogiatzis & Vanhonacker, 2016; Zheng et al., 2017; Nieuwenhuizen & Yntema, 2018).

In Lithuania, the biggest problem related to the noise emitted by railway roads arises on the straight line sections (where the speed of trains reaches up to 160 km/h), passing through residential areas, especially at crossings, where it is not possible to apply high noise barriers because they limit visibility. The main source of noise in these sections is the rolling noise caused by the wheel-rail interaction, which is predominant among other types of noise caused by the railway track at rolling stock speeds from 50 km/h to 240–250 km/h (Hemsworth, 2008; Guiral et al., 2018). The lower height noise barriers would be an appropriate measure to be used in Lithuania, but a rather large clearance gauge, i.e., distance from railway track structures, is applied in Lithuania. If a low noise barrier is installed at a too long distance, its effectiveness will be low, the noise generated by the wheel-rail interaction will spread over its top. The aim of the study is to determine which low noise barriers are the most effective in Lithuanian conditions.

In Lithuania, according to the requirements of legal acts Guidelines for the Application of Structure Gauge 163/K (Lietuvos geležinkeliai, 2001), distances to railway tracks are limited. The main requirements are transposed to Commission Regulation No 1299/2014 (European Union, 2014) Appendix H, which regulates the structure gauge of engineering structures of the 1.520 mm track gauge system.

According to Commission Regulation No 1299/2014 (European Union, 2014), in railway sections on straight lines, the minimum distance at which signals, embankment wall and railing on the other structures of railway subgrade can be installed is 2.45 m. This gauge requirement limits the height of installations and structures from the level of the top of the head of a rail to 1.07 m. In the Guidelines for the Application of Structure Gauge 163/K (Lietuvos geležinkeliai, 2001), it is stated that in case of complex topographical conditions, after coordination with the Lithuanian Railways Administration, the minimum distance at which contact network supports, semaphore and traffic light poles and embankments can be installed on straight lines is 2.75 m. The minimum distance at which small traffic lights can be installed is 2.45 m. In this gauge, the height of devices and structures from the level of the top of the head of a rail is limited to 1.10 m. In exceptional cases, with the permission of the Lithuanian Railways Administration and ensuring the safety of railway personnel, industrial and transport company employees and passengers (when there is no pedestrian infrastructure near the road or bypass provided), the minimum distance at which buildings and fences can be erected is 2.45 m. However, the legislation does not clearly state that noise barriers can be installed at this distance. According to Commission Regulation No 1299/2014 (European Union, 2014), on railway sections of straight lines, engineering structures and equipment on the outside of "edge" tracks can be installed at a distances of 3.1 m. For this gauge, the height of equipment and structures is limited to 3.20 m.

Methodology

In order to compare the acoustic efficiency of noise barriers of different heights and to select the optimal technical parameters of the barrier, a numerical modelling was performed using the CadnaA (Computer Aided Noise Abatement) software. Numerical modelling was performed along the railway road Kyviškės-Valčiūnai with an existing high noise barrier of 3.5 m.

After analysing the experience of applying low noise barriers on railways in foreign countries, it was found that low noise barriers are installed at a distance of 1.73–2.0 m from the axis of the railway track. According to the requirements of the legal acts currently in force in Lithuania, it is not possible to install low noise barriers at this distance, therefore, for the numerical comparison of noise barriers of different heights, the distances at which certain structures and equipment are allowed to be installed in Lithuania have been selected for modelling. In addition, in order to evaluate the effectiveness of insertion loss of the modelled barriers, a high noise barrier (simulating the existing 3.5 m high barrier) and a low noise barrier, installed on the railway track axis at the distance in applicable foreign countries were modelled under the same conditions.

Calculations were also carried out during modelling in search of optimal parameters for a noise barrier with a sufficient insertion loss. A barrier of various heights was modelled at a distance of 2.45–3.1 m from the axis of the track; and its shape was variable. The aim was to select the most appropriate low noise barrier that can be installed at the distances legally permitted in Lithuania, which could be used in other foreign countries that strictly regulate the distances at which structures and equipment can be installed from the axis of the railway track.

In order to evaluate the effectiveness of the noise barrier under conditions of different speeds, it is planned to model the noise barrier for 160 km/h (simulating current maximum permitted speed for freight trains on category I and II railway lines), 240 km/h and 250 km/h (maximum limit at which rolling noise prevails). The latter speed limit was chosen also because it is planned that the maximum speed of rolling stock will be up to 250 km/h on the Rail Baltica electrified dual European-gauge railway line running from Warsaw through Kaunas and Riga to Tallinn.

