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Subjective and objective assessments of noise barriers in terms of the loudness level

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ABSTRACT

The common measure of noise reduction caused by acoustic barrier is its insertion loss, IL. It is expressed in A-weighted decibels, IL_A, as a difference between A-weighted time-averaged sound pressure levels, L_A, calculated or measured without and with the presence of acoustic barrier. By definition, insertion loss IL_A does not depend on the absolute value of the A-weighted sound pressure level. Thus, for example in case of road traffic noise, the IL_A is insensitive to the change of factors influencing sound level, like vehicle speed, fleet composition, distance to the road and so on. On the other hand, it is widely known that for some environmental noises L_A poorly correlates with subjective noise assessment. A better correlation can be observed for more sophisticated noise indexes, like Zwicker loudness, expressed in sones. The insertion loss in sones, IL_N, is to be determined as the ratio between the loudness without (N) and with the barrier (N_b). The results of both, numerical calculations as well as psychoacoustic experiments, will be presented to show the relation between IL_A and IL_N and their correlation with the subjective assessments of barrier insertion loss as a function of different traffic noise levels.

Keywords: Acoustic barrier, Insertion loss, Loudness

1. INTRODUCTION

As so far road traffic noise measures are mostly based on the A weighted time-averaged sound pressure level. For many years a lot of effort is made [ex. 1, 2 from early 90's] to introduce other, more sophisticated objective measures of noise assessment. Some measures are based on subjective assessment. For example, in [2] listeners were asked to assess different categories of vehicles (heavy vehicles, delivery vans and passenger-cars) in varying road situations (accelerating, braking, driving uphill and going downhill). It has been shown [2, 3] that the best correlation between objective noise measures and subjective annoyance assessment of these noises was obtained for A weighted sound pressure level, L_A, and loudness, N.

On the other hand, it is known that any noise reduction measure expressed in A-decibels, including the insertion loss of the acoustic barrier does not depend on the sound pressure level [4]. It means that the insertion loss for a given location of the immission point (observer) will be the same in case of a heavy vehicle and a passenger car pass-bys or for the same vehicle moving at different speeds and so on.

If we adopt loudness to assess barrier insertion loss its value won't be relative any longer since it depends on the sound level. In this paper a loudness ratio is proposed as a measure of the barrier's insertion loss. The aim of this study was to verify whether the insertion loss expressed in terms of loudness ratio, IL_N, gives better correlation with the subjective assessment of noise compared to the insertion loss defined by the difference of A-weighted sound levels, IL_A. It was made by comparison of both measures, IL_A and IL_N, with the results of psychoacoustic experiment. Both objective measures were calculated from recorded signals, in the presence of and without the acoustic barrier. In psychoacoustic part of experiment subjects were asked to judge the loudness of the above mentioned signals. The stimuli were presented to the listeners for seven noise situations, distinguished by sound level values.

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2. MEASURES OF THE INSERTION LOSS OF THE ACOUSTIC BARRIER

Insertion loss defined as a difference of the A-weighted sound levels with- and without the barrier, IL_A, comes from ISO 10847:1997

$$IL_A = L_{pA} - L_{pAb} \quad [dBA]. \tag{1}$$

Regardless of other factors influencing sound propagation in the presence of barrier the above formula is equal to the effectiveness of a given acoustic barrier.

Proposed measure of the insertion loss is based on the standardized definition of loudness and the method of its calculation (ISO 532B). Loudness, N, is defined as $N = \int_0^{24Bark} N'(z)dz \quad [Sone]$, (2)
where N' is "specific loudness" with a dimension of sone/Bark. The total loudness N is then the integral of specific loudness over all critical-band rates expressed in Barks. To assess the impact of noise barrier loudness has to be calculated twice, using signal recorded with-, N_b, and without the barrier, N. In order to compare the loudness of two signals one has to examine the ratio between two numbers, N and N_b. If the ratio N/N_b equals to e.g. 2, it means that the signal recorded without the barrier is twice as loud as the signal recorded with the barrier and so on. This loudness ratio is used in the present study as a measure of the insertion loss of the acoustic barrier,

$$IL_N = N/N_b. \tag{3}$$

3. METHOD

A psychoacoustic experiment in which the listeners assessed the loudness of noise signals without and with the barrier, for different initial sound level values, i.e. without barrier, was carried out. The aim of the experiment was to verify the hypothesis that the effectiveness of the acoustic barrier, expressed by the volume ratio of signals (3), is better correlated with the subjective assessment of listeners than effectiveness expressed by differences in sound levels, as in eq. (1). That's why both measures of effectiveness were compared with the subjective ratings.

