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RELATIONSHIPS AMONG VARIOUS SINGLE-NUMBER INDICES FOR SOUND INSULATION OF BUILDING WALLS

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1. INTRODUCTION

Air-borne sound insulation is a very important property of buildings. In order to measure and evaluate this property reasonably, various methods have been proposed and standardized in national and international standards. In ISO/TC43/SC2, the work to revise ISO 140 series (measurements) and ISO 717 series (rating) are being made. In Japan, we have unique national standards (JIS A 1417 and 1419), but they will have to be revised for international conformity. As a among representative single-number indices for airborne sound insulation in buildings and of building elements by using a lot of data obtained in Japan. Although these data include sound reduction index (sound transmission loss) of wall constructions, board materials and building elements and sound pressure level difference between rooms measured in actual buildings, they are pit together and treated homogeneously as the airborne sound insulation data in this study.

2. SINGLE-NUMBER INDICES

As the single numbers for the assessment of airborne sound insulation, the following indices were used for the rating in 1/3 octave band and in 1/1 octave bands, respectively. The rating procedures for representative indices are briefly introduced in the Appendix of this paper.

Single-numbers based on 1/3 octave band data

■ $X_w(1/3)$: the value evaluated from the data in 1/3 octave bands from 100 to 3150 Hz according to ISO DIS 717/1 and the existing ISO 717/1.

■ *STC* : the value evaluated from the data in 1/3 octave bands from 125 Hz to 4 kHz according to AStM E413.

■ $X_{A1}(1/3)$: the value calculated in the process of obtaining the spectrum adaptation term specified in ISO/DIS 717/1, calculated from the data in 1/3 octave bands from 125 Hz to 3150 Hz. This value means the A-weighted sound pressure level difference when a pink noise representing indoor noises is assumed as the loading noise.

■ $X_{A2}(1/3)$: the value calculated in the process of obtaining the spectrum adaptation term C_2 specified in ISO/DIS 717/1, calculated from the data in 1/3 octave bands from 125 Hz to 3150 Hz. This value means the A-weighted sound pressure level difference when a representative urban traffic noise is assumed as the loading noise.

Single-numbers based on octave band data

■ $X_w(1/1)$: the value evaluated from the data in octave bands from 125 to 2 kHz according to ISO/DIS 717-1.

■ $D_{JIS}(1/1)$: the value evaluated from the data in octave bands from 125 Hz to 4 kHz according to JIS A 1419.

■ $X_{w,J}(1/1)$: the value evaluated in the same weighting (curve shifting) method as in the case of rating $X_w(1/1)$ using the reference curve specified in JIS A 1419.

■ $X_{A1}(1/1)$: the similar value as $X_{A1}(1/3)$, evaluated from the data in octave bands from 125 Hz to 2 kHz.

■ $X_{A2}(1/1)$: the similar value as $X_{A2}(1/3)$, evaluated from the data in octave bands from 125 Hz to 2 kHz.

■ $X_{ave}(1/1)$: the arithmetic average of sound insulation data in octave bands from 125 Hz to 2 kHz. (This index was used in former days just for convenience, but through our recent psychoacoustic experiments it has been found that this index is a excellent estimator for the rating of sound insulation of building walls [1,2]. In this study, the arithmetic average of the levels of sound insulation in octave bands from 125 Hz to 2 kHz is adopted in accordance with

3. DATA OF SOUND INSULATION OF BUILDING WALLS

In this study, the following data obtained in Japan were used.

■ A-group : 837 data of sound reduction index measured in 1/3 octave bands from 100 Hz to 5 kHz for building walls, facades, board materials and elements (windows and doors).

■ A'-group : sound reduction index in octave bands from 125 Hz to 4 kHz calculated from the 1/3 octave band data mentioned above.

■ B-group : 892 data of mean sound pressure level difference between adjacent two rooms in octave bands from 125 Hz to 4 kHz measured in actual buildings.

4. RESULTS AND DISCUSSIONS

From the data of A and A' groups, the mutual relationships between five kinds of single-number indices were investigated. The results are shown in Table 1 and Fig.1 to Fig.4. In these results we can see the following tendencies.

1) In Fig.1, there exists a very high correlation (correlation coefficient:R=0.991) on the whole between $X_w(1/3)$ and STC which are based on a similar evaluation method. However, six samples are deviated; they have sharp insulation defects and they are evaluated low in STC according to the "8 dB rule".

2) In Fig.2, $X_w(1/3)$ and $X_w(1/1)$ are much highly correlated (R=0.993); their relationship can be simplified as

$$X_w(1/3) \approx X_w(1/1) + 1.1$$

3) In Fig.3, there also exists a high correlation between $X_w(1/3)$ and $X_{A1}(1/3)$ (R=0.982). While, in Fig.4, the correlation between $X_w(1/3)$ and $X_{A2}(1/3)$ is lower than the former case (R=0.922).