Numerical modelling of noise emitted by rolling stock and noise barriers of different heights was carried out with the help of CadnaA software, evaluating the topography of the area and the noise absorption properties of the area, the height of buildings and meteorological conditions. The Cnossos-EU methodology, which is intended for European countries, was used to calculate railway traffic noise. In order to model the noise barriers, a noise model was created (existing situation without a noise barrier and with a 3.5 m high noise barrier), which was calibrated according to the natural results of railway noise measurements at a distance of 4 m from the Kyviškės–Valčiūnai double-track railway.

Noise level calculations were performed at a distance of 7.5 m and 45 m from the axis of the railway track. The distance of 7.5 m was chosen to determine the noise level behind the noise barrier, where the acoustic shadow zone is located and where the insertion loss of a high noise barrier occurs. The distance of 45 m was chosen in order to determine what the noise level is at a greater distance, where there is no longer an acoustic shadow of the barrier, and where there are buildings in the vicinity of which the threshold noise level must not be exceeded. The noise level and insertion loss were calculated at different heights from the top of the rail track (1.5 m, 3.5 m and 5.5 m) to determine how noise levels change with height.

The CadnaA software does not allow to select the type of material of the barrier, but it is possible to specify what sound absorption coefficient $DL\alpha$ of the noise barrier should be modelled, which expresses the ability of the material to absorb sound. There are no residential or public buildings on the other side of the Kyviškės–Valčiūnai railway road on which the noise barrier is modelled, so there is no need to protect them from the negative impact of reflected noise. Taking this into account, the same sound absorption coefficient $DL\alpha$ – 4 dBA was chosen for all modelled barriers, i.e., sound absorption category A0, according to the Rules for the Selection, Modelling, Design and Installation of Noise Barriers T TU 15 (Valstybės įmonė Lietuvos automobilių kelių direkcija, 2015), i.e., sound non-absorbing noise barriers have been modelled. In order to check whether the upper element of the barrier can influence the insertion loss, inverted L-shaped barriers with which experiments are also carried out in other countries were also calculated.

In order to evaluate the insertion loss of different noise barriers, 7 alternatives were modelled:

- Current situation: height of the noise barrier from the top of the rail – 3.50 m, barrier length – 45 m, the barrier is located at a distance of 4.0 m from the track axis;
- Option I: height of the noise barrier from the top of the rail – 0.76 m, barrier length – 45 m, the barrier is located at a distance of 1.75 m from the track axis;

