Abstract
An experiment was conducted concerning the effect of frequency characteristics of sound insulation on the impression of rail noise including super express train. Using semantic differential participants judged the impression of four kinds of noise which were simulated as if they were transmitted through facades having various sound transmission characteristics. The following results were found: (1) The sound quality of rail noise was judged to be more powerful, fluctuating, metallic and unpleasant as the values of $L_{Aeq}$ became higher. When overall values of $L_{Aeq}$ were equal, the impression of “shrill”, “metallic” or "hard" became stronger for the direct sounds than for transmitted sounds. On the other hand, the impression “calm” became stronger for the sound equalized by a filter of 5 dB/oct. than for direct sounds. (2) Four factors were extracted by the factor analysis: "dynamic", "unpleasant", "metallic", and “rough” factors. (3) According to the physical analysis, the sound quality of rail noise was judged to be more unpleasant as higher became the value of $L_{Aeq}$. The results in this experiment were compared with the former studies using road traffic noise and aircraft noise and similar results were found among the results with the three sound sources. A cognitive aspect of unpleasantness was discussed on the basis of these results.

1. Introduction
Subjective impressions of environmental noise have two aspects: quantity and quality. Quantitative aspect corresponds to the sound pressure level and causes the sensation of loudness. Qualitative aspect corresponds to not only sound pressure level but also frequency characteristics or temporal variation. Namba [1] suggested that loudness has a large effect on sound quality. When the effects of quantitative aspect decreased, it would be important to consider the effects of qualitative aspect. Several experiments have been conducted on sound quality of machine noise using semantic differential [2]. Hatoh et al. [3, 4], and Kuwano et al. [5] examined the impression of road traffic noise and aircraft noise transmitted through simulated walls and windows. The results suggested that the frequency characteristics of transmission loss had an effect on the impression of “metallic”. The value of $L_{Aeq}$ and calculated sharpness influenced the impression of annoyance.

The present study was designed to examine the effects of sound reduction of walls and windows on the impression of loudness and sound quality using rail noise and the noise metrics were compared taking the frequency characteristics into consideration.

2. Experiment
2.1. Stimuli
The local rail passing noises were recorded using a sound level meter (RION NL-05) and a DAT recorder (SONY TCD-10) beside the edge of the track of Chuo line in Kokubunji City. The noises from super express train were also recorded using the same facilities in Hiratsuka City in Kanagawa Prefecture.

The types of rail noise were as follows:
Stimulus 1:Conventional train with motor fan noise.
Stimulus 2:Conventional train without motor fan noise.
Stimulus 3:Super express train with noise barrier.
Stimulus 4:Super express train without noise barrier.
The speed of trains of stimuli 1-2 and stimuli 3-4 was 80-100 km and 235-273 km per an hour, respectively. In stimulus 1 high frequency components(4000-8000 Hz) were dominant, in stimulus 3 low frequency components(32-63 Hz) were dominant.
The recorded sounds were edited for the experiment. The duration of the stimuli was about 20 s. Four kinds of frequency characteristics were prepared using a digital filter (FFT Filter of Cool Edit Pro) as shown in Fig.1 (a) – (d). They were simulated to direct sound for filter A, concrete block for filter B, a single glass for filter C, paired glass for filter D, light bubble concrete board for filter E.

The frequency characteristics of the loudspeaker were checked at the position of subject’s ears using 1/1 oct. band filters. Three kinds of A-weighted sound pressure level were used, i.e. 45, 55 and 65 dB in L_{A\text{eq}20S}(abbreviated as L_{A\text{eq}}). Therefore in total 60 kinds of stimulus were used.

2.2. Procedure

The impression of the sound was judged using semantic differential. 60 sounds were presented to subject in random order. 19 pairs of adjective scale (Table 1) were prepared and each adjective scale was presented on a computer monitor one after the other in random order. Participants were asked to judge the impression in 7-point scale and respond with a keyboard of a computer. Two trials were conducted after training for each subject in different days. Before the trials participants judged three sounds for practice.

2.3. Apparatus

Stimuli were reproduced with a DAT recorder (PIONEER D-05) and presented to participants through an amplifier (SONY F222WSJ) and a loudspeaker (DIATONE DS-500ZX) in a sound proof room of Osaka University. The distance from the head of subject to the loudspeaker was 1.9 m.