Table 1 Results of the regression analysis for the data of A and A' groups (correlation coefficient and rms value in the parenthesis)

	STC	$X_{A1}(1/3)$	$X_{A2}(1/3)$	$X_W(1/1)$
$X_W(1/1)$	0.991 (0.865)	0.982 (1.20)	0.922 (3.68)	0.933 (0.777)
STC	…	0.977 (1.34)	0.912 (2.62)	0.985 (1.09)
$X_{A1}(1/3)$	…	…	0.973 (1.49)	0.992 (0.812)
$X_{A2}(1/3)$	…	…	…	0.949 (2.01)

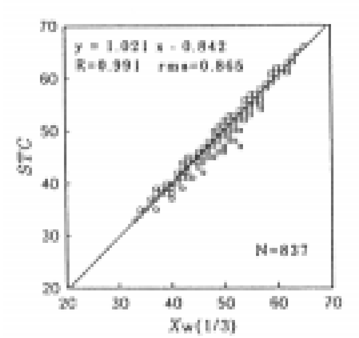

Fig.1 $X_W(1/3) - STC$

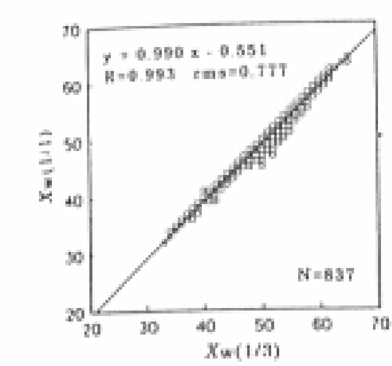

Fig.2 $X_W(1/3) - X_W(1/1)$

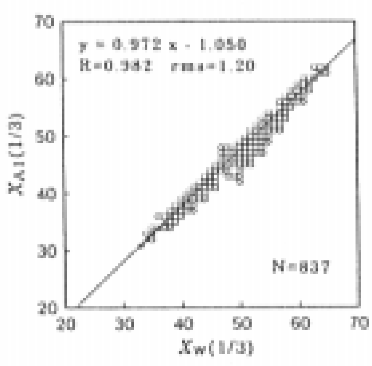

Fig.3 $X_W(1/3) - X_{A1}(1/3)$

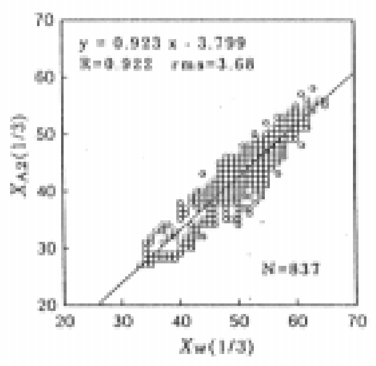

Fig.4 $X_W(1/3) - X_{A2}(1/3)$

From the data of A' and B groups (1729 in total), the relationships between six kinds of single-number indices were investigated. The results are shown in Table 2 and Fig.5 to Fig.9, and the following tendencies have been found.

4) In Fig.5, the correlation between $X_w(1/1)$ and $D_{JIS}(1/1)$ is low. This is because the rating method is much different between these indices. The results show that 2 or 3 grades difference can arise in $D_{JIS}(1/1)$ even if the rating in $X_w(1/1)$ is the same.

5) While, in Fig.6, a high correlation (R=0.982) can be seen between $X_{w,J}(1/1)$ and $X_w(1/1)$ on the whole. This result might indicate that the reference curves are not necessarily definite. (In the result, six samples are deviated in lower part. These samples are for building walls and elements with relatively low sound insulation in 2 and/or 4 kHz bands.)

6) In Fig.7 and Fig.8, we can see a high correlation (R=0.987) between $X_w(1/1)$ and $X_{A1}(1/1)$ and a bit lower correlation (R=0.940) between $X_w(1/1)$ and $X_{A2}(1/1)$ as in the case of 1/3 octave band rating mentioned above.

7) In Fig.9, there exists a high correlation (R=0.967) between $X_w(1/1)$ and $X_{ave}(1/1)$. Their relationship can be simplified as

$$X_W(1/1) \approx X_{ave}(1/1) + 2.9$$

8) In Fig.10, $X_{ave}(1/1)$ and $X_{A1}(1/1)$ are in relatively high correlation (R=0.950).