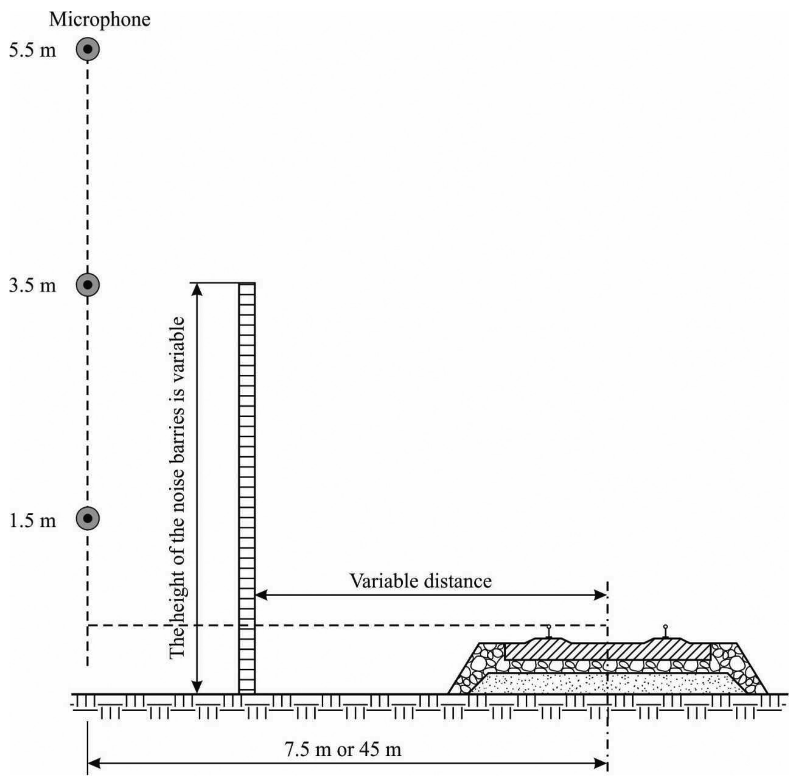

Figure 1. Principal scheme to calculate the noise level and the insertion loss

- Option II: height of the noise barrier from the top of the rail – 1.2 m, barrier length – 45 m, the barrier is located at a distance of 2.6 m from the track axis;
- Option III: height of the noise barrier from the top of the rail – 1.0 m, barrier length – 45 m, the barrier is located at a distance of 3.75 m from the track axis; The barrier is expected to be inverted L-shaped, the length of the bracket, folded towards the railway track, is 0.9 m;
- Option IV: height of the noise barrier from the top of the rail – 1.2 m, barrier length – 45 m, the barrier is located at a distance of 2.45 m from the track axis;
- Option V: a noise barrier with different parameters was modelled in order to determine the optimal low noise barrier for Lithuanian conditions, keeping the same length as the existing high noise barriers, i.e., 45 m, and installing it at a distance of 3.1 m from the track axis. Initial conditions: height of the noise barrier from the top of the rail – variable, barrier length – 45 m, the barrier is located at a distance of 3.1 m from the track axis; The barrier is expected to be of variable shapes;
- Option VI: a noise barrier with different parameters was modelled in order to determine the most optimal low noise barrier for Lithuanian conditions. Initial conditions: height from the top of the rail – variable, barrier length – variable, the barrier can be located at a distance of 2.45–3.1 m from the track axis; The barrier is expected to be of variable shapes.

The principal scheme for calculating the noise level and the insertion loss is presented in Figure 1. The microphone shown in the scheme represents the height of the noise level calculation from the top of the rail.

Calculation results

The results of the numerical modelling calculations are presented in Tables 1–2, Figures 2–3.

After the numerical modelling of noise barriers, it was determined that high noise barriers are the most effective when it is necessary to protect the areas adjacent to the barrier. The insertion loss of a 3.5 m high noise barrier located at a distance 4.0 m from the track axis, determined at a height of 1.5 m from the top of the rails, 7.5 m from the track axis, is as much as 8.6–8.9 times higher (depending on the running speed of the rolling stock) than that of the lowest, 0.76 m high noise barrier located at a distance of 1.75 m from the track axis. The insertion loss of a high noise barrier determined under the same conditions is 2.9–3.1 times higher (depending on the running speed of the rolling stock) than that a low noise barrier of 1.2 m height, located at a distance of 2.6 m from the track axis. It can be seen that ultra-low noise barriers are less effective even if they are closer to the railway track.

The insertion loss of a 3.5 m high noise barrier located at a distance of 4.0 m from the track axis, determined at 3.5 m from the top of the rails, 7.5 m from the

Table 1. Calculations of noise level of all modelled noise barrier options

Distance from the track axis, m	Microphone height, m	Current situation		Option I	Option II	Option III	Option IV	Option V	Option VI
		dBA							
		without barrier	H– 3.5 m, L – 45 m, at 4 m distance	H– 0.76 m, L – 45 m, at 1.75 m distance	H– 1.2 m, L – 45 m, at 2.6 m distance	H– 1.0 m, L – 45 m, at 3.75 m distance Length of L-shaped bracket – 0.9 m	H– 1.10 m, L – 45 m, at 2.45 m distance	H – 1.3 m, L – 45 m, at 3.1 m distance Length of L-shaped bracket – 0.65	H – 1.3 m, L – 100 m, at 2.75 m distance Length of L-shaped bracket – 0.3 m
160 km/h									
7.5	1.5	75.2	52.9	72.6	67.6	70.5	69.0	67.7	67.7
	3.5	75.1	62.3	75.1	75.1	75.1	75.1	75.1	75.1
	5.5	73.9	73.9	73.9	73.9	73.9	73.9	73.9	73.9
45	1.5	65.4	59.9	62.0	60.8	61.2	61.0	60.8	56.6
	3.5	65.6	60.4	62.9	61.6	62.2	62.0	61.6	58.6
	5.5	66.1	61.6	64.7	63.0	63.6	63.2	63.0	61.1
250 km/h									
7.5	1.5	79.3	57.0	76.8	72.1	74.9	73.4	72.2	72.2
	3.5	79.3	67.4	79.3	79.3	79.3	79.3	79.3	79.3
	5.5	78.1	78.1	78.1	78.1	78.1	78.1	78.1	78.1
45	1.5	69.5	64.3	66.3	65.2	65.5	65.4	65.2	61.6
	3.5	69.7	64.8	67.2	65.9	66.5	66.3	65.9	63.3
	5.5	70.2	66.0	68.8	67.3	67.9	67.5	67.3	65.5

