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ACCURACY AND REPRODUCIBILITY OF AUDITORIUM ACOUSTICS MEASURES

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1.0 Introduction

The use of four types of newer acoustical quantities has become accepted as an important component of an assessment of the acoustical properties of a hall. We have developed software so that these measures can be calculated conveniently while in the hall using a portable computer and a Norwegian Electronics type 830 real time analyser[1]. The measurement system uses a specially modified calibrated blank pistol as a source, and each measurement is based on the mean of 4 shots to minimize the variations between blank cartridges. We have in several cases used the measurement system to identify acoustical problems in particular halls. Ongoing work to compare values obtained from the measurement techniques of different researchers and to measure the effect of small changes to a hall, have led to the present study to consider the accuracy and reproducibility of these quantities. Although there are many variations of each type of measure, a total of only 5 quantities are mentioned in this paper. In general, other quantities are found to be strongly correlated with one of these 5 measures.

C80 is a measure of the balance between clarity and reverberance and is defined as follows:

$$C80 = 10\log \left\{ \int_0^{.08} p^2(t)dt \Big/ \int_{.08}^{\infty} p^2(t)dt \right\}, \text{dB}$$

where p(t) is the instantaneous pressure response.

G is a measure of the overall strength or level relative to a fixed source strength, and is defined as follows:

$$G = 10\log \left\{ \int_0^{\infty} p^2(t)dt \Big/ \int_0^{\infty} p^2_A(t)dt \right\}, \text{dB}$$

where $p_A(t)$ is the anechoic pressure response at a distance of 10 m.

RT is the conventional reverberation time measured using the Schroeder integrated impulse response technique and using a straight line fit to the portion of the decay between -5 and -30 dB. The early decay time, EDT, was measured in a similar manner but over only the first 10 dB of decay. While RT values relate to other physical properties of the hall, EDT is more closely related to subjectively perceived reverberance. The lateral energy fraction, LF, is a measure of the fraction of the early arriving energy that arrives from lateral directions, and is related to the subjective sense of spatial impression. It is defined as follows:

$$LF = \int_0^{.08} p^2_L(t)dt \Big/ \int_0^{.08} p^2(t)dt$$

where $p_L(t)$ is the figure of eight microphone pressure response.

2.0 Accuracy and Reproducibility for One Source-Receiver Combination

To determine how reproducible the results were for individual source-receiver combinations, measurements at a particular location were repeated, including re-positioning the source and receiver, 5 times over a period of several hours. Figure 1 shows an example of the results for C80 values. Similar measurements were made with the source or the receiver moved 10 or 30 cm in each direction from the initial position. Figure 2 is an example of these results for the receiver moved 30 cm. in each direction.

It is easier to consider these differences by calculating the mean and the standard deviation about the mean for each condition. Figure 3 is an example of these standard deviations for C80 values. Measurements were made at 2 locations in the Opera of the National Arts Centre in Ottawa, and the larger of the 2 standard deviation results is plotted in each case in these figures. The lowest curve is the standard deviation of the repeated measurements at the same location, and thus indicates how accurately one can repeat the C80 measurement including the errors of re-positioning the source and receiver. At mid frequencies C80 values were repeated within just over 0.25 dB. It is also seen from Figure 3 that C80 values varied more as the source or receiver were moved further away from the central position, but that even a 10 cm. movement produced measurable changes. Thus to repeat a measurement, one must relocate the source and receiver very precisely. In the same hall we measured at a total of 42 source-receiver combinations. The standard deviation about the mean of all these measurements is also shown for comparative purposes. It is indicative of the spatial variations in this hall, but larger or smaller values could be found in other halls. The results of Figure 3 indicate that it is possible to measure sufficiently accurately to correctly describe the spatial variations of C80 values.

Figure 4 plots a similar set of standard deviations for G values. The errors on attempting to repeat a measurement at the same location were a little larger than for C80 values, because these results were also influenced by the small variations in the strength of the source from one shot to another. It is not possible to detect differences over a distance of only 10 cm, but the reproducibility is certainly sufficient to accurately characterize the spatial variations of G values in the hall.