Table 2 Results of the regression analysis for the data of A' and B groups (correlation coefficient and rms value in the parenthesis)

	$D_{JIS}(1/1)$	$X_{W,J}(1/1)$	$X_{A1}(1/1)$	$X_{A2}(1/1)$	$X_{ave}(1/1)$
$X_W(1/1)$	0.933(2.40)	0.982(1.19)	0.987(1.00)	0.940(2.20)	0.967 (1.51)
$D_{JIS}(1/1)$	…	0.949(1.96)	0.944(2.02)	0.910(2.66)	0.896 (2.63)
$X_{W,J}(1/1)$	…	…	0.976(1.33)	0.926(2.43)	0.969 (1.46)
$X_{A1}(1/1)$	…	…	…	0.976(1.41)	0.950 (1.85)
$X_{A2}(1/1)$	…	…	…	…	0.894 (2.65)

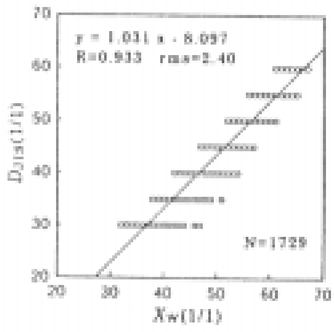

Fig.5 $X_W(1/1) - D_{JIS}(1/1)$

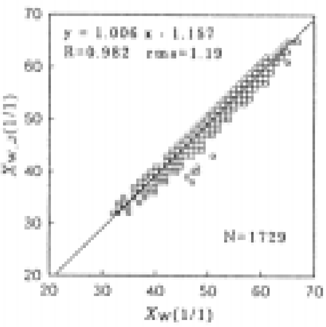

Fig. 6 $X_W(1/1) - X_{W,J}(1/1)$

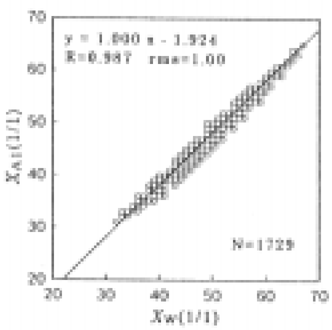

Fig. 7 $X_W(1/1) - X_{A1}(1/1)$

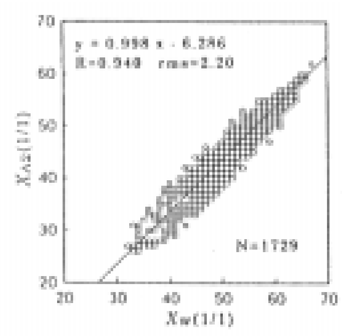

Fig. 8 $X_W(1/1) - X_{A2}(1/1)$

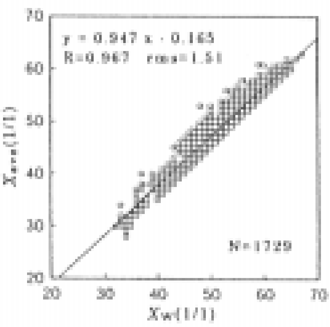

Fig. 9 $X_W(1/1) - X_{ave}(1/1)$

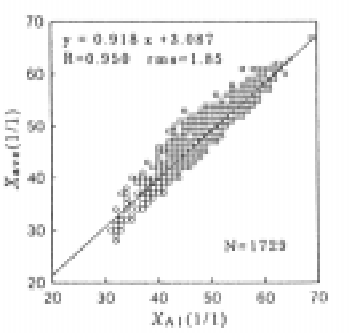

Fig.10 $X_{A1}(1/1) - X_{ave}(1/1)$

5. CONCLUSION

In this study, the relationships among representative single-number indices for evaluating airborne sound insulation in buildings and of building elements have been investigated by simple statistical analysis. X_W based on the weighting (curve shifting) method is again proposed in ISO/DIS 717-1 as the main single-number index. This index have been widely used in many countries, but it was originally proposed based on empirical stand point and the physical and psychoacoustic reason is not necessarily clear. On the other hand, X_{A1} and X_{A2} which mean A-weighted sound pressure level difference are simple and clear in these aspects. The arithmetic average of level difference X_{ave} which was used in former days simply because of convenience has been reevaluated by the authors through psychoacoustic experiments performed by concentrating upon loudness against transmitted sounds [1, 2, 3]. This index is very simple and easy to be calculated.

In recent international society, it is very important and necessary to establish true international standards. It holds true in the case of the topic treated in this paper. For this purpose, further basic investigations and discussions are necessary from physical and psychoacoustic viewpoints.