2.4. Participants

Six female and fourteen male participants, aged between 19 and 25, with normal hearing participated in the experiment.

3. Results

3.1. Reliability of the judgments

The coefficient of correlation between two trials of cue sounds was calculated for each participant. Statistically significant correlation was obtained for 17 participants. Therefore, the following analyses were conducted with the data of 17 participants.

3.2. Impression of the sound

3.2.1 Effects of sound level

An example of the effect of sound level is shown in Fig.2. These are the profiles for the sounds of super express train with noise barrier through Filter B. It can be seen that the lower the sound level became, the milder the impression became in most of the adjective scales. This suggests that the sound level has a great effect on various impressions of the sounds.

However, in some adjective scales such as “hard-gentle”, other physical properties seem to play more important role than sound level (Friedman two–way analysis of variance by ranks were taken from now on, p<.05).

3.2.2 Effect of frequency characteristics of sound transmission

An example of the effect of frequency characteristics is shown in Fig.3. These are the profiles for the sounds of: super express train with noise barrier in 65 dBA. The difference is clearly seen especially in the impressions such as “shrill-calm (p<.05)”, “metallic-deep (p<.05)” and “hard-gentle (p<.05)”.

II - 1788
From the results of multiple comparison the sound with filter “B” might be perceived as having the best sound quality among the five filter conditions. Also concerning the adjective scales such as “swing-not swing (p<.05)”, filter “D” was perceived better among the five filters. The same tendencies were found when the sound levels were 55 dBA and 45 dBA, though the difference was small when $L_{Aeq}$ was 45 dBA.

3.3. Factor analysis

The result of factor analysis using principal factor method is shown in Table 1. Four factors over “1” characteristic root were found by the principal component analysis. Accumulate amount of contributions of these four factors was 0.63. It could be explained that these factors could express over the half of the results.

Factor 1 shows a high loading for adjective scales, “loud” and “powerful”. Factor 1 can be interpreted as “dynamic”. Factor 2 shows a high loading for adjective scales “discordant”, “unpleasant”, “dirty” and “bad”. Factor 2 can be interpreted as “unpleasant”. Factor 3 shows a high loading for adjective scales “shril” and “metallic”. Factor 3 can be interpreted as “metallic”. Factor 4 shows a high loading for adjective scale “rough”. Factor 4 can be interpreted as “rough”.

3.4. Relation between subjective impressions and physical values

It was found that the sound level has a great effect not only on the impression of loudness but on various impressions. On the other hand, the effect of frequency characteristics of sound transmission was mainly found on the adjective scale “metallic” even when the $L_{Aeq}$ values were equal.

In order to predict the sound quality of rail noise transmitted through walls, some physical metrics were calculated and related to the subjective impressions. They were: $L_{Aeq}$, sharpness [6], fluctuation strength [7] and roughness [8]. Sharpness, fluctuation strength and roughness, sampled every 2, 1000, and 100 msec, respectively, were measured by the work station (Cortex Psychoanalyser CF90) and maximum values were used in the data.

The coefficients of correlation between each physical metric and subjective impression were calculated. The value of $L_{Aeq}$ showed high correlation over 0.70 with the impression of most adjective scales except for “calm-shril” and “metallic-deep”. The calculated sharpness was well correlated with the subjective impression of metallic factors(r>.70).

![Fig.3 Example of semantic profiles (Super express train with noise barrier in 65 dBA).](image)

![Fig.4 Relations between calculated unpleasantness and psychological impression (Road traffic noise).](image)

Table 1 List of adjective scales used in experiment and results of factor analysis.

