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A note on the acoustics of orchestra rehearsal rooms

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ABSTRACT

The acoustical conditions of rehearsal rooms are of primary importance during the training process of an orchestra. Therefore these spaces should be specifically designed to allow the musicians to clearly hear themselves and each other. At the same time an appropriate sound level should be maintained to avoid extensive exposure to high pressure levels. Despite the peculiar role of these rooms in the musical production process, acoustic design criteria are not still sufficiently clarified. This paper deals with a description of a design process which, staring from simple formulas of a reverberant field, leads to investigate the relevance of geometrical and acoustical parameters on the final performance of a rehearsal room. The influence of the values of the ratio V/N (Volume/Number of musicians), S/N (floor surface/number of musicians), W/N (Sound power/Number of musicians) on objective acoustic parameters such as ST_{Early} (Early support) will be described. A guide line for the acoustic design of an orchestra rehearsal room will be finally proposed. Some specific case histories of rehearsal rooms will be discussed.

INTRODUCTION

Both in the case of renovations and of planning for a new rehearsal room the acoustician is asked to resolve a non banal problem. The room has to host a large number of musicians in a volume which is often subject to architectural constraints. Moreover the sound level has to be controlled to avoid excessive exposure and the space has to be properly acoustically designed to provide good communication between musicians and with the conductor. It is then clear that a good rehearsal room can be seldom a challenge in particular due to the risk of crowding under certain repertoire or when the composition of the orchestra is unbalanced towards the more powerful sections (i.e. brasses).

Moreover these types of rooms seem not particularly well documented in the literature since most of the works deal with rooms for both concert and rehearsal [1, 2] and just a few works seem specific for the rehearsal use only [3]. The difference in the destination of rooms is vital since it has to do primarily with the room volume, which is one of the key design parameters. From the point of view of the requirements and tools there is a rich literature for the orchestra platforms (see [4] for review) but to what extent these findings can be transposed to the design of orchestra rehearsal rooms is still to be investigated.

This work has the aim of providing a systematic approach to the design of such rooms and of focusing on a subset of parameters and values already considered appropriate from the current knowledge. Then the role and the interrelation of the most important design variables are represented by several charts that will guide the practitioner during the early design phases of the rehearsal room.

FORMULAS FOR PRELIMINARY DESIGN

Early support

The preliminary design steps can be taken over with the help of formulas derived by the so called revised theory applied to the definition of the parameters Early and Late Support defined in [5].

$$ST_{Early} = 10\,log\left(\frac{314}{Q_\theta}\frac{T_0}{V}\left(e^{-\frac{0.276}{T_0}} - e^{-\frac{1.38}{T_0}}\right)\right) \text{ [dB] (1)}$$

$$ST_{Late} = 10\,log\left(\frac{314}{Q_\theta}\frac{T_0}{V}e^{-\frac{1.38}{T_0}}\right) \text{ [dB] (2)}$$

Where: T_0 = reverberation time of the empty room (s)

V = Volume of the room (m^3)

Q_θ = Directivity factor of the source

Unfortunately the simple equations (1) and (2) have the limit of not taking into account any geometrical contribution to the energetic ratio defining the support parameter. As a result they proved to underestimate the support by a few dBs.

For this reason a more realistic tool can be developed by isolating the two outstanding first reflections of the reflective floor and ceiling which give an important energetic contribution to the denominator and numerator of the support ratio respectively. Fig. 1 depicts the geometry of this simple system for a room of height H.

