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Study of the Pressure Loads on Noise Barriers Using Moving Model Rig Tests

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Abstract

In this paper, the loads on noise barriers adjacent to a high-speed railway line are discussed on the basis of experimental test results gained using a moving-model rig. Two different barrier heights as well as three train speeds were tested, the train model was generic. The tests showed that the pressure amplitude at the barrier, which is resulting in the load on the barrier, is mainly induced by the train head passing the test position. Typically, the pressure measured near the ground is higher than near the top of the barrier because of the ground effect. It was found that due to the higher obstruction the higher noise barrier leads to higher pressure amplitudes. The loads increase for increasing speed, in the test even more than expected due to a Mach-Number effect.
A comparison of the tested results with the assumption given in the European and the Japanese Standard for loads on noise barriers showed, that both assumptions overestimate the pressure amplitudes slightly, whereas the safety coefficient is higher for the Japanese Standard.

Keywords: high-speed train, noise barrier, aerodynamic loads, moving model test, head pressure pulse, pressure amplitude.

1 Introduction

Railway lines are an important backbone of the national as well as international transportation of people and goods. A wide network of railway lines is necessary to offer convenient transportation to people in cities and urban areas. The lines have to cross the cities and inhabited areas in order to provide the transportation services needed leading to a high number of inhabitants affected by the noise of passing trains. Therefore, noise barriers are important to reduce noise emission and to ensure the public acceptance of railway services.

Passing trains do not only emit noise but also induce wind and loads on trackside objects like houses, infrastructure or the noise barriers. To ensure a safe operation of a track, the noise barriers have to be built robust so that there will be no damage due to the passing trains. The loads can be derived from the pressure due to the train's flow field as the pressure leads to a force on the area of the noise barrier and therefore causes the load on the barrier.

The loads on trackside objects are part of research activities all over the world. Liu et.a. [1] give a resume about research activities regarding loads on trackside objects, also but not limited to noise barriers.

To evaluate the loads of trains on the trackside objects, track tests were performed by Soper et.al. [2] resulting in a data base of loads induced by UK trains on walls near the tracks.

The effect of the dynamic behavior of the flow and the noise barrier was studied by Tokunaga [3] as well as by Lachinger [4]. Later studied the topic numerically. Kikuchi [5] did also numerical studies of train passing effects in Japan. Especially in Japan, researchers are committed to reducing noise emission, for example see Kitagawa [6], Maeda [7] or Moritoh [8]. The focus lies not only on reducing vehicle noise emission but also to optimize the noise attenuation by infrastructural measures.

As the noise barriers are directly adjacent to the rail, national or international regulations force to ensure safe transportation and prevent damage of components on or near the rail. In Europe, several Standards are on force to prevent damage due to aerodynamic loads (see [9], [10] or [11]), the same holds for counties like Japan (see [12]).

As the number of moving-model rigs available for testing train passing effects is limited, only few test campaigns in model scale were conducted to study the effect of a passing train on infrastructure or objects beside the rail [13]. In this paper a novel parametric study of the pressure loads on a noise barrier is presented whose purpose is to give insight into the effect of barrier height and the train speed on the pressure amplitude at the barrier wall.

2 Methods

To analyze the loads on the noise barrier, measurements were performed using a train model passing a model barrier in the test section of a moving-model rig. Additionally, theoretical estimations were made according to the current international standards.

Standardization of Pressure Loads on Noise Barriers in Europe and Japan

As noise barriers have to withstand the high loads due a train passage, they have to be built sufficiently robust. In Europe, the standard EN16727 in [9] gives a reference of the typical loads on the barrier depending on the height of the barrier, the measurement position of the load, the train speed and the distance between train and wall (for further information see EN16727 [9]). This assumption is specified in the German Standard RIL804.5501 (see [11]), which was the basis for setting up the European Standard. The assumption given in the standard is based on generic factors with x: coordinate in train's driving direction, *z*: testing height, *h*: height of noise barrier, c_p: pressure coefficient.

$$c_p(x,z) = f(x) \cdot c_p(z) \tag{1}$$

with

$$f(x) = 1.0312 \cdot (1 + u^2 + u^4)^{-0.8291} \cdot (-2.2430 \cdot u - 0.0879 \cdot u^2) \tag{2}$$

and

$$u = (0.1754 \cdot (x - 100)) \tag{3}$$

For the pressure cp the following assumption is used:

$$c_p(z) = [0.01329 \cdot h + 0.07254] \cdot [1 - (0.04689 \cdot h + 0.2594) \cdot (z/h)^2] \tag{4}$$

for $0 \leq z \leq h$.