3.1 Signals and measurement set up

Noise signals with- and without the acoustic barrier were recorded in both laboratory (fully controlled environment) as well as in real life conditions. Hereafter an anechoic chamber recordings (Institute of Acoustics, AMU) are used. The acoustic barrier and dummy heads used in this study are presented at Fig.1.

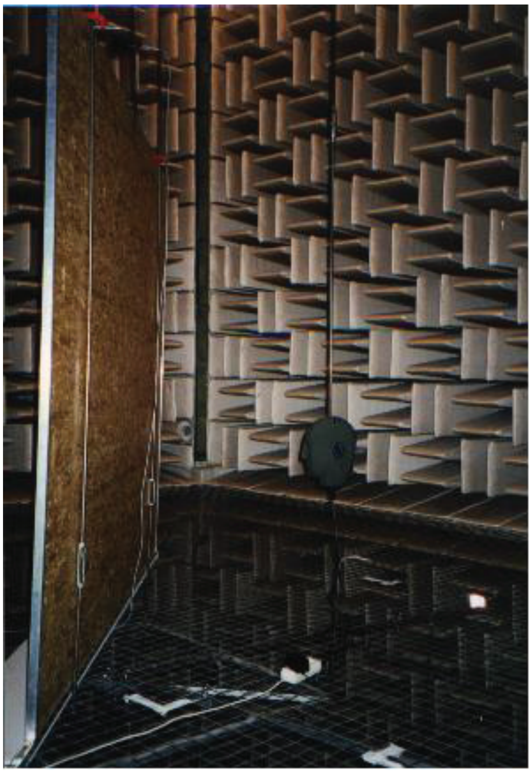

Figure 1 – The model of acoustic barrier and dummy head used for signal recording

Stationary noise signal was generated by the Brüel & Kjar type 4224 sound source. It was withe noise weighted by traffic noise spectrum, according to ISO 1793-1, which was controlled with a reference microphone. Signals were recorded at two points, for seven input sound levels (Table 1). Duration of sound sample used in psychoacoustic experiment was set to 3 seconds.

Table 1 – The sound level values L_{pA} [dB] without and in the presence of a barrier recorded in two, M_1 and M_2, observation points

Position	**Barrier**	L_{max-18}	L_{max-15}	L_{max-12}	L_{max-9}	L_{max-6}	L_{max-3}	L_{max}
M1	without	56.5	59.4	62.3	65.3	68.4	71.2	74.0
	with	34.3	37.0	39.9	42.8	45.7	48.5	51.4
Position	**Barrier**	L_{max-18}	L_{max-15}	L_{max-12}	L_{max-9}	L_{max-6}	L_{max-3}	L_{max}
M2	without	57.3	60.2	63.2	66.1	69.1	72.1	75.1
	with	38.0	40.9	43.8	46.6	49.6	52.4	55.3

The model of acoustic barrier was built of chipboard (size: 2,7 x 5,0 x 0,02 m). Sound source was located at H_s=1.8m above the "floor" level and in the distance D_s=1.3m from the barrier. Signals were recorded at two distances of the dummy head and sound level meter microphones: M_1=2.6m (first observation point) and M_2=4.9m (second observation point). Two distances were selected to take into account differences in sound spectrum which comes from diffraction on small barrier edges. The dummy head and microphones were located at H_M = 1.8 m above the floor level. The signals were recorded using Neumann KU100 dummy head.

Based on these recording both measures of the insertion loss, IL_A and IL_N, were calculated.

3.2 Procedure Psychoacoustic experiment

The psychoacoustic experiment was fully controlled by computer software (Matlab's environment). Signals were played back by the sound card RME DIGI 96 PRO and trough an equalizer PEQ IV.1 to the headphones Sennheiser HD 600. The headphone presentation was diotic with the subject sitting in a sound-proof booth. Listeners were asked to judge the loudness of 14 signals, each sample of 3s duration and calibrated to obtain sound pressure level as of Table 1. During 15-minute session each listener was exposed to 140 random order signals (14 signals repeated 10 times). Each session was repeated three times. The sequence of the stimuli was randomized. All in all, each signal was repeated 30 times. The loudness estimation of the signals was conducted with the use of the Absolute Method of Estimation (AME).