The maximum standard deviations of EDT and RT values are shown in Figures 5 and 6 respectively. As expected it was more difficult to accurately repeat EDT measurements than RT measurements. However in both cases the measurements seem to be sufficiently accurate to characterize the spatial variation in the hall, and a movement of 30 cm or less led to readily measurable changes in these quantities.

Figure 7 plots the various maximum standard deviations for LF values. For LF values it appears that even a 10 cm movement of the source or the receiver can lead to measurable changes. The quite low overall mean LF values of this hall may contribute to the small spatial variation of LF values within the hall.

Small changes in the acoustical properties of the room, errors in re- positioning the source or receiver, as well as the constancy and directivity of the source would effect the accuracy of these measurements. In particular G values might be even more accurately repeatable with other types of sources, but more directional sources would introduce quantitatively unknown effects.

These results indicate how accurately each type of measurement can be reproduced and the errors that are likely from small differences in the position of the source or receiver. For G values it is also of interest to verify that they are of the correct absolute magnitude. To do this G values were measured at the 42 source-receiver combinations in this hall by both the gun impulse source method and with an ILG fan sound power source. The overall mean G values are compared in Figure 8. It is seen that the two methods agree within 0.5 dB or less in all octave bands above 125 Hz. While the gun source has been tested to be reasonably omni-directional, the fan source is not and so differences can occur depending on the orientation of the fan source. There are also problems measuring the necessary source sound power levels in a reverberation chamber sufficiently accurately at 125 Hz. In view of these practical limitations, it is thought that this result represents good agreement between the two methods.

Both G values and LF values are also dependent on the accuracy with which the microphone is calibrated and is stable over time. This is particularly a problem with LF values as two different microphones are involved and one of these must be a figure of eight pattern microphone. Thus one must use studio type microphones that are usually more difficult to calibrate and may be less stable over time. As an example, measuring an LF value of 0.2 with 0.5 dB calibration errors in each microphone could result in a measured value somewhere between 0.15 and 0.25. Thus while the need for careful calibration is obvious, there is perhaps a need for a more easily calibrated figure of eight microphone.

3.0 Accuracy of Measurement of Hall Mean Values

Even if each source-receiver combination is measured accurately, there is still the question of how many source and receiver positions are necessary to accurately determine the mean characteristics of a hall. This was examined by first comparing the mean results obtained for only one central source position with mean values over 3 separate source positions in the same Ottawa hall. C80 values changed by as much as 0.5 dB, G values by up to 1.0 dB, EDT values by up to .15 seconds, and RT values by as much as 0.04 seconds. The changes for these four measures were generally largest at lower frequencies with practically no effect at higher frequencies. LF values varied by as much as 0.05 with some smaller changes at all frequencies.

The question of the necessary number of source-receiver combinations was also considered by arbitrarily dividing the 42 combinations into four groups each containing 10 or 11 source-receiver combinations distributed over all parts of the hall. In this way one can determine the differences that would have resulted if only 10 or 11 source-receiver combinations had been used instead of 42.

Figure 9 plots the mean C80 values from each of these 4 groups with the overall mean of all source-receiver combinations. It is seen from this figure that using 1/4 of the positions could lead to differences of up to 1.0 dB relative to the overall mean values. As mean C80 values vary by only a few dB between halls[2], an error of 1.0 dB seems unacceptably large. Thus in this case 10 source receiver positions is not considered to be enough. Of course one does not know what errors are present with the mean of 42 source-receiver positions, but they would be smaller, perhaps varying approximately as the the square root of the number of source receiver positions used.

The mean G values for each of the 4 sub-groups and the overall mean values are shown in Figure 10. The maximum difference between the group means and the overall mean was approximately 0.8 dB and occurred at 2000 Hz. An error of almost 1.0 dB is again probably unacceptably large because the between hall variation of mean values is typically only a few decibels[2].

For EDT values, shown in Figure 11, the largest differences between the group means and the overall means were a little greater than 0.1 seconds except at 125 Hz where larger differences existed. RT values are not shown but the associated differences were smaller, reaching a maximum of approximately 0.02 seconds above 125 Hz.