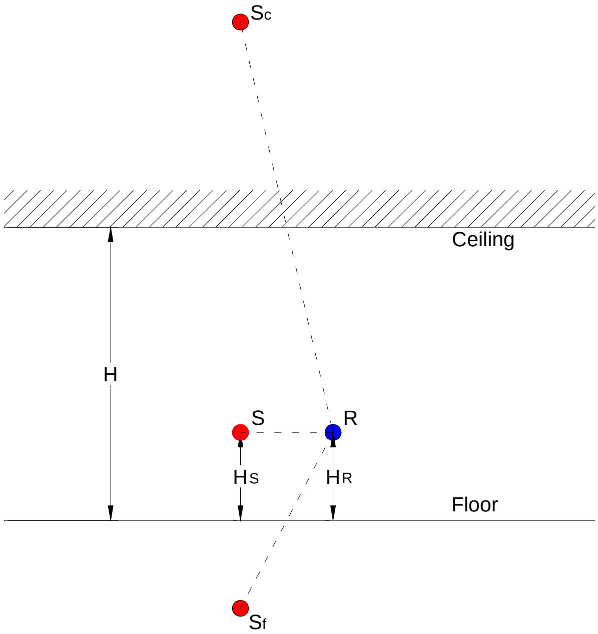

Figure 1. The geometry of floor and ceiling reflections. Both surfaces are assumed sound reflecting.

Note that in this case the first reflections from the lateral walls are not taken into account due to their intrinsic variability with the position. On the contrary the floor and ceiling reflections are almost the same in all of the positions of the performers. As a consequence it can be derived that this approach will be generally more effective for central room positions or when the lateral walls are highly diffusing or sound absorbing. Following the geometry of Fig. 1 it is straightforward to calculate the distances involved in the floor and ceiling reflections once the source-receiver distance is set to 1 m as mandatory in [5]. Also H_S and H_R must be equal even though they can be set in the interval ranging from 1 m to 1.5 m. In what follows H_S is set to 1.5 m. In formulas one then has:

$$\overline{S_c R}^2 = 4(H - H_s)^2 + 1 = r_c^{\,2}$$

$$\overline{S_f R}^2 = 4 H_S^{\,2} + 1 = r_f^{\,2}$$

$$\overline{SR} = 1\,m \quad \text{and} \quad H_S = H_R$$

The integral in the numerator of the support will be split in a first geometric contribution traced back to the ceiling and the statistical decay will start shortly after that: this is the reason why in the first exponential of Eq. 3 one finds the term r_c. On the other hand the denominator will include direct sound at 1 m and the reflection at r_f.

$$ST_{Early} = 10\,log\left(\frac{\dfrac{1}{r_c^{\,2}} + \dfrac{4\pi}{0.04}\dfrac{T_0}{V}\left(e^{-0.04\frac{r_c}{T_0}} - e^{-1.38\frac{1}{T_0}} \right)}{1 + \dfrac{1}{r_f^{\,2}}} \right) \quad \text{[dB] (3)}$$

A similar formula can be easily derived also for ST_{Late}. In this respect it is to be noted that, since we are dealing with rehearsal rooms, it was argued that reflections coming from relatively short distances would be more relevant. It is known in fact that ST_{Early} was conceived to assess the role of reflections from the surfaces of an orchestra platform, whose distances can be compared to those typical of rehearsal rooms. In other words, in this case there is not a concert hall giving a sort of feedback as described by the other support parameter, namely ST_{Late} .Thus this latter indicator seems to be not a design tool for rehearsal rooms as appropriate as the ST_{Early}.

Sound levels for performers

It is also possible to simply derive the relationship between the sound level in the room and the averaged sound power level of the musical instruments. The exercise will produce the formula (4) where the asterisk indicates the average volume for performer, T_0 is the empty room reverberation time and A_i are the absorption units of a single musician which can be set at a value close to 0.7 m^2. Despite its simplicity Eq. (4) highlights the main points that clearly regulate the sound level in the room as a design criteria.

$$L_D - L_{W^*} = 10Log\left(\frac{4}{\dfrac{0.16V^*}{T_0} + A_i} \right) \quad \text{[dB] (4)}$$

DISCUSSION

Early support

Typical trends of Eq. (3) are reproduced in Fig. 2. The attention is focused on a realistic interval of reverberation times ranging from 0.6 s to 1.4 s and a set of curves is traced corresponding to combinations of room volume and heights. These parameters are also chosen in a suitable range usually found in rooms hosting a symphonic orchestra. As expected the dependence of ST_{Early} on reverberation time is very similar for all of the rooms and spans over a range of about +2.5 / +3 dB from shorter to longer reverberation.