Acknowledgments
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References
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[2] M.Koyasu and H.Tachibana : Subjective tests on assessment of sound insulation efficiencies of building facades, Inter-noise 90, 155-158, 1990
[3] H.Tachibana et. al. : Validity of arithmetic average of sound pressure levels in octave bands as a loudness index, J.Acoust.Soc.Jpn.(E), 14(3), 197-204, 1993

APPENDIX

Evaluation of X_w

According to ISO/DIS 717-1, the relevant reference curve (Fig.A1) is shifted in steps of 1 dB towards the measured curve until the sum of unfavorable deviations is as large as possible but not more than 32.0 dB (16 third octave bands) or 10.0 dB (5 octave bands). The value, in decibels, of the reference curve at 500 Hz after shifting it according to this procedure is $X_w(1/3)$ or $X_w(1/1)$, respectively. ($X_w(1/3)$ and $X_w(1/1)$ used here mean sound reduction index, apparent sound reduction index, level difference, normalized level difference, or standardized level difference.) The assessment in octave bands have been newly introduced in ISO/DIS 717-1.

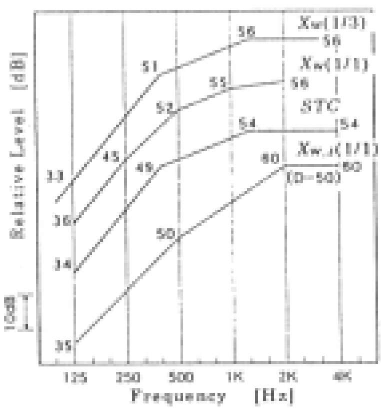

Fig. A1 Referenve curves

Evaluation of X_{A1} and X_{A2}

In ISO/DIS 717-1, the spectrum adaptation terms $C_j\,(j=1,2)$ is specified as a secondary indices. In the process to calculate these terms, X_{Aj} which mean the difference in A-weighted sound pressure level are to be calculated as follows.

$$C_j = X_{Aj} - X_w$$

$$X_{Aj} = -10\lg\sum 10^{(L_{ij}-X_i)/10}$$

where i is the index for the 1/3 octave bands from 100 Hz to 3150 Hz or the octave bands

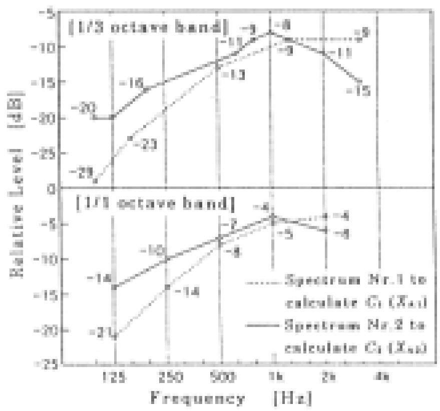

Fig. A2 Sound level spectra to calculate the spectrum adaptation terms from 125 Hz to 2000Hz, and L_{ij} is level as given in Fig.A2. In the figure, the spectrum Nr.1 is a A-weighted pink noise which represents general noises inside buildings and the spectrum Nr.2 is a A-weighted urban traffic noise. These terms means the level difference between the A-weighted sound insulation

Evaluation of *STC*

The value of *STC* specified in ASTM E413 is evaluated in similar way as in ISO 717-1 except that the reference curve is specified from 125 Hz to 4 kHz (see Fig.A1) and the maximum unfavorable value of 8 dB is specified (8 dB rule).

Evaluation of D_{JIS}

For the evaluation of airborne sound insulation of buildings in Japan, the reference curves shown in Fig.A3 is specified in JIS A 1419. In this figure, the dotted curves were added by the Architectural Institute of Japan. In this method, the mean sound pressure level difference between adjacent two rooms in each octave band from 125 to 4 kHz is plotted in the figure, and when the values exceed a certain reference curve at all frequency bands, the sound insulation grade is represented by the designation of that highest reference curve above stated. In the foregoing, the measured value for each frequency band may be added by 2 dB. The example plotted in Fig.A3 is rated as D-45.

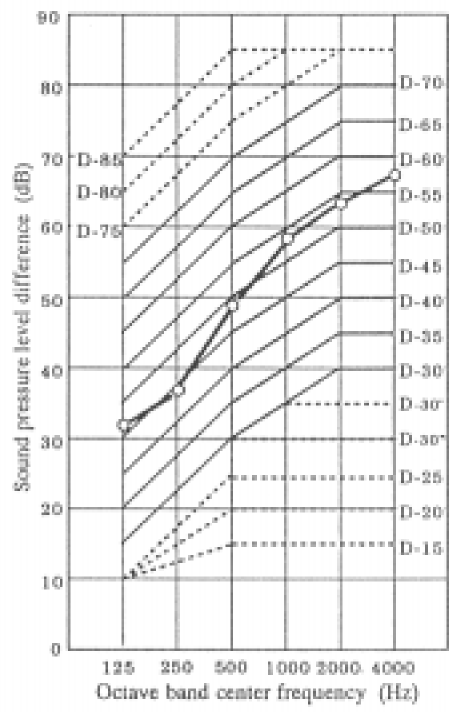

Fig. A3 Reference curves specified in JIS A 1419