These assumptions hold for a distance between wall and middle of rail of 3.8m. For other distances a_g, the following transition has to be done:

$$c_p(a_g) = c_p(3.8) \cdot \left[\frac{14.5}{(a_g+0.25)^2} + 0.116\right] \tag{5}$$

It is assumed that the trains are streamlines trains while for bluff train heads the corresponding pressure coefficients have to be scaled with a train geometry factor as bluff train heads will lead to higher pressure values. For adverse train geometries, the factor can be supposed to be up to $\varphi_{train,adverse} = 1.67$.

In contrast to the European Standard, the Japanese standard does not take into account the finite height of the noise barrier so the barrier is assumed to be infinitely high (for details, see [12]). This assumption represents a worst-case scenario.

Japanese standard assumes the special maximum pressure is expressed as [12]:

$$c_p(a_g) = k_1 \left[\frac{2.5}{(a_g+0.25)^2} + 0.02\right] \tag{6}$$

where k_1 denotes the effect of the train nose shape and $k_1 = 0.85$ is used for typical Shinkansen noses. In z direction, the uniform pressure distribution is assumed. Although a dynamic amplification factor is applied to Eq. (6) to account for dynamic effects caused by frequency components close to the resonant frequency of the noise barrier [12], this factor is neglected in the present paper because it represents non-aerodynamic effects.

Test Setup and Measurement Positioning

The pressure distributionon a noise barrier adjacent to a railway track were measured in model scale using the low-noise moving model test facility of RTRI in Tokyo, Japan (for more information, see [14]). The scaling of the setup was 1:20. Two different heights of noise barriers were tested, 2,5m and 5m and the length of the barrier was 180m in full-scale. The barriers were placed at both sides of the rail, whereas the rail is not placed in the middle but closer to the tested wall for modeling the Japanese double track railways. A schematic overview of the placement of rail and walls is shown in Figure 1. Shown are the two barriers on both sides of the rail (blue), the train on the model rails as well as the ground plate. Please note that the configuration tested is a flat ground configuration.

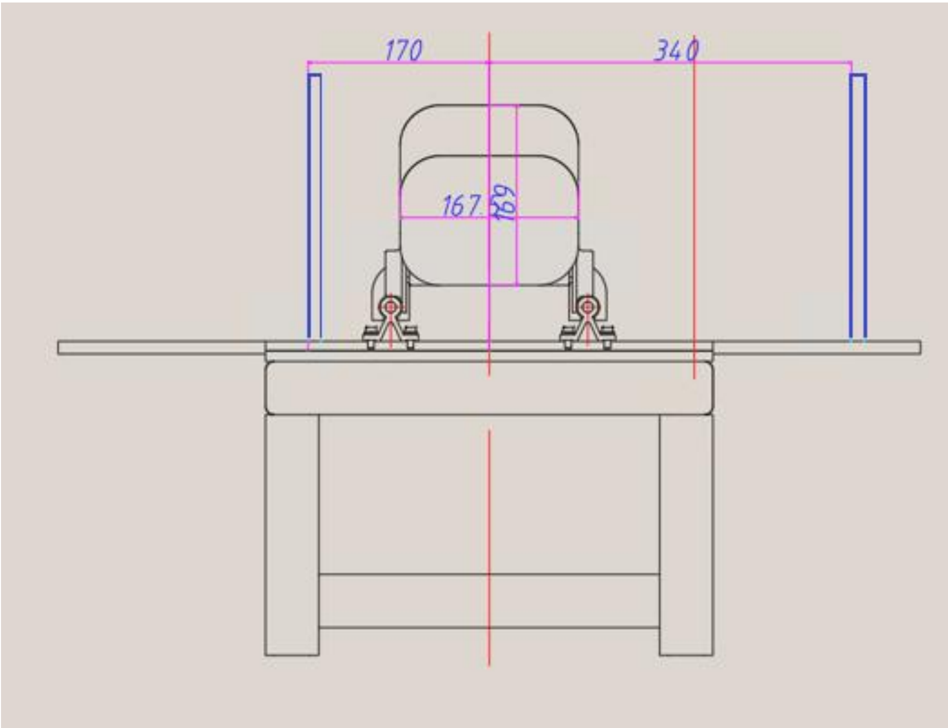

Figure 1: schematic setup of the high noise barrier (dimensioning in mm and model scale).

