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Consideration of new environmental noise evaluation index

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ABSTRACT

In this study, we considered new environmental noise evaluation index which is suitable for evaluating subjective loudness and could be obtained by simple procedure. In the experiment, we measured rail traffic noise and road traffic noise, and calculated LAeq of them. Next, we performed a subjective loudness evaluation test by employing the measurement noise of rail and road traffic noise in a test room. In the test, the loudness evaluation of rail and road traffic noise were performed separately. As results, the correlation coefficient between LAeq and the subjective loudness of rail traffic noise was high at 0.97, but the coefficient of road traffic noise was low at 0.64. Then, we employed a headphone type microphones for measurement of the environmental noise for taking into account for the effect of head related transfer function (HRTF) and applied D-weighting frequency characteristic to the measured signal instead of A-weighting. The calculated value through this process was called as LhDeq. The correlation coefficient between LhDeq and the subjective loudness of road traffic noise increased very much at 0.92. Consequently, the new environmental noise evaluation index became suitable loudness evaluation index and the index could be obtained easily similar with that of LAeq.

INTRODUCTION

Reduction of environmental noise is important for living comfortably. For the reduction of environmental noise, it is necessary to set and follow an appropriate environmental noise evaluation index in addition to reduce the sound source level and setting sound insulation barrier. If the evaluation index does not fit to the feeling of human beings, the environment does not become comfortable even if the index at a measurement area is under the environmental noise evaluation standard. Therefore, the environmental evaluation noise index is desired to fit the feeling of human beings. On the other hand, the environmental noise evaluation is performed by various people at various area not only by noise specialists. Hence, the evaluation index should be obtained easily by simple procedure.

For the environmental noise evaluation index, LAeq is employed as a standard index at present [1, 2, 3, 4]. This index is useful index because the value is calculated by averaging the energy of sound pressure and could be obtained from an integrating-averaging sound level meter. However, this index is sometimes reported not to express sensation of human beings accurately [5, 6, 7].

In this study, we verified how degree LAeq expresses the loudness sensation of human beings by the measurement of rail traffic noise and road traffic noise and performing subjective evaluation tests. In addition, we considered new environmental noise index which is suitable for evaluating the subjective loudness and could be obtained by simple procedure similar with that of LAeq.

EXPERIMENT AND EVALUATION

In the experiment, we measured environmental noise and performed subjective evaluation tests to verify how degree LAeq correlates subjective loudness.

Measurement of Environmental Noise

We measured two kinds of environmental noise in this study. The one is rail traffic noise, and the other is road traffic noise.

In the measurement of rail traffic noise, we chose three measurement points, where locates near rail, and measured seven rail traffic noise in all three points. The duration of the each noise was four to five seconds. In the recorded sound, the rail traffic noise was dominant sound source but the other traffic noise was recorded a little.

As the measurement system, we used two standard type microphones to obtain LAeq and used head set type microphones (HEAD acoustics MHS3), that enable us to record and reproduce sound source at a live performance. The measured signals by the head set type microphones are used in the subjective loudness evaluation test. These four channel time signals (standard mic. $\times$ 2, head set mic. $\times$ 2) were measured at 44.1 kHz sampling rate and recorded in a handy type data recorder (HEAD acoustics SQuadriga). After the measurement, LAeq was calculated at post process. When we measured the environmental noise, the experimenter who attached head set type microphones stood at road side, and the one of the standard microphones was set 0.5 m away from the left side of the head set type microphones, and the other standard microphone was set 0.5 m away from the right side of the head set type microphones. The height of these microphones were set at 1.5 m. Figure 1 shows the measurement condition. The calculated LAeq (averaged between LAeq of standard microphones at left and right side) of rail traffic noise are shown in Fig. 2(a). Next, road traffic noise was measured at three points that located at road side by using the same experimental system of rail traffic noise. We measured seven road traffic noise in all three points. In the recorded sound, the road traffic noise was dominant sound source and the other noise was hardly recorded. Figure 2(b) shows the LAeq of the seven traffic noise. By comparing LAeq between rail traffic noise and road traffic noise, it is found that the range of LAeq among road traffic noise is narrower than the range among rail traffic noise in this experiment.