Figure 12 compares the 4 group means and the overall mean LF values. The largest differences between the overall mean values and the group means was about 0.05. Gade[3] found hall mean LF values related to hall width, but his best fit regression line indicated changes of LF values of only 0.17 from 20 to 40 metre widths. Thus an error of 0.05 would appear to be quite significant.

It is difficult to generalize these results but in the case of this large hall increasing the number of measured source-receiver combinations from 10 to 42 produced useful increases in the accuracy of the overall mean values of all 5 quantities.

4.0 Conditions of the Hall

For two independent measurements of the same hall to achieve the same result, the hall must be in exactly the same condition. In some halls there may be many variables that may be difficult to repeat exactly. The details of the condition of the stage were found to be quite important. Measurements were made in Roy Thomson Hall in Toronto for combinations of 3 source and 3 receiver positions with and without music stands and some risers on the stage. In all cases the stands did not obstruct the direct path between the source and the receiver.

Figure 13 shows the measured mean C80 values for these two conditions, indicating that details of the stage conditions can vary the mean C80 values by 1 dB at frequencies above 125 Hz and more at 125 Hz. Figure 14 shows the effect of the stands and risers on G values. Here again the maximum differences are approximately 1 dB. The effect of the stands and risers on the EDT values produced differences of up to 0.15 seconds at medium and higher frequencies, and up to 0.2 seconds at lower frequencies. The effect on RT values are not shown and were much smaller. LF values were influenced most at 250 Hz where they changed by a little in excess of 0.1. At other frequencies the changes were much less.

5.0 Conclusions

These results give some preliminary indications of the reproducibility of individual measurements of 5 newer auditorium acoustics measures, and demonstrate the need to use quite large numbers of source-receiver combinations to accurately assess the overall hall mean values of each measure. It was found possible to make individual measurements sufficiently accurately to assess the spatial variation of the newer measures, and that measurable changes in these quantities occurred over distances of 30 cm or less. To obtain accurate hall mean values it is suggested that measurements should be made at a minimum of all combinations of 3 different source positions and 10 to 12 receiver positions in large halls.

References

[1] J.S. Bradley, and R.E. Halliwell, New Room Acoustics Measurement Software, JASA Vol. 80 S1, S39, (1986)

[2] J.S. Bradley, Progress in Auditorium Acoustics Measurements, Vancouver Symposium on Acoustics and Theatre Planning, Aug. 1986.

[3] A.C. Gade, Objective Measurements in Danish Concert Halls, Proceedings of the Institute of Acoustics (UK), 7(1), 9-16, 1985.

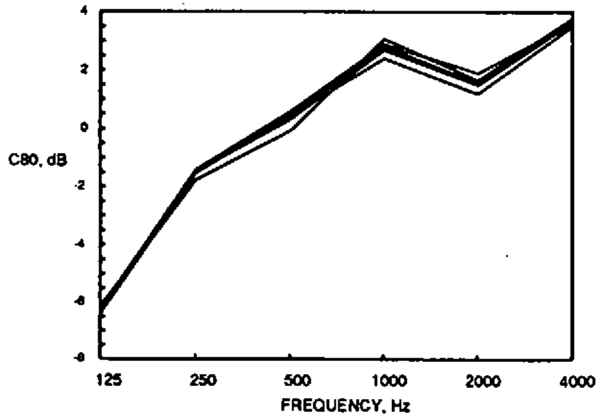

Figure 1. Repeated measurements of C80 versus frequency at seat W34.

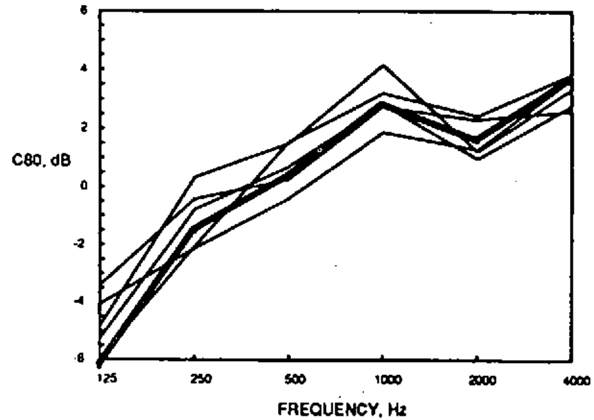

Figure 2. Effect of 30 cm. movement on C80 versus frequency at seat W34.