track axis, is ~ 2 times lower than that determined at a height of 1.5 m from the top of the rails, and at a height of 5.5 m, the barrier is ineffective, i.e., same noise level as in the case of no barrier at all has been determined with the insertion loss equal to 0. This is because, when calculating the insertion loss next to the barrier, the lower the receiver (microphone) level, the higher the insertion loss, because the area falls into the acoustic shadow zone. Low noise barriers are not effective when measured at a height of 3.5 m and 5.5 m at a distance of 7.5 m from the track axis. As can be seen from the results of the study, the effectiveness of the low noise barrier is manifested further away from the barrier, which is useful when you want to protect residential or public buildings located not in immediate proximity to the railway from negative impact of noise.

The highest loss insertion in all 45 m long low sound barriers at a distance of 45 m from the track axis was found for the 1.2 m high straight sound barrier located 2.6 m from the track axis and the 1.3 m high and inverted L-shaped (bracket length – 0.65 m) noise barriers located at a distance of 3.1 m from the track axis. Under the same conditions, a slightly lower insertion loss was determined for a 1.10 m high L-shaped (bracket length – 0.65) noise barrier located at a distance of 2.45 m. The lowest insertion loss was determined for the ultra-low

Table 2. Calculations of insertion losses of all modelled noise barrier options

Distance from the track axis, m	Microphone height, m	Current situation	Option I	Option II	Option III	Option IV	Option V	Option VI
		dBA						
		H– 3.5 m, L – 45 m, at 4 m distance	H– 0.76 m, L – 45 m, at 1.75 m distance	H– 1.2 m, L – 45 m, at 2.6 m distance	H– 1.0 m, L – 45 m, at 3.75 m distance Length of L-shaped bracket – 0.9 m	H– 1.10 m, L – 45 m, at 2.45 m distance	H – 1.3 m, L – 45 m, at 3.1 m distance Length of L-shaped bracket – 0.65	H – 1.3 m, L – 100 m, at 2.75 m distance Length of L-shaped bracket – 0.3 m
160 km/h								
7.5	1.5	22.3	2.6	7.6	4.7	6.2	7.5	7.5
	3.5	12.8	0	0	0	0	0	0
	5.5	0	0	0	0	0	0	0
45	1.5	5.5	3.4	4.6	4.2	4.4	4.6	8.8
	3.5	5.2	2.7	4	3.4	3.6	4	7
	5.5	4.5	1.4	3.1	2.5	2.9	3.1	5
250 km/h								
7.5	1.5	22.3	2.5	7.2	4.4	5.9	7.1	7.1
	3.5	11.9	0	0	0	0	0	0
	5.5	0	0	0	0	0	0	0
45	1.5	5.2	3.2	4.3	4	4.1	4.3	7.9
	3.5	4.9	2.5	3.8	3.2	3.4	3.8	6.4
	5.5	4.2	1.4	2.9	2.3	2.7	2.9	4.7

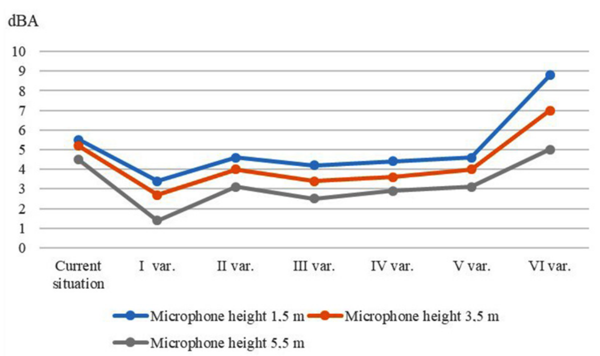

Figure 2. Calculations of insertion losses of all modelled noise barrier options at a distance of 45 m from the track axis, with a rolling stock speed of 160 km/h