Subjective Evaluation Test

We performed subjective evaluation test employing recorded environmental noise to verify the correlation LAeq with loudness sensation. Reproduced environmental noise were the time

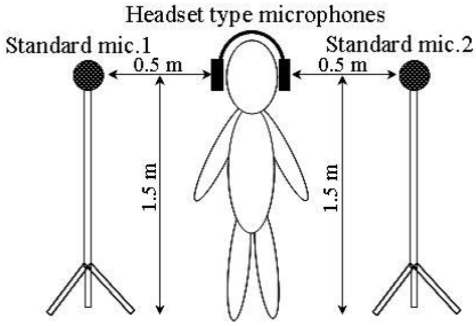

Figure 1: Measurement condition of environmental noise. Head set type microphones and standard type microphones were employed. The experimenter attached the head set type microphones and the standard microphones were set 0.5 m away from the head set type microphones. The height of these microphones were 1.5 m.

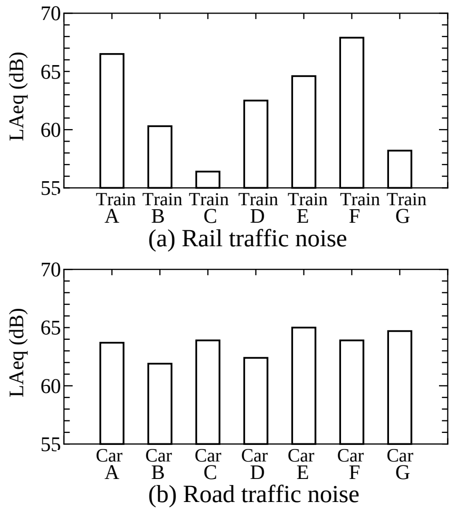

Figure 2: LAeq calculated from the signals from rail traffic noise and road traffic noise. (a) is LAeq of rail traffic noise and (b) is LAeq of road traffic noise.

signals measured by the headset type microphones. The subjective evaluation test was performed separately to each rail traffic noise and road traffic noise by employing paired comparison method. In the evaluation test, the environmental noise was reproduced from personal computer (PC) via headphones (HEAD acoustics MHS3). The headphones were identical with the headset type microphones used for the measurement of environmental noise. After presenting a pair of the environmental noise to the experimental subject, we asked the subject to answer the following question: “Which sound is felt louder, the first sound or the second sound?” on the test sheet. There were 21 evaluation pairs in each test of rail traffic noise and road traffic noise because seven evaluation sounds exist in each noise. These evaluation pairs were evaluated randomly in one session, and each subject performed five sessions separately. There are, therefore, 105 pairs were evaluated in each subject in each sound type (rail traffic noise and road traffic noise). Five male subject aged from 20 to 22 years old who have normal hearing acuity participated in this evaluation test. Therefore, 525 trials were performed in all subject in each sound type and 1,050 trials were conducted in all. Figure 3 shows the subjective loudness averaged in all subject in each sound. Figure 3(a) is the loudness at rail traffic noise, and Figure 3(b) is the loudness at road traffic noise. The error bars in each figure show the 95% confidence intervals in each value. From these figures, the subjective loudness of rail traffic noise, that had wide LAeq range, is observed to be evaluated clearly. On the other hand, the loudness of road traffic noise, that had narrower LAeq range than that of railway noise, has wide 95%

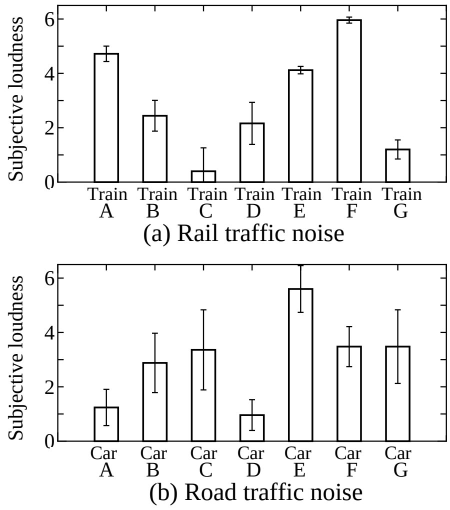

Figure 3: Subjective loudness of rail traffic noise and road traffic noise obtained from subjective evaluation test. (a) is the loudness of rail traffic noise and (b) is the loudness of road traffic noise. Error bars show the 95% confidence interval of each value.

confidence intervals comparing with that of rail traffic noise. Then, to verify the significance of the subjective loudness difference of road traffic noise and rail traffic noise, we performed analysis of variance (ANOVA). Table 1 shows the results of ANOVA.

Table 1: Result of analysis of variance to subjective loudness at rail traffic noise evaluation and road traffic noise evaluation.