<table>
<thead>
<tr>
<th>adjective</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>loud-soft</td>
<td>0.78</td>
<td>-0.31</td>
<td>0.16</td>
<td>-0.15</td>
</tr>
<tr>
<td>distinct-soft</td>
<td>0.40</td>
<td>-0.01</td>
<td>0.61</td>
<td>-0.07</td>
</tr>
<tr>
<td>powerful-unsatisfactory</td>
<td>0.01</td>
<td>-0.19</td>
<td>0.14</td>
<td>-0.18</td>
</tr>
<tr>
<td>shrill-calm</td>
<td>-0.23</td>
<td>0.05</td>
<td>-0.67</td>
<td>0.07</td>
</tr>
<tr>
<td>metallic-deep</td>
<td>0.00</td>
<td>-0.22</td>
<td>0.75</td>
<td>0.05</td>
</tr>
<tr>
<td>hard-metallic</td>
<td>0.23</td>
<td>-0.26</td>
<td>0.49</td>
<td>-0.27</td>
</tr>
<tr>
<td>rough-powerful</td>
<td>0.29</td>
<td>-0.22</td>
<td>0.16</td>
<td>-0.80</td>
</tr>
<tr>
<td>wavy-noisy</td>
<td>0.16</td>
<td>-0.25</td>
<td>0.19</td>
<td>-0.60</td>
</tr>
<tr>
<td>unbalanced-rough</td>
<td>-0.22</td>
<td>0.78</td>
<td>-0.29</td>
<td>0.20</td>
</tr>
<tr>
<td>fluctuating-not fluctuating</td>
<td>0.06</td>
<td>-0.23</td>
<td>0.11</td>
<td>-0.19</td>
</tr>
<tr>
<td>swing-not swing</td>
<td>0.55</td>
<td>-0.35</td>
<td>0.11</td>
<td>-0.29</td>
</tr>
<tr>
<td>dynamic-static</td>
<td>0.58</td>
<td>-0.30</td>
<td>0.30</td>
<td>-0.15</td>
</tr>
<tr>
<td>rich-poor</td>
<td>0.55</td>
<td>0.00</td>
<td>0.10</td>
<td>-0.07</td>
</tr>
<tr>
<td>thick-clear</td>
<td>-0.22</td>
<td>0.44</td>
<td>0.20</td>
<td>0.56</td>
</tr>
<tr>
<td>unpleasant-pleasant</td>
<td>-0.27</td>
<td>0.75</td>
<td>-0.28</td>
<td>0.13</td>
</tr>
<tr>
<td>dirty-unbalanced</td>
<td>-0.20</td>
<td>0.74</td>
<td>-0.03</td>
<td>0.33</td>
</tr>
<tr>
<td>bad-beautiful</td>
<td>-0.18</td>
<td>0.77</td>
<td>-0.11</td>
<td>0.27</td>
</tr>
<tr>
<td>noisy-quiet</td>
<td>0.67</td>
<td>-0.44</td>
<td>0.32</td>
<td>-0.14</td>
</tr>
<tr>
<td>annoying-not annoying</td>
<td>0.65</td>
<td>-0.46</td>
<td>0.26</td>
<td>-0.13</td>
</tr>
</tbody>
</table>

![chart1](chart1)

![chart2](chart2)
4. Discussion

It is not easy to find appropriate physical metrics for the “unpleasant” impression since various factors may have an effect on the impression of “unpleasant”, such as cultural and cognitive factors as well as physical properties of the sounds. However it may be possible to find appropriate physical metrics for the “unpleasant” impression if the situation is limited. In this study, sounds are limited to the rail noise transmitted into buildings.

In the former study the combination of $L_{Aeq}$ and sharpness showed good correlation with the impression of unpleasantness [5]. The round numbers of weighting, 0.1 and 1.0, were used for $L_{Aeq}$ and sharpness, respectively. The regression coefficients for road traffic and aircraft noise were very high as shown in Figs.4 and 5. The same model was examined for rail noise in this experiment. The result is shown in Fig.6. Fairly good correlation can be seen though the coefficient of correlation is a little lower than those for aircraft noise and road traffic noise. This may be due to the fact that various conditions of rail noise, with and without motor noise and noise barrier, were used in this experiment.

When this model applied to the three kinds of noise sources together, the value of the coefficient correlation decreased. In the case of unpleasant impression, cognitive aspect may affect the response. To estimate unpleasant impression of different kinds of noise sources using physical measure, it is better to apply the measure for each sound source separately.

5. Final Remarks

The following results were found:

1. The result of this study shows that $L_{Aeq}$ values have a great effect on the subjective impression of a rail noise transmitted through walls and windows.

2. When $L_{Aeq}$ values are equal, the frequency characteristics of sound reduction of walls and windows may affect the sound quality.

3. The combination of $L_{Aeq}$ and sharpness showed fairly good correlation with the unpleasant impression as in the former study.

It is important to take the frequency characteristics of walls and windows into considerations in order to improve the sound quality of indoor noises transmitted from outside.

6. References