The following instruction was given to the subject: *Estimate the loudness of each signal by assigning a positive number which in your opinion represents the loudness of the sound. Negative numbers or zero should not be used.*

Ten listeners with normal hearing participated in the experiment. No subject had to be excluded due to hearing loss.

4. RESULTS

4.1 Calculated values of the insertion loss

The calculations were performed for 7 different input values of sound pressure levels. The results of these calculations are presented in Fig. 2 (for the insertion loss of the acoustic barrier expressed as the level difference) and in Fig. 3 (for the insertion loss of the acoustic barrier expressed as a loudness ratio).

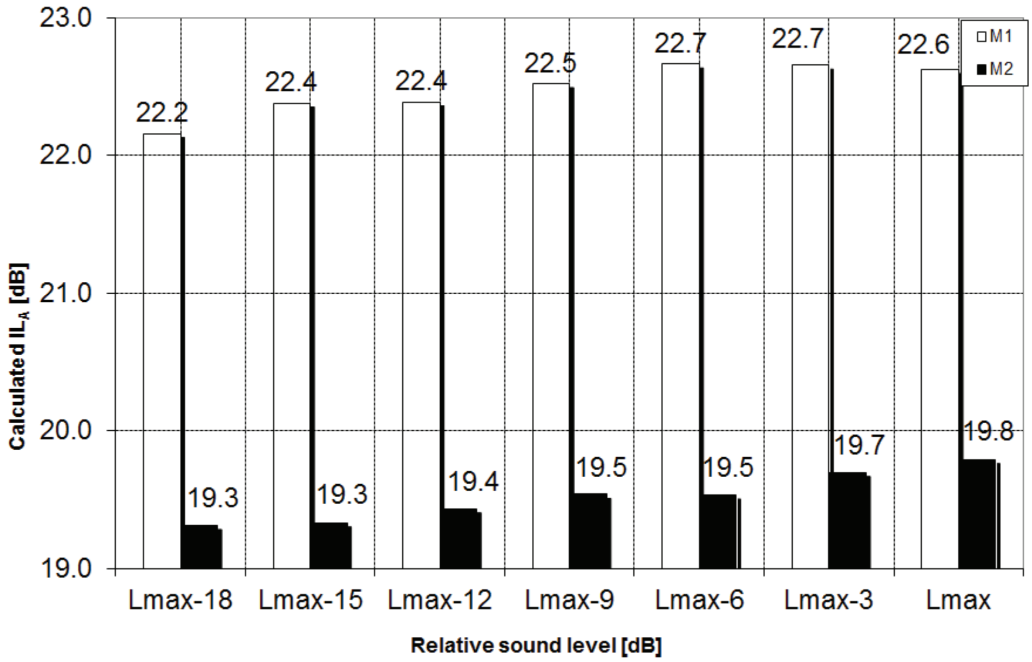

Figure 2 – Insertion loss of the acoustic barrier expressed as the difference in sound levels, IL_A [dB], for different input signal levels, at two locations, M1 and M2