Target	Rail traffic noise	Road traffic noise
Sign.Prob.	0.000*	0.000*

∗: Significance level 0.05

These results indicate that there is significantly difference among the subjective loudness not only at rail traffic noise but also at road traffic noise when the significance probability is set at 0.05. This indicates the experimental subject evaluated the loudness of road traffic noise having small LAeq range clearly as same as rail traffic noise. Also, the fact, in which the subject can evaluate the loudness clearly even if their LAeq difference is small, means LAeq has a possibility to be difficult to express the subjective loudness accurately when LAeq difference is small.

Correlation LAeq with Subjective Loudness

Next, we evaluated the correlation LAeq with the subjective loudness to verify how degree LAeq expresses the loudness feeling of human beings. Figure 4 shows the relationship between LAeq and subjective loudness of rail traffic noise. The horizontal axis shows LAeq and the vertical axis shows subjective loudness obtained by the subjective evaluation test. In the figure, LAeq correlates the subjective loudness very well and the correlation coefficient is very high at 0.97.

Figure 5 shows the relationship between LAeq and the subjective loudness of road traffic noise. In this figure, the correlation between LAeq and subjective loudness at road traffic noise is not so high and the coefficient was 0.62. From these results, LAeq was clarified to be hard to express the loudness feeling accurately to road traffic noise measured in this experiment. The reason, why LAeq of road traffic noise could not express the loudness sensation very well, is considered the LAeq range of road traffic noise was narrower than that of rail traffic noise. However, the experimental subject evaluated the loudness clearly to the road traffic noise. This result indicates

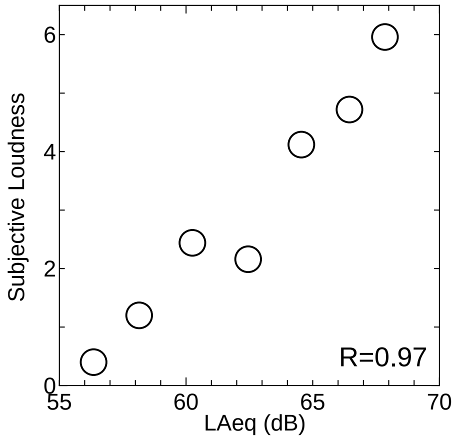

Figure 4: Relationship between LAeq and subjective loudness of rail traffic noise. The horizontal axis indicates LAeq and the vertical axis indicates subjective loudness obtained from the subjective evaluation test. R value means correlation coefficient between LAeq and loudness.

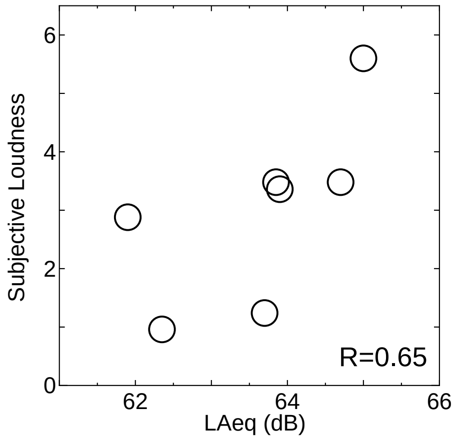

Figure 5: Relationship between LAeq and subjective loudness of road traffic noise. The horizontal axis indicates LAeq and the vertical axis indicates subjective loudness. R value means correlation coefficient between LAeq and loudness.

the calculation or measurement procedure of LAeq may not include some functions to express the subjective loudness of human beings accurately. Therefore, it is necessary to consider new environmental noise index suitable for evaluating subjective loudness.

CONSIDERATION OF NEW INDEX

In this section, we consider new environmental noise evaluation index for increase the correlation with subjective loudness at road traffic noise, where the correlation was not high enough. Also, the environmental noise evaluation index should be obtained easily, therefore, we considered the index not to become complex index than LAeq.