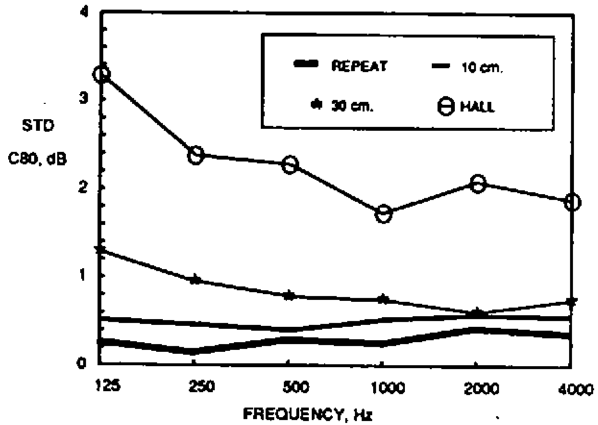

Figure 3. Maximum standard deviation versus frequency of C80 values.

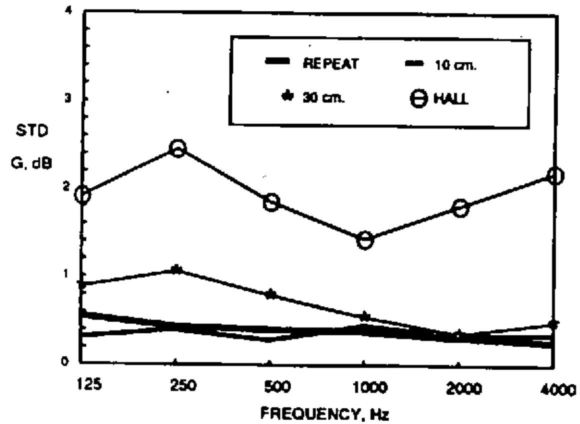

Figure 4. Maximum standard deviation versus frequency of G values.

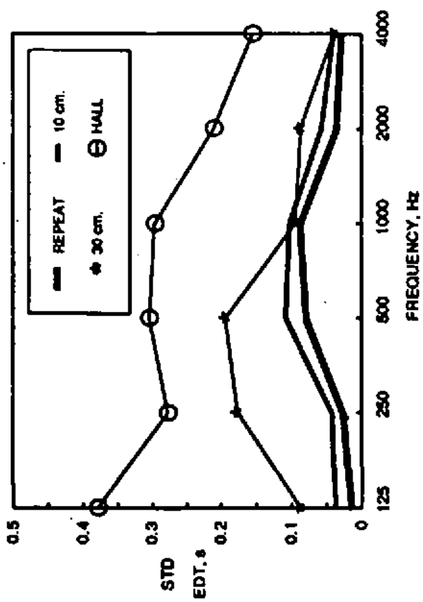

Figure 5. Maximum standard deviation versus frequency of EDT values.

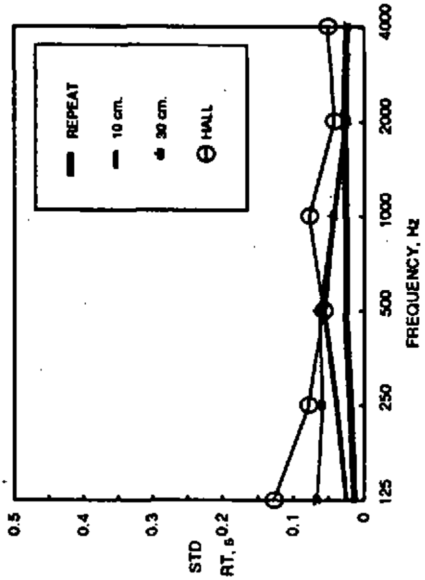

Figure 6. Maximum standard deviation versus frequency of RT values.