The barriers were equipped with in total 4 pressure sensors (Kulite XCS-190-5G) at 92m from the beginning of the noise barrier in full scale. All sensor measured pressure difference between inside and outside of the barrier. Each of these sensor lines consists of four sensors placed at a height of 0.525m, 1.05m, 1.575m and 2.1m above ground plate for the low barrier and 1.15m, 2.3m, 3.45m and 4.6m above ground plate for the high barrier in full scale.

The trains utilized for the tests were two generic train noses shown in Fig.2 with a train head length of 5m in full-scale. The train lengths were respectively 50.5 m and 58.75 m for the types N and E in full scale.

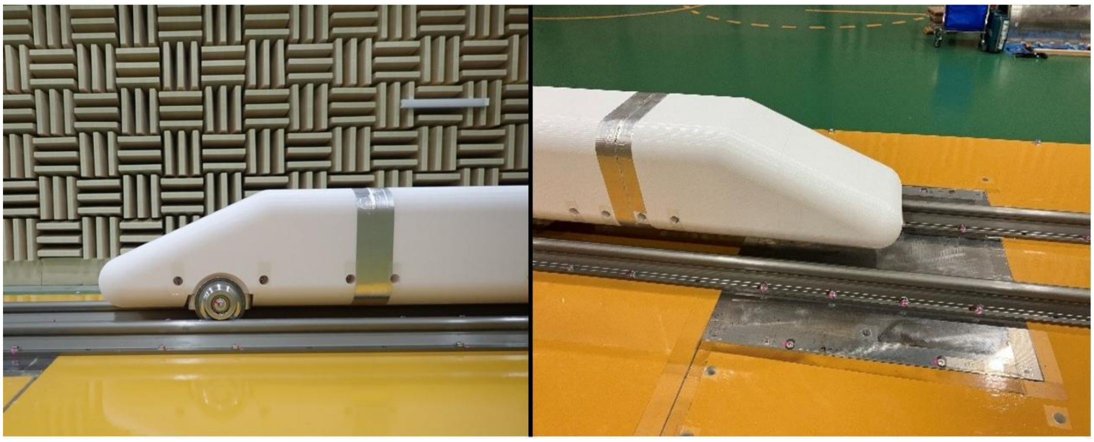

Figure 2: generic train head type N (left), generic train head type E (right).

Both noise barriers, one line of pressure sensors and the train model are shown in Figure 3.

Figure 3: high noise barrier (left) and low noise barrier including middle line of pressure sensors (right).

The pressure at the noise barriers was tested during the passage of the train with varying train speed (V1=92km/h, V2=185km/h, V3=263km/h).

3 Experimental and Theoretical Results

To get information about the loads on the noise barrier, the pressure on the wall was measured at 8 different locations of the wall. One exemplary set of results is shown in Figure 4.