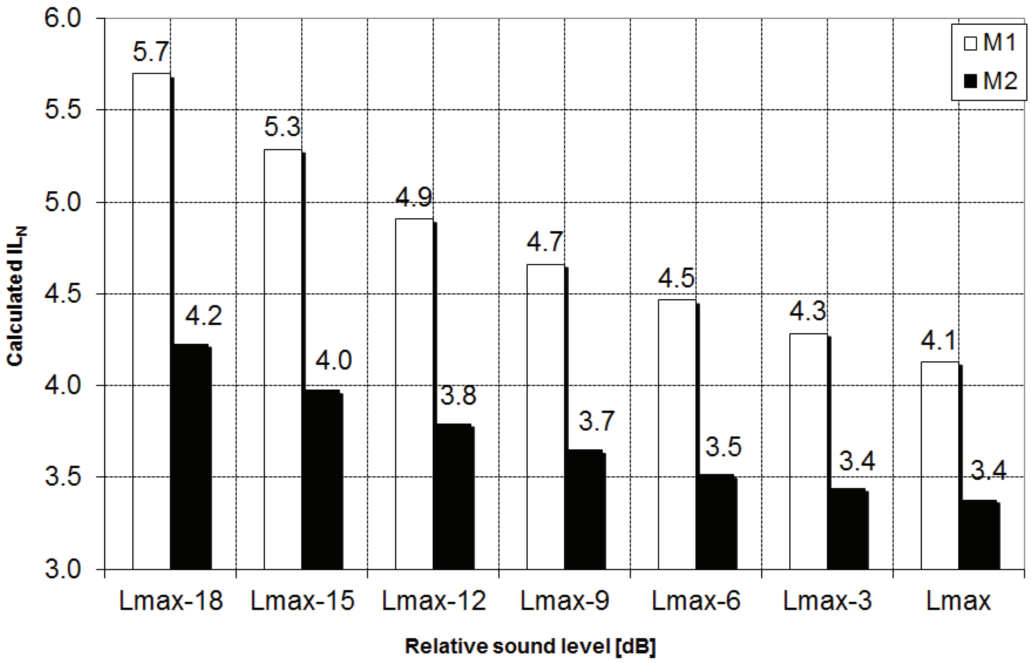

Figure 3 – Insertion loss of the acoustic barrier expressed as a loudness ratio, IL_N, for scenarios as in Fig. 2

As expected the insertion loss, calculated as the difference of the sound levels with- and without barrier, IL_A, does not depend on the level of the presented signal (Fig. 2), with the differences in the range of 0,5 dB. The results are different when the insertion loss of the barrier is defined as a loudness ratio, IL_N. In this case, IL_N depends on the sound level of the signal. The value of this measure decreases when the levels of presented signal increases (Fig. 3).

4.2 Results of the psychoacoustic experiment

The geometric means of the perceived loudness were calculated for each individual subject (30 repetitions for each signal). The term "perceive loudness" means the estimate of loudness performed by the subject. The term "loudness" itself means in this study calculated value of the loudness according to ISO532B standard. As an example of individual data, the results obtained for two subjects are presented in Figs. 4-5. The upper curve in each diagram refers to the perceived loudness of the signal recorded without the barrier, while the lower curve represents the perceived loudness of the signal recorded with barrier.

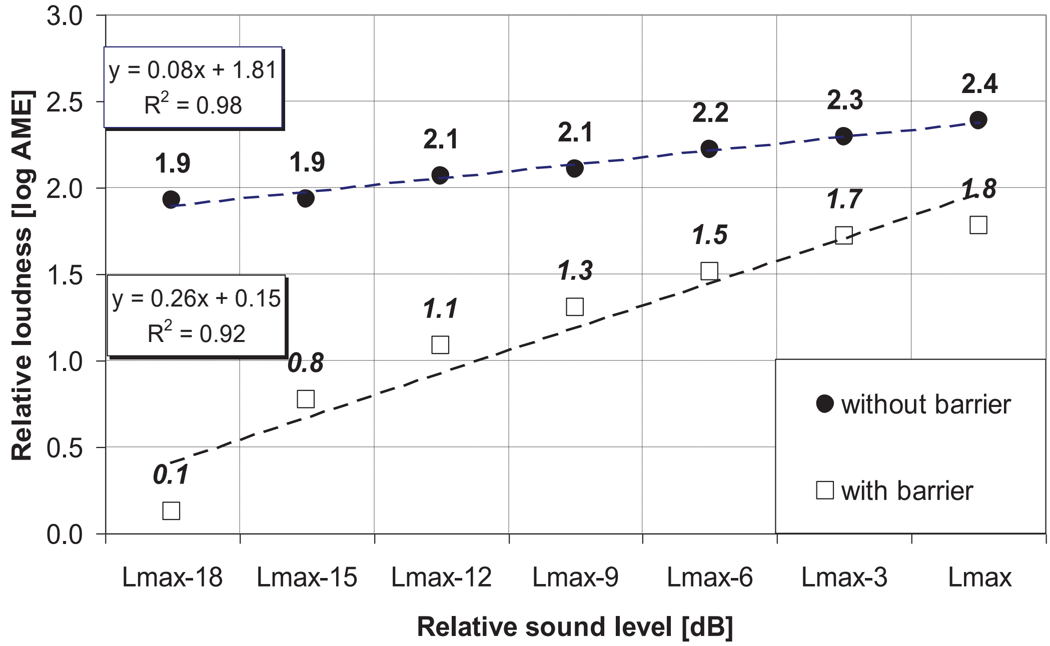

Figure 4 – Perceived loudness scales expressed as a log of the AME judgments of the signals recorded without (the upper curve) and with the barrier (the lower curve) for subject AD

