Calculation and Measurement of Acoustic Factors for the Kirishima International Concert Hall

Tatsum # Nakajima* and Yoichi Ando t

* Takenaka Research Laboratory, 5-1-1 Ohtsuka Inzai, Chiba 270-1395 Japan and
† Graduate School of Science and Technology, Kobe University, Rokkodai, Nada, Kobe, 657-8501 Japan.

Abstract: The Kirishima International Concert Hall was designed by architect F. Maki with the Ando's acoustic design theory and opened on July 22, 1994. The 770 seat main hall, which has a volume of 8475 m³, was primarily designed for chamber music. Computer simulations were studied for a main hall with a plan like a 'leaf shape' and a cross section like the 'bottom of a ship' and with a ceiling of large euphonic triangles. We were aiming at getting a low IACC sound field in the front seats by sound reflections from walls on the stage as well as side walls. This paper shows typical systematic calculations of acoustic factors at each seat in the early design stage and the measured results for the main hall.

THE METHOD FOR THE NUMERICAL CALCULATION OF ACOUSTIC FACTORS

Acoustic factors, which independently affect subjective preference judgements, have been found to be listening level \(LL\), the initial time delay gap between the direct sound and the first reflection, \(\Delta t\), the subsequent reverberation time \(T_{\text{sh}}\) and the IACC. A computer simulation calculated these acoustic factors. The IACC calculation is expressed by

\[
IACC = \frac{\sum_{n=1}^{\infty} \beta^n A^n \Phi^n(\tau)^*}{\sqrt{\sum_{n=1}^{\infty} \beta^n A^n \Phi^n(0)^*}} \max_{|\tau| \leq 1.0 \text{ ms}}.
\]

Where \(A_n\) is the pressure amplitude of the \(n\)th reflection and \(\beta_n\) is sound pressure reflection coefficient of the boundary for \(n\)th reflection. Functions \(\Phi_{\text{left}}(0)\) and \(\Phi_{\text{right}}(0)\) are the autocorrelation at \(\tau = 0\) of the pressures of left and right ears, respectively. Function \(\Phi_{\text{cross}}(\tau)\) is the crosscorrelation function of signals at both ears. In the calculation of Eq. (1), discrete reflections are assumed and the effects of diffraction at low frequencies by seat rows are not taken consideration. This means that a simplified model of a room is adequate for a practical purpose.

In the calculation of Eq. (1), a simple method of calculating IACC was applied, which gives precise values of \(\Phi_{\text{left}}(0)\), \(\Phi_{\text{right}}(0)\) and \(\Phi_{\text{cross}}(0)\) for each frequency range of any sound source.

COMPARISON BETWEEN CALCULATED AND MEASURED RESULTS

In the calculation, the direct sound, and up to three time reflections at boundaries in the hall, were simulated according to the image method. Fig.1 show the measured results and the calculated IACC (for white noise) in the main hall. The calculations were carried out in the design process of the main hall considering effects of the main stage ceiling complex comprising large triangle flat plates (Nakajima et al., 1992). The audience width \(W\) of the computer simulation model is 17.9m, which is 1.8m smaller than that of the present hall (19.7m). Taking into account the width difference, the calculated and the measured values of \(LL\), \(\Delta t\), \(\Delta t\), \(\Phi_{\text{total}}\) (total amplitude of reflections) and IACC (for white noise) are in close agreement for all of the receiving points (Fig.1).

NUMBER OF REFLECTIONS NEEDED FOR IACC CALCULATION

In order to see how the IACC converges with arrival of reflections, values of IACC as a function of the number of reflections were calculated for octave bandpass noise (125Hz - 8kHz) and allpass noise. As shown in Fig.2, if the reflections arrive at a receiving point from side walls, then the IACC magnitude rapidly decreases. It converges to a final value when \(n = 40\).

Another studies for Boston Symphony Hall and Fujita Hall 2000 also show that the calculated IACC magnitude converges to a final value at \(n = 40\). Therefore, the number of reflections needed for predicting IACC is recommended to be \(n = 40\) during the design process.
CONCLUSION

We have summarized typical examples of calculations and measurements of acoustic factors of the sound field in the main hall of the Kirishima International Concert Hall. The calculated and the measured IACCs are good in agreement and the calculated CCFs correspond roughly with the measured values for its peak and for its position on the time delay axis.

Therefore, Eq. (1) by the use of a simple method of calculating IACC \(^3\) and \(n = 40\) were proved effective. This method is recommended for the practical IACC calculation during the design stage of a hall.

REFERENCES