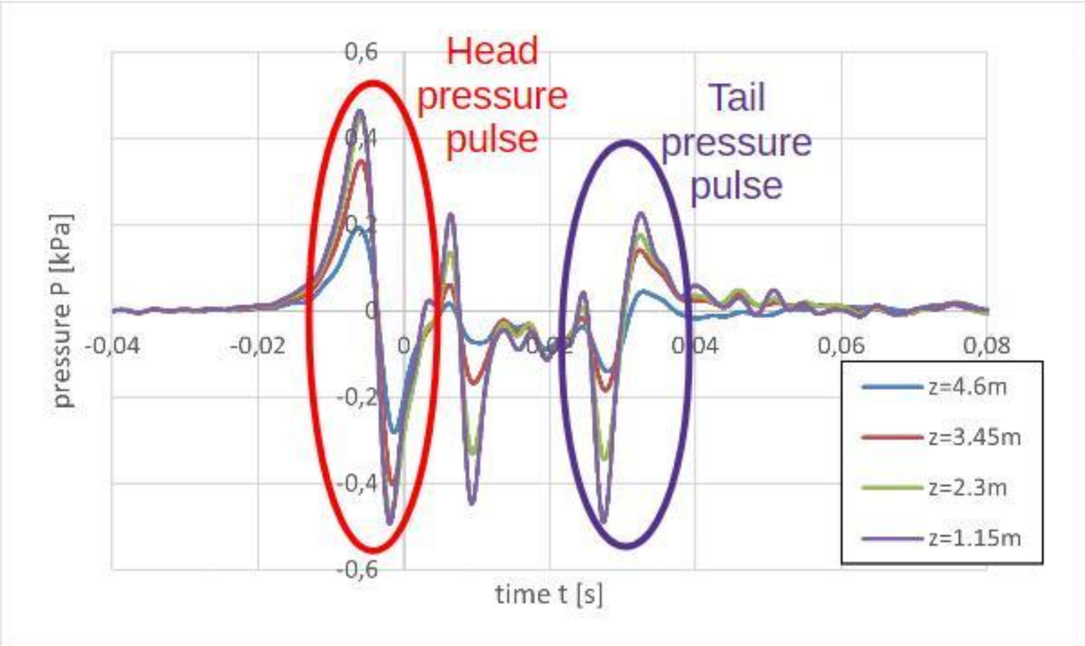

Figure 4: pressure-time history at the second sensor line, high noise barrier with V3=263km/h, nose type N.

The pressure at the barrier wall is shown at four heights over ground. The first pressure peak is the head pressure pulse, where the train head arrives at the testing position leading to an alternating pressure amplitude. Apparent in the Fig. 4 is also the tail pressure pulse. The pressure amplitude at the tail pressure pulse is much smaller than at the head as there is certainly a detachment of the flow leading to a wake region which affects the train's flow and pressure field. The effect is well-known for a train traveling on open track (for example see Sterling [15] or Baker [16]).

In between the head and tail pressure pulse, pressure fluctuations arise when the train's bogies with the mounting system pass the sensors. Therefore, these fluctuations can be attributed to the characteristics of the train model and do not arise for real trains.

The amplitudes of the head and tail pressure pulses differ for the various sensor positions. The higher the measurement position is, the smaller is the pressure amplitude. The high pressure amplitude due to the train's passage only arises on the side of the wall facing to the rail. At the top of the noise barrier, the pressure fields of both wall sides merge leading to a pressure equalization. The higher the sensor position is, the higher is the effect of the equalization leading to a pressure decrease.

To gain information about the loads on the noise barrier, the maximal pressure amplitude of the head pressure pulse is analysed for the different sensor heights and test configurations.

In Figure 5, the maximal pressure amplitudes are shown for the low noise barrier and the three different train model speeds.

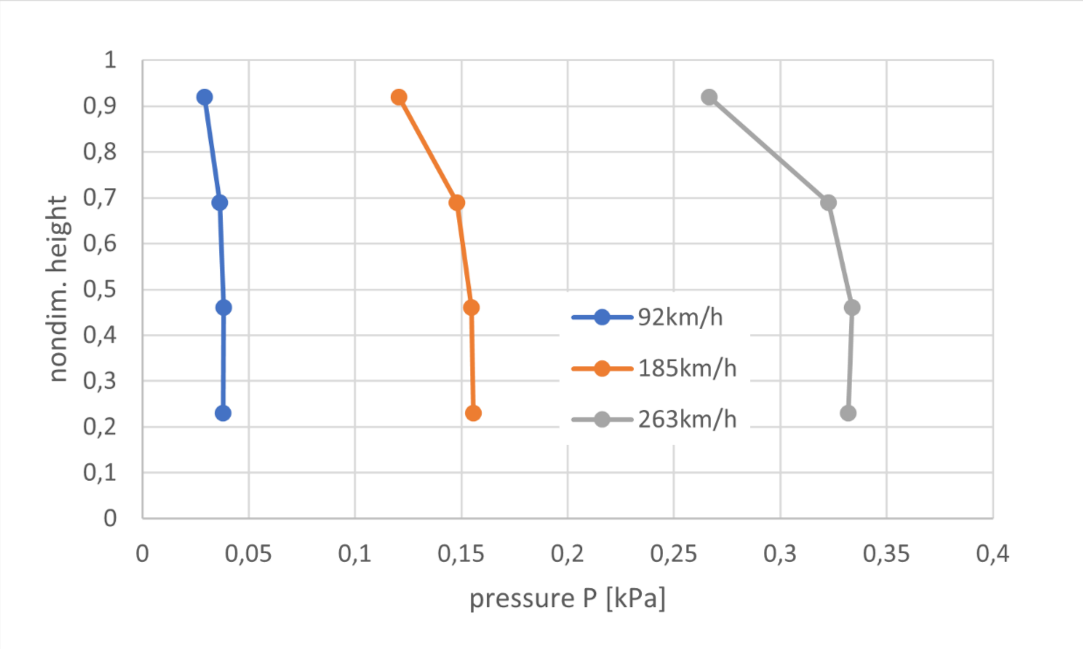

Figure 5: max. pressure amplitude with low barrier and different train speed (nose type E).