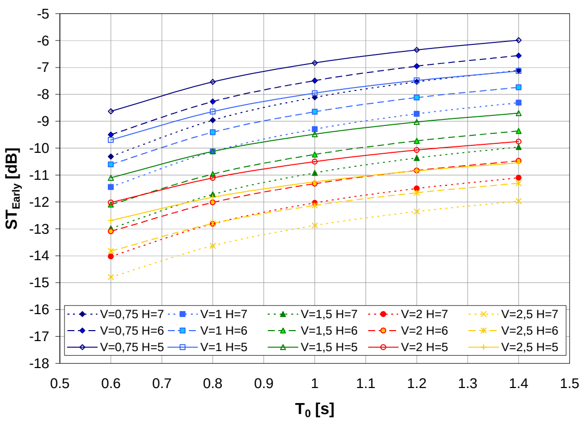

Figure 2. A design chart for ST_{Early} depending on rev. time expressed as function of room height and volume (in [m] and [10^3 m^3] respectively).

It is interesting to note that also the room height has an important effect and a change of 1 to 2 dB can be expected by moving the ceiling from 5 m to 7 m.

Thus the necessity and the benefit gained by the design of ceiling reflectors, not accounted for in the eq. (3), can be evaluated once the height of the ceiling is assessed by this simple formula.

Sound level for performers

Another tool in the early design stages is the chart representing the typical values of Eq. (4) shown in Fig. 3. In order to be effective the chart must be supplemented by the information on the averaged sound power level of each performer. This value L_W* clearly depends on the type of repertoire and on the orchestra composition. By referring to the data by [6] it can be hypothesized that for a theatre orchestra of 84 musicians including 64 strings, 8 woodwinds and 12 brass one has L_W*=95 dB when they play "*forte*".

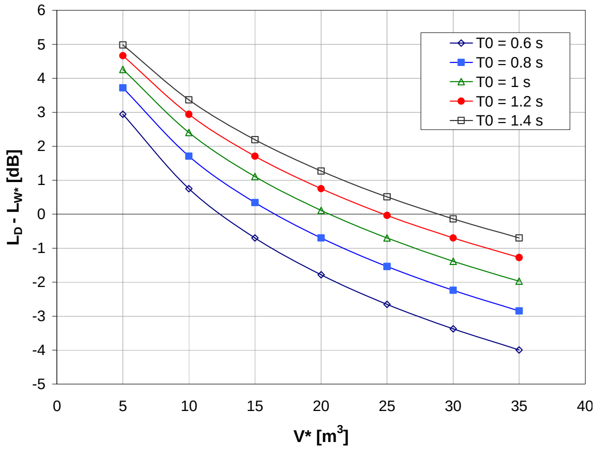

Figure 3. A design chart for the sound level as function of volume for performer *V** and reverberation time T_0 (A_i = 0.7 m^2).

The room volume for performer *V** is most critical for the sound level as appears in Fig. 3. It is to be underlined that the data in Fig. 3 do not depend on *N* but on "*for performer*" quantities only.

Although it is not possible to correlate directly the chart data to "noise" exposure values this approach is useful to create the conditions for mitigating the impact of excessive level at the early phase of design.

DESIGN PROCEDURE

With the tools above it is possible to trace a dimensioning and acoustical planning process of the rehearsal room from few initial data to the expected final support values. In particular the number of performers *N* is set and their arrangement is the first step in the procedure. This is done with the help of Fig. 4 where the number of rows *Ny* and columns *Nx*, and the cell dimension *d* are taken as variables.