Applying Head Related Transfer Function

To increase the accuracy of the evaluation index, we considered two characteristics, the one is the transfer characteristics from sound source to eardrum and the other is the perception characteristics after the signal arrived at eardrum. When we listen to a sound, the frequency characteristics of the signal is affect by the head related transfer function (HRTF) from the sound source to ear. Therefore, applying HRTF to the signal is considered to increase the correlation with subjective loudness. But the standard type microphone employed in the measurement of the environmental noise at present is not able to measure the sound signal affected by HRTF. Then, we thought to measure the environmental noise including the HRTF by employing artificial head microphones at first. However, the artificial head microphones is expensive and large system. Therefore, it is difficult to be the new index as simple and easy index as LAeq.Then, we tried to measure the environmental noise by using head set type microphones, those were used for the measurement of the signal employed in the subjective evaluation test. The frequency characteristics measured by the head set type microphones varies a little depending on the experimenter who attached the microphones because the body and head shapes are different among each other. But we can obtain the environmental noise affected by generally same HRTF and the system for the measurement of new index becomes as simple as LAeq. Therefore, we considered using the head set type microphones is appropriate for the environmental noise evaluation. Then, new index was calculated from the signal measured by using the head set type microphones. The calculation procedure of new index was identical with that of LAeq except for using the head set type microphones instead of standard microphone. We averaged the value at left ear and the value at right ear of the head set type microphones, and called the new index as LhAeq. Figure 6 shows the relationship between LhAeq and subjective loudness. The result shows the correlation coefficient between LhAeq and subjective loudness increased at 0.71 than that of LAeq (0.65). From these analytical result, it was clarified that the index could express subjective loudness more accurately by applying HRTF.

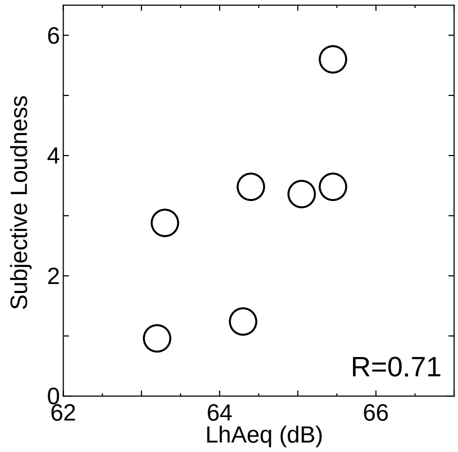

Figure 6: Relationship between LhAeq and subjective loudness of road traffic noise. The horizontal axis indicates LhAeq calculated from the signal measured by using the head set type microphones and the vertical axis indicates subjective loudness. R value means correlation coefficient between LhAeq and loudness.

Applying D-Weight

Next, we considered the perception characteristics after the signal arrived at eardrum. In the calculation of LAeq, A-weighting frequency curve are employed. The A-weighting curve based on 40-phon curve in equal loudness contour, in which sound pressure level is adjusted to subjective loudness of pure tone [8]. In practically, the environmental noise is considered to consist of band noise mainly not only pure tone, and the loudness evaluation to environmental noise is considered to be affected by the annoyance perception characteristics. Then, we tried to apply D-weighting curve instead of A-weighting curve. D-weighting curve was defined by Karl Kryter and weighting characteristic based on 40 noy curve, in which the sound pressure level is adjusted to subjective noisiness of band noise [9, 10, 11]. Then, we calculated new index by applying D-weighting to the signal measured by the standard type microphones. The other calculation method of new index was identical with that of LAeq. We averaged the value at left side and the value at right side of the standard microphones and called the new index as LDeq. The relationship between LDeq and subjective loudness is shown in Fig. 7. From this figure, the correlation of

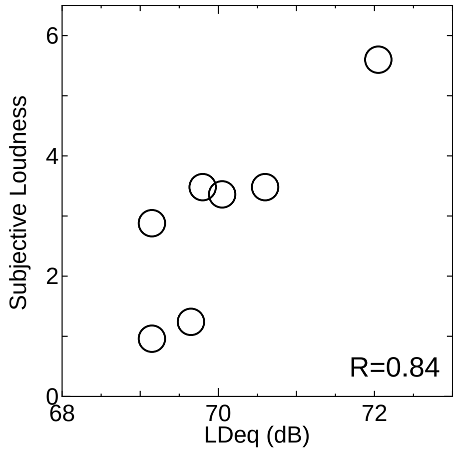

Figure 7: Relationship between LDeq and subjective loudness of road traffic noise. The horizontal axis indicates LDeq calculated by using D-weighting instead of A-weighting and the vertical axis indicates subjective loudness. R value means correlation coefficient between LDeq and loudness.

LDeq is found to be increased at 0.84 than that of LAeq (0.65). This result indicates that the new index applying D-weighting instead of A-weighting can express the subjective loudness accurately.

New Environmental Evaluation Index

Through the experiments and analyses, it was clarified that applying HRTF and D-weighting increases the correlation to subjective loudness. Then, we applied the D-weighting characteristics to the signal measured by the head set type microphones and calculated new environmental evaluation index. We called the new index as LhDeq. The relationship between LhDeq and subjective loudness is shown in Fig. 8. As results, the correlation coefficient between LhDeq and subjective loudness increase very steeply at 0.91 than that of LAeq (0.65). Also, the coefficient was increased from that of LhAeq (0.71) and that of LDeq (0.84). This indicates the new environmental evaluation index can express the subjective loudness at road traffic noise very accurately by applying both HRTF and D-weighting.