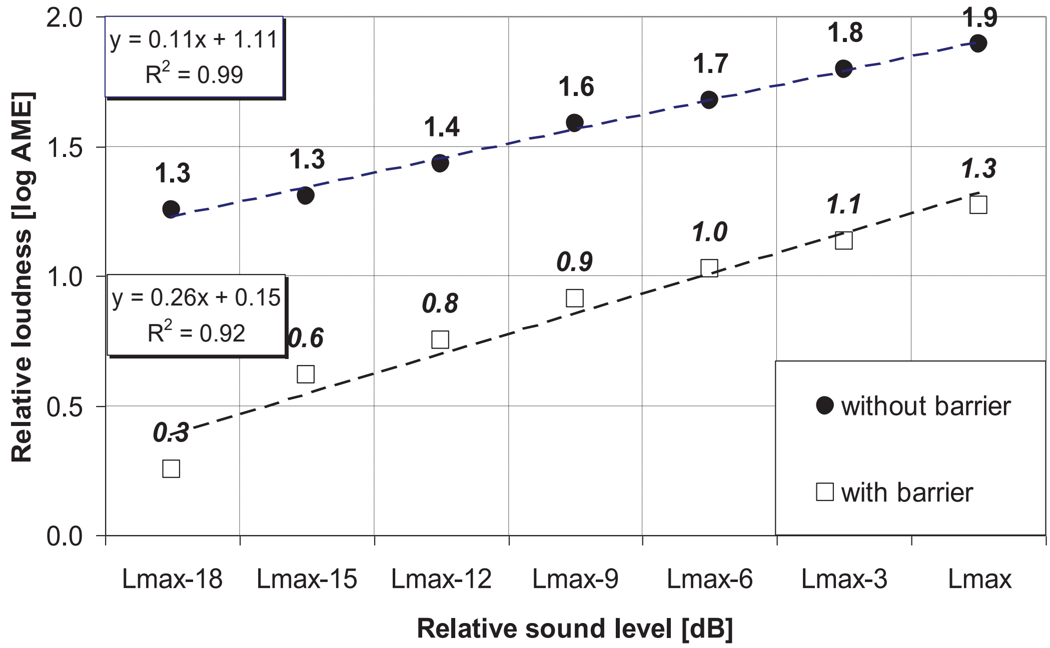

Figure 5 – Perceived loudness scales expressed as a log of the AME judgments of the signals recorded without (the upper curve) and with the barrier (the lower curve) for subject AC

Application of the Absolute Magnitude Estimation (AME) method assumed that subjects could use a different numerical scales in their loudness judgments. It allows to present the results as a geometrical mean for all subjects. On the other hand, a statistically significant difference between signals are possible to determine applying ANOVA method. This method however, requires normalization of each subjects data. In this study the estimates were normalized to the maximum value, different for each subject. As a result it was shown that there are statistically significant differences between stimuli [F(6,54)=14.4, p=0].

In Fig. 6 insertion loss of acoustic barrier expressed as a perceived loudness ratio calculated on relative loudness estimates is presented for 7 stimuli and all subjects participated in the experiment.

Assuming as a starting point the insertion loss of the acoustic barrier for a signal of maximum level (L_{max}), i.e. taking $IL_N(L_{max}) = 0\%$, it is possible to calculate the relative IL_N expressed in % of $IL_N(L_{max})$. This is presented at Fig. 7.