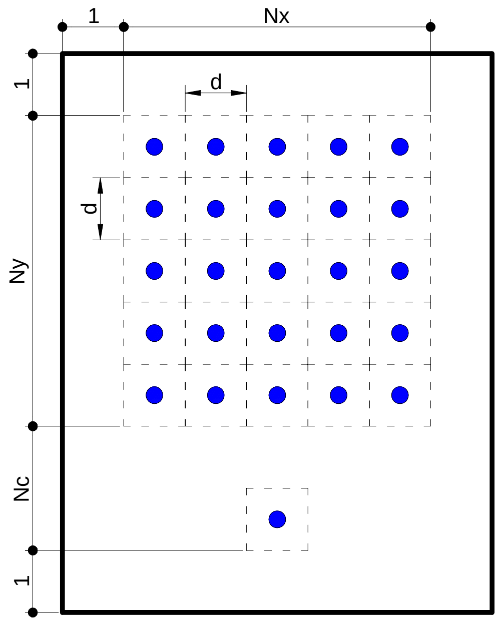

Figure 4. A possible scheme for the disposition of the orchestra in the rehearsal room.

With the lettering of Fig. 4 and leaving a pathway on the room borders, the floor extension is calculated as

$$S = (N_x + 2)(N_y + N_c + 2)d^2 \quad [\text{m}^2] \quad (5)$$

where N_C is the number of free rows close to the conductor and where, for example, a piano may be located.

The floor per performer is simply

$$S^* = \frac{S}{N} = \frac{(N_x + 2)(N_y + N_c + 2)d^2}{N_x N_y} \quad [\text{m}^2] \quad (6)$$

If the number of rows and columns is equal and few rows (four in the example) are left in the area close to the conductor, that is

$$N_x = N_y = \sqrt{N} \quad \text{and} \quad N_c = 4$$

then a simple formula derives the area per performer *S** which is intended as the floor area divided by the number of performers.

$$S^* = \frac{\left(\sqrt{N} + 2\right)\left(\sqrt{N} + 6\right)d^2}{N} \quad [\text{m}^2] \quad (7)$$

The height of the room *H* fixes on the one hand the *V** and the overall room volume is obtained too. With these data the chart in Fig. 4 shows the dependence of *V** from the number of performers for several cell dimensions and ceiling heights.

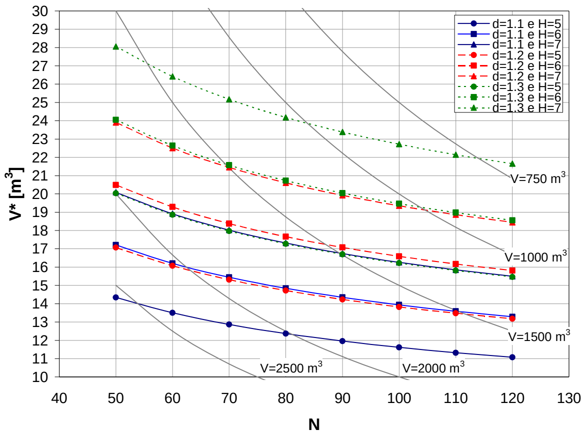

Figure 5. Volume for performer V^* as function of Number of performers (N) for cell dimension (d) and height (H) (both in [m]).

The same figure 5 shows the curves of the overall volume which is $V= V^* \cdot N$ for constant values of V between 750 m^3 and 2500 m^3.

If N is the input data of the design process, from Fig. 5 one may chose different values of d and H and obtain V^* and then V.

From Fig. 2, with the V and H values, we estimate ST_{Early} as a function of T_0. Acceptable values of ST_{Early} and T_0 can be evaluated and/or adjusted.

Finally the chart in Fig. 3 is used to obtain the sound level in the room in order to assess the acoustical comfort that the environment will provide. As it is obvious, the lowest value of the sound level is obtained with the lowest values of T_0 and the highest values of V^*.

If during the rehearsal the number of musicians N will be different from the one use to design the room, the V^* values will change and a different sound level will be obtained: ST_{Early} will be still the same because it includes the reverberation of the empty room T_0.