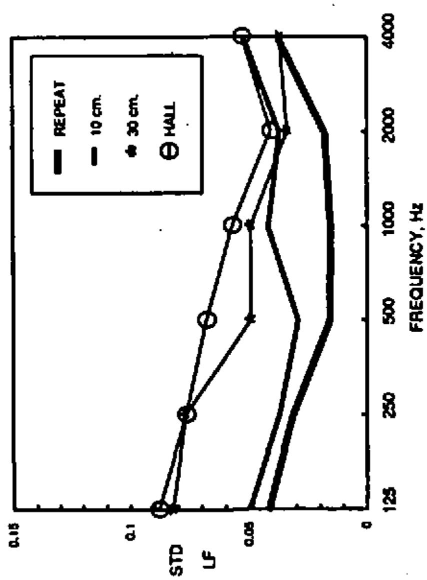

Figure 7. Maximum standard deviation versus frequency of LF values.

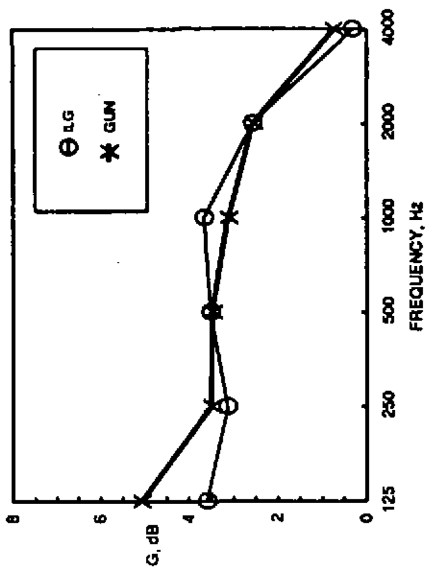

Figure 8. Comparison of mean G values versus frequency.

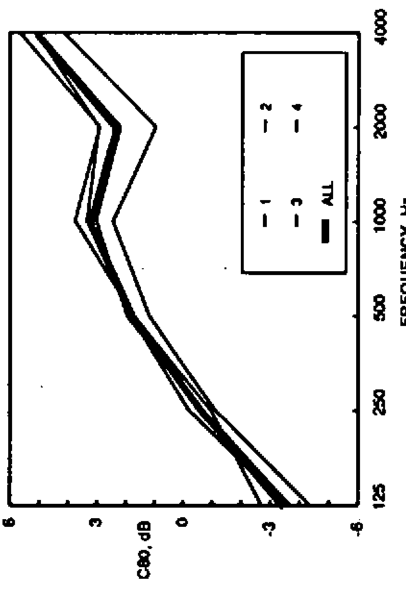

Figure 9. Mean C80 values for 4 groups and all source receiver combinations.

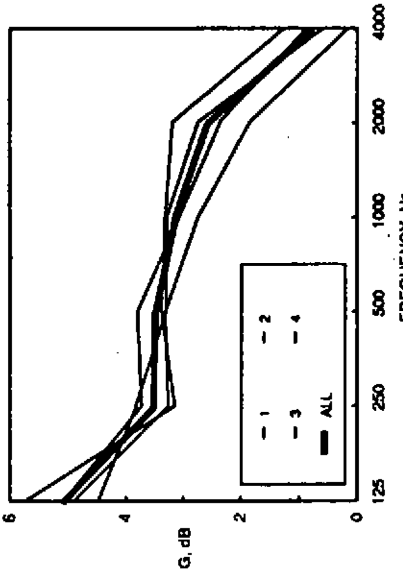

Figure 10. Mean G values for 4 groups and all source receiver combinations.