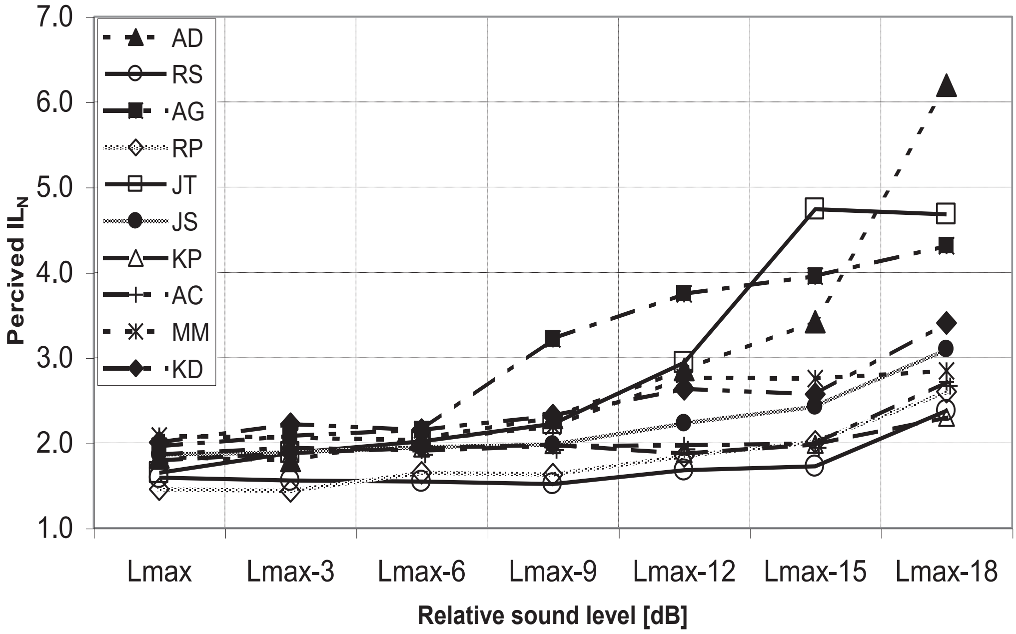

Figure 6 – Subjective insertion loss of acoustic barrier for ten subjects, expressed as a perceived loudness ratio for seven signal levels

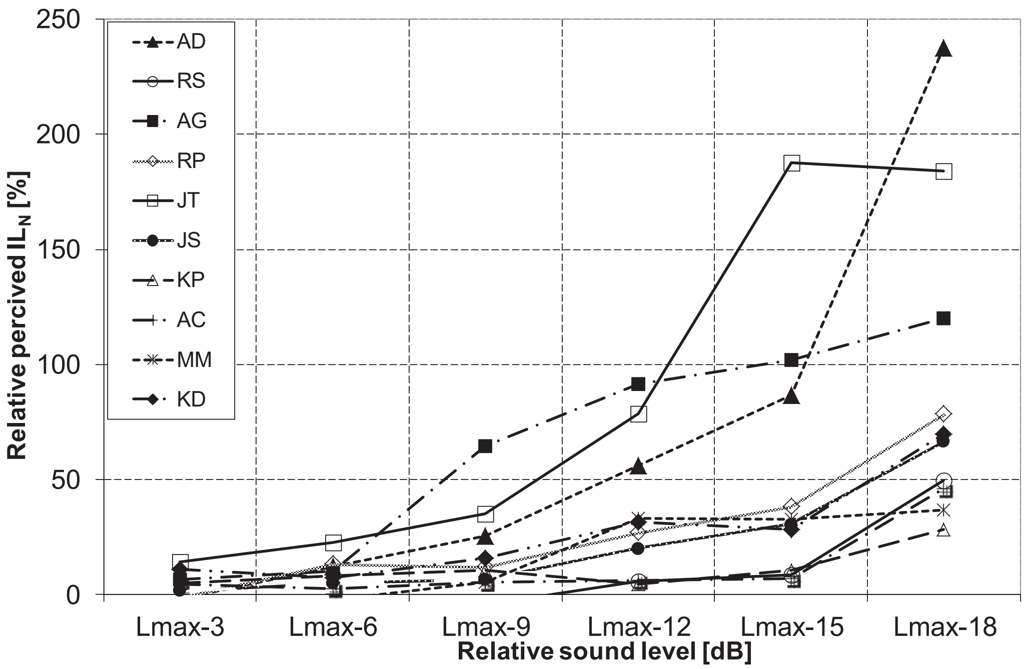

Figure 7 – Relative insertion loss of the acoustic barrier for ten subjects, expressed in % in relation to the insertion loss of L_{max} signal

5. FINAL CONCLUSIONS

Proposed measure of the insertion loss of acoustic barrier, expressed as the signal loudness ratio, has a following properties:

- the insertion loss, IL_N depends on the absolute sound level of the signal. This conclusion comes from the results of loudness calculation (Fig. 3) and listeners' subjective assessment (Fig. 7)
- insertion loss expressed as both loudness ratio as well as listeners' subjective assessment decreases as the sound pressure level increases,
- one can notice a substantial subjective rise in the insertion loss for lower sound pressure levels.

The psychoacoustic experiment based on a stationary noise signal confirms the findings of the previous numerical calculations [5]. According to this measure insertion loss of the barrier, IL_N, for light vehicle passby (low sound pressure level) and heavy vehicle passby (high sound pressure level), will be different. It is not observed for the existing measure of insertion loss, IL_A. This conclusion has practical potential in noise barrier design.

In the next step the above results should be confirmed based on real life recordings, eg. vehicles moving at different speeds, what is the subject of current research.

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