It is obvious that an increasing train speed leads to higher loads as expected. The correlation between the pressure amplitude and the train speed is expected to be quadratic. For the highest train speed, the influence of the test height becomes more clear. However, for this speed the maximal pressure amplitude cannot be found at the lowest position but at the second sensor at 2.3m height over ground, although the difference is rather small. The reason for this higher value is the vertical position of the train nose. The nearest sensor to the ground is placed slightly below the train nose leading to a slightly smaller pressure. However, as this tendency was not observed in results with nose type N (see Fig. 7), it depends on the nose shape.

To assess the quantitative effect of the train speed on the pressure amplitude, the pressure coefficient is studied which is shown in Figure 6.

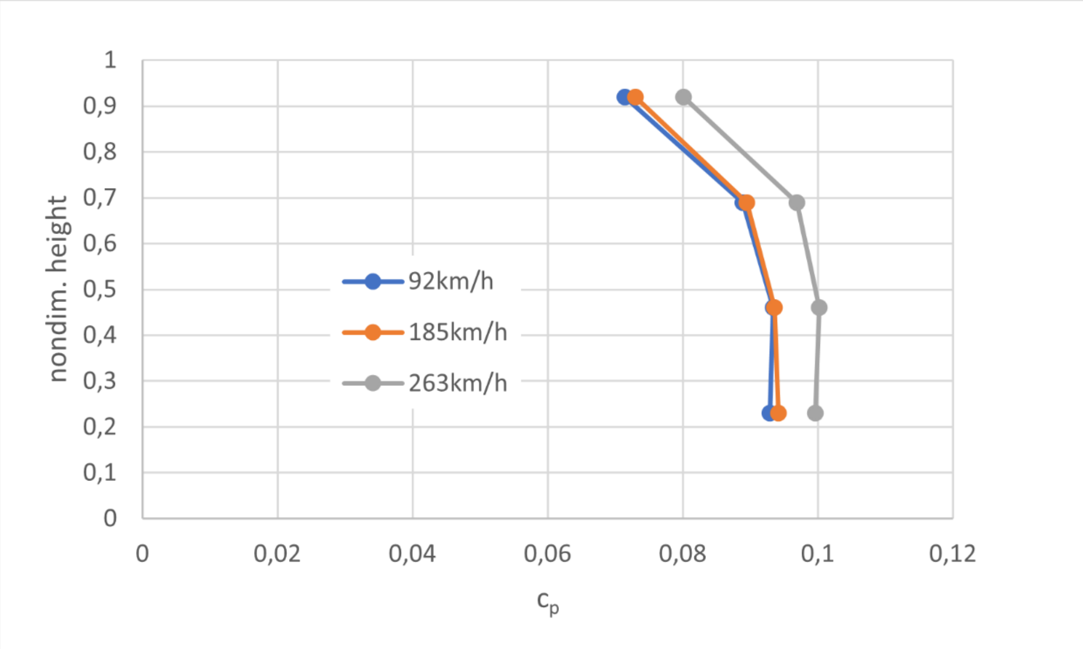

Figure 6: c_p-values for low barrier and diff. train speeds (nose type E).

Figure 6 shows the nondimensionalised pressure curves for all three train speeds and the low noise barrier. The curvature of the curves, so the change of pressure coefficient with test height, is the same for all train speeds. For the two lower train speeds, the curves coincide nicely, only slight differences can be seen which are in the range of the spreading of values for different test runs. However, a visible offset can be stated for the highest train speed. Apparently, there is a change in the flow characteristics between the two lower and the high-speed test leading to this difference in pressure amplitude results. It can be stated that a Mach-Number effect occurs for the given test configuration due to the high test speed.
In Figure 7, the test results for both barrier heights are shown for the high train speed. Additional to the tests, the values assessed using the mathematical formula given in the European Standard are shown for both test cases (see formulas (1) to (5)).
It is obvious that for low test positions, the pressure amplitude is larger for the higher barrier. This is due to the spatial restriction resulting from the higher noise barrier. However, for the highest test positions, the measured pressure amplitudes of the low barrier exceed the ones measured with the high barrier. The top of the high noise barrier is higher than the train roof, which is the reason for a decrease in pressure amplitude. This is certainly not the case for the low barrier, which is why the pressure is higher in this configuration.