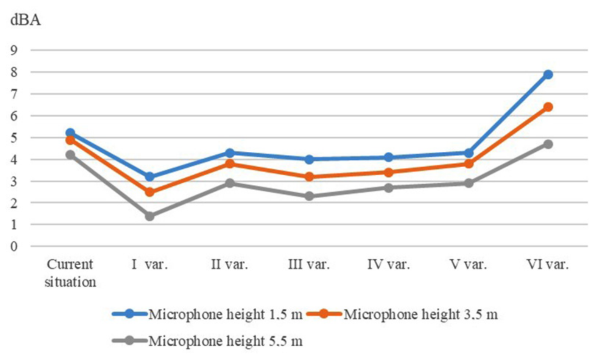

Figure 3. Calculations of insertion losses of all modelled noise barrier options at a distance of 45 m from the track axis, with a rolling stock speed of 250 km/h

0.76 m high noise barrier located at a distance of 1.75 m from the track axis – the insertion loss was determined to be ~2 times lower than the insertion loss of other low noise barriers. In all cases, higher insertion loss was determined at lower speed of rolling stock, although this difference is rather insignificant.

Calculations showed that the most effective low noise barrier is a 1.3 m high barrier installed at a distance of 2.75 m from the track axis, extended in both directions for a total length of ~100 m (~15 m in the south direction and ~40 m in the north direction). The barrier is inverted L-shaped, the length of the bracket is 0.30 m. T-shaped low noise barriers were found to be ineffective. During the modelling, an attempt was made to bend the bracket at a different angle. By reducing the angle of inclination, for example, by bending the barrier at an angle of 45°, an equivalent insertion loss was determined, therefore, if there is a need to maintain a slightly greater distance from the track axis, it is possible to provide the barriers with a bended upper element.

Conclusions

- In order to reduce the emitted noise and its negative impact on the environment, various noise abatement measures are available for installation along the railway tracks. In Lithuania, one of the most widely used measures is a high noise barrier, which suppresses noise very effectively, but also has negative aspects, therefore, low noise barriers also have a worldwide application. They are installed right next to the railway tracks, which are quite effective in protecting the territories situated away from the railway track on which rolling stock runs at a speed of up to 250 km/h.
- In Lithuania, the biggest problem related to the noise emitted by railway roads arises on the straight line sections (where the speed of trains reaches up to 160 km/h), passing through residential areas, especially at crossings, where it is not possible to apply high noise barriers because they limit visibility. Low noise barriers on railway tracks would be an effective measure, but Lithuanian legislation regulates a relatively large gauge (a distance of 3.1 m from the track axis), the insertion loss of which, if a standard low noise barrier is installed, would be too low to effectively protect against negative effects of noise. In some exceptional cases, a gauge of 2.45 m may apply.
- The highest loss insertion in all 45 m long low sound barriers at a distance of 45 m from the track axis was found for the 1.2 m high straight sound barrier located 2.6 m from the track axis and the 1.3 m high and inverted L-shaped (bracket length – 0.65 m) noise barriers located at a distance of 3.1 m from the track axis. Their insertion loss is 2.9–4.6 dBa, depending on the running speed (slightly) and microphone level.
- The lowest insertion loss was determined in the ultra-low 0.76 m high noise barrier located at a distance of 1.75 m from the track axis – the insertion loss was determined to be ~2 times lower than the insertion loss of other low noise barriers. Its insertion loss is 1.4–3.4 dBa, depending on the running speed (slightly) and microphone level.
- After calculations were made, it was established that the most effective low noise barrier with a length of 100 m is a barrier with a height of 1.3 m installed at a distance of 2.75 m from the track axis. The barrier is inverted L-shaped, the length of the bracket is 0.30 m. Its insertion loss is 4.7–8.8 dBa, depending on the running speed (slightly) and microphone level.
- Numerical modelling allowed to determine that high noise barriers are the most effective in protecting adjacent noise sensitive areas, but with distance, the insertion loss decreases, and the calculated insertion loss levels are closer to the insertion loss levels of some of the analysed low noise barriers. At a greater distance, the reduction of insertion loss is strongly influenced not by the height of the barrier, but by its length, and to a certain extent by the shape and distance to the track axis.
- In the future, straight and inverted L-shaped barriers with the same parameters should be modeled in order to determine the influence of the upper element on the insertion loss.

Disclosure statement

Authors declare what they do not have any competing financial, professional, or personal interests from other parties.

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