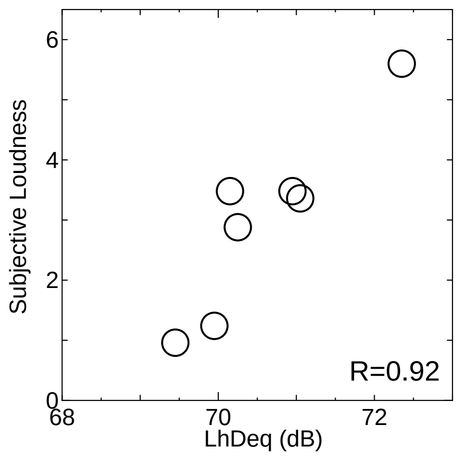

Figure 8: Relationship between LhDeq and subjective loudness of road traffic noise. The horizontal axis indicates LhDeq calculated from the signal measured by using the head set type microphones and by applying D-weighting. The vertical axis indicates subjective loudness. R value means correlation coefficient between LhDeq and loudness.

Next, we verified whether the new index can evaluate the loudness at rail traffic noise. The result is shown in Fig. 9. The correlation coefficient between LhDeq and subjective loudness at rail traffic noise decreased a little at 0.94 than that of LAeq (0.97). But the coefficient is still very high and over 0.9, therefore, LhDeq is considered to be able to express the subjective loudness very accurately both at rail and road traffic noise. In addition, as the important point to consider the environmental noise evaluation index, the index should be easy to be measured and calculated similar with those of LAeq. In this point, LhDeq could be obtained almost same procedure as that of LAeq described in Fig 10. From these consideration, we could make a new environmental noise evaluation index that can express the loudness perception at high accuracy and can be obtained by employing simple procedure as same as that of LAeq.

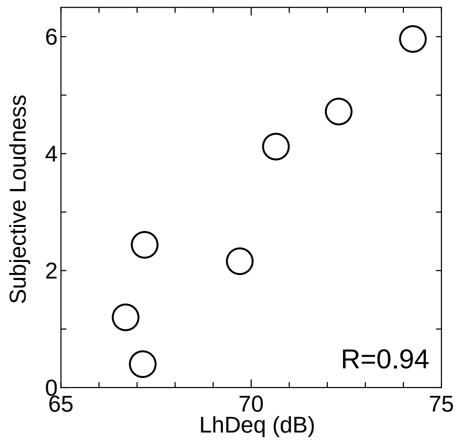

Figure 9: Relationship between LhDeq and subjective loudness of railway noise. The horizontal axis indicates LhDeq and the vertical axis indicates subjective loudness. R value means correlation coefficient between LhDeq and loudness.

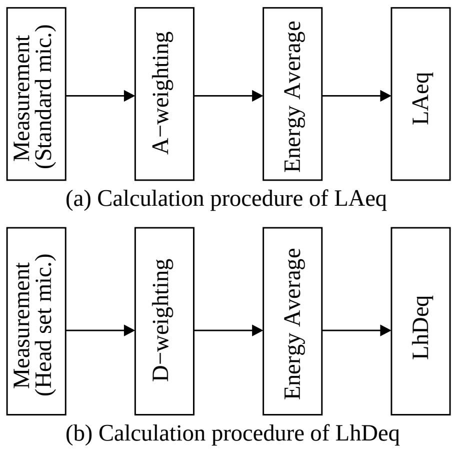

Figure 10: Measurement and analysis procedure of LAeq and LhDeq. (a) shows the procedure of LAeq and (b) shows the procedure of LhDeq.

CONCLUSION

In this study, we verified how degree LAeq express the loudness perception of human beings through the measurement of environmental noise and the subjective loudness evaluation test, and considered new environmental noise evaluation index. As results, the follows were clarified.

1. The correlation LAeq with subjective loudness was very high (correlation coefficient is 0.97) at rail traffic noise evaluation, But the correlation LAeq with loudness was low (0.65) at the road traffic noise evaluation.
2. By applying D-weighting characteristic instead of A-weighting to the environmental noise measured by using head set type microphones, the new index (LhDeq)

can express the loudness very well. The correlation coefficients between LhDeq and the loudness were over 0.9 at both condition (rail traffic noise and road traffic noise).
3. The LhDeq could be obtained as easy as that of LAeq.

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