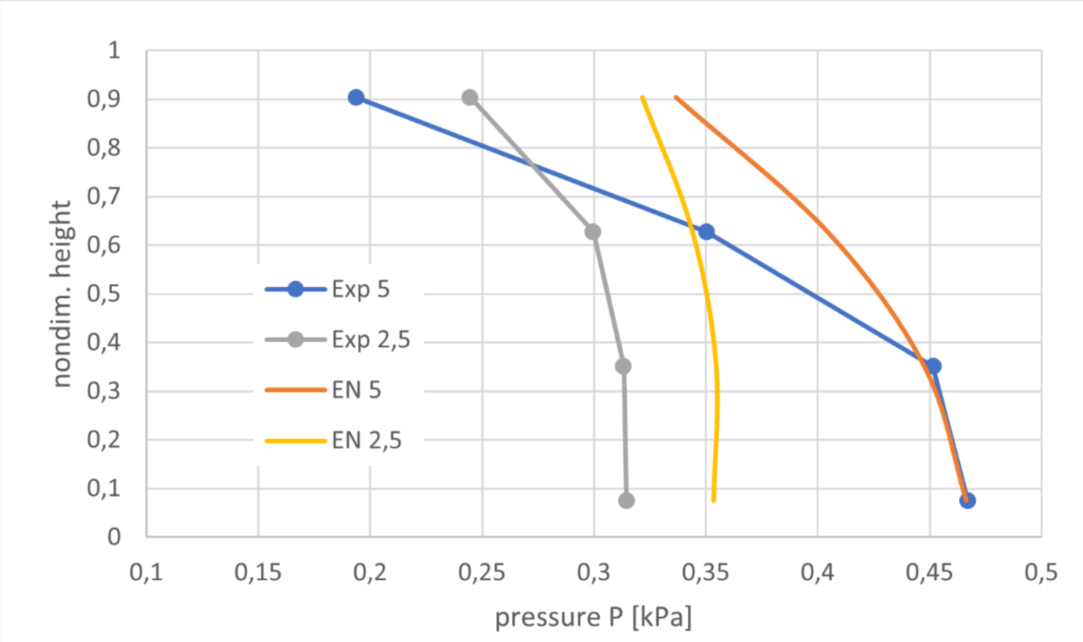

Figure 7: max. pressure amplitude for both barrier heights, comparison with theoretical results (nose type N).

When comparing the measured curves to the theoretically determined ones, it can be observed that for both speeds, the measured values are smaller than the values assessed with the standardization formula. Especially for higher test positions, the theoretical assumption overestimates the pressure amplitude. However, the flow beside the train and in the rooftop region of the train can change with the train head geometry, which might result in local increase of the pressure amplitude at the noise barrier. The theoretical assumption is meant to provide a limit for pressure loads on the walls, so smaller pressure amplitudes in the test campaign are not to be interpreted as too small but as sufficiently small.

When it comes to the Japanese Standard, the attenuating effect of the limited barrier height is not taken into account. The load is taken to be constant over the whole noise barrier height and is taken to be the highest value predicted with a uniform assumption as in the European Standard. Therefore, the loads on the noise barrier are overestimated. Especially if the crucial factor for the loads is not the load on separate barrier elements but on the mounting poles as the stability of the pole is not affected by the load itself but by the momentum, so the load on the highest position of the barrier is contributes to the momentum much more than the load in the bottom region. Therefore, the momentum is overestimated even more than the loads leading to high requirements for the poles.

4 Conclusions

Noise barriers are essential when operating a high-speed rail line through urbanized areas. However, the loads during operation can damage them and building robust noise barriers can result in significantly higher construction costs of a new line.

Therefore, the pressure on noise barriers were tested using a moving model rig and the results compared to theoretically expected loads.
The pressure exerted on the noise barrier by the train depend strongly on the train speed. The higher the speed is, the higher will be the loads. The correlation between the speed and the pressure amplitude was expected to be quadratic, however, for the highest speed a Mach-Number dependency weas found so that the loads exceed the expected ones.
It is apparent that the highest loads on the barriers occur at the bottom of the barrier, so at the lower test position. The higher the sensor is positioned, the smaller is the pressure because of pressure compensation over the top of the barrier. This effect is also taken into account in the European Standard EN16727 for the load assessment on noise barriers. However, the loads are slightly overestimated by this standard. When having a look at the correspondent Standard in Japan, it can be stated that the mitigating effect of the specific barrier height is not taken into account. This results in higher loads than measured and therefore higher requirements for the noise barriers due to the higher coefficient of safety in the theoretical approach.

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