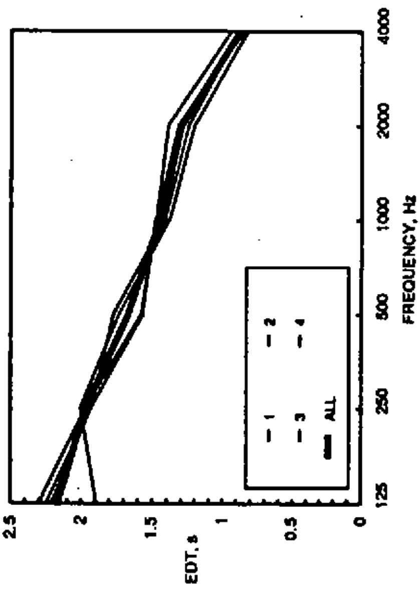

Figure 11. Mean EDT values for 4 groups and all source receiver combinations.

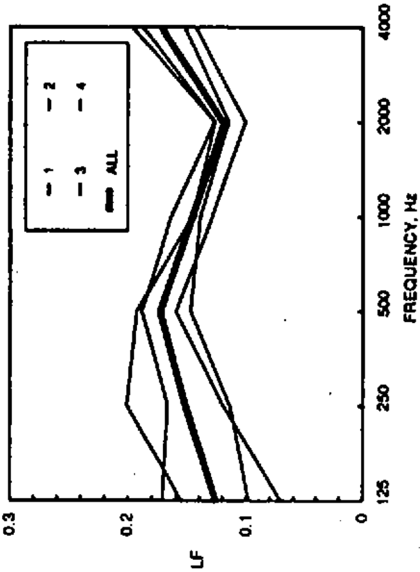

Figure 12. Mean LF values for 4 groups and all source receiver combinations.

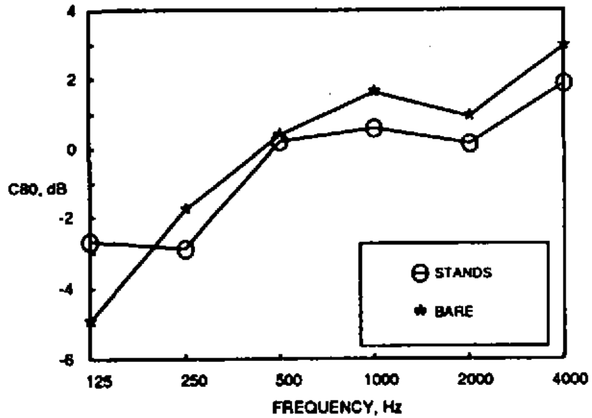

Figure 13. Mean C80 values with and without stands and risers on-stage.

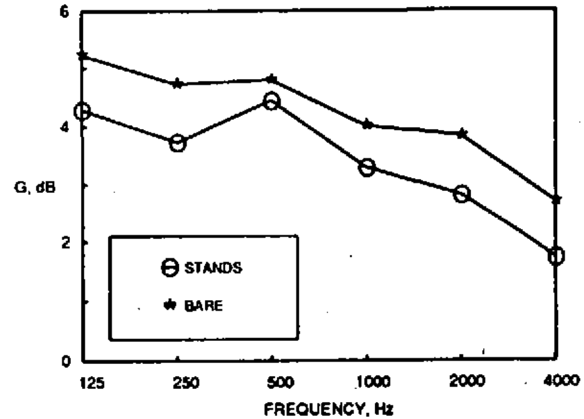

Figure 14. Mean G values with and without stands and risers on-stage.

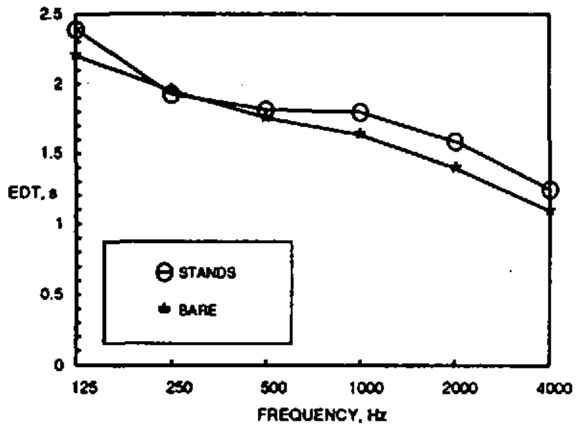

Figure 15. Mean EDT values with and without stands and risers on-stage.