CHECKING PROCEDURE

The same set of information can be used in a complementary way to check the suitability of a given room volume to host under convenient acoustical conditions a number of performers. If this is the case then V_0 and H_0 are given.

From Fig. 2 values of ST_{Early}, as a function of V_0 and H_0 are obtained. Choosing a suitable value of ST_{Early}, it is possible to get the reverberation time of the empty room T_0. From fig 5, entering the curves V_0= const, and H_0= const., it is possible to choose 3 different values of V^* as a function of 3 different values of N. With these 3 V^* values and T_0, from Fig. 3, it will be possible to estimate the sound level in the room. The lowest value of the sound level will be obtained with the lowest value of T_0 and highest value of V^* (or the lowest value of N as in Fig. 5).

With this procedure, for a fixed V_0 and H_0, it is possible to find, for a suitable ST_{Early}, the value of T_0 and the number of musicians which produces the lowest sound level.

CASE STUDIES

In order to test the validity of the simplified approach above, the formulas have been specialized to two design cases of orchestra rehearsal rooms whose design was managed by the authors in the recent past. They both belong to big musical production centres with resident symphonic orchestras reaching seldom the figure of N=100 musicians inside. In the case B it was possible to trace an evolution according to several steps in the acoustical design.

The values presented in Fig. 6 are related to the average of several points located in the central area of the room. The number of measurement positions in B was not enough to put dispersion bars whereas in A a dispersion of 1.3 dB was measured.

The room A has acoustically treated lateral walls so that few early reflections can be expected at least in the frequency range covered by the ST_{Early} definition. The floor and the ceiling are reflective but the latter has some big pyramidal scattering elements. The comparison with the simple prediction formulas is quite satisfactory in this case since the gap between data and prediction is less than 1 dB. In this respect it is to be noted that the positioning of the source and of the receiver has indeed a very strong impact on the measured values. In fact by using the same formulas above with just minor modifications in the distance SR, it can be verified that a misplacing of 20 cm can result in a variation of 1.5 dB.

In the case of the room B the match is not as good though the trend in the points at the different reverberation values appears to follow the overall course of the theoretical curve. In this case the room has reflectors instead of a proper ceiling in B-2 and B-3, and a non negligible contribution from lateral reflections is probably to be expected due to the nature of the lateral walls.

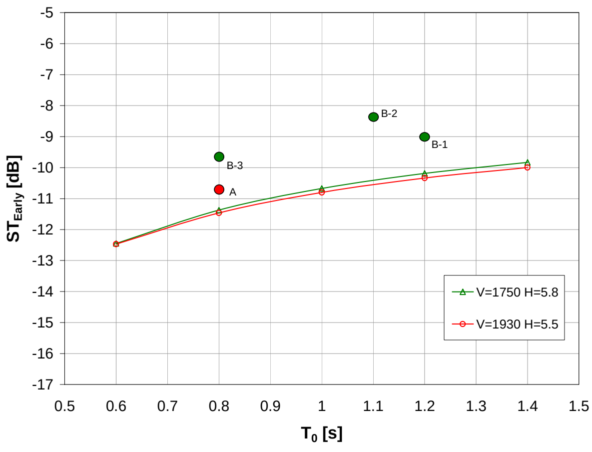

Figure 6. Data for rooms A and B (three phases of acoustical design). Volume in [m^3] and height in [m].

CONCLUDING REMARKS

An acoustic designing procedure for rehearsal rooms has been described based on the objective parameter "early support" (ST_{Early}). Even if optimum values of ST_{Early} for rehearsal room do not exist, the values suggested for stage in concert hall have been considered suitable. Moreover the designing procedure estimates the sound level in the room as a function of T_0 and V^*.

In the hypothesis of considering a suitable value of ST_{Early} = -12 dB (± 2 dB), the procedure shows that, when H

is comprised in the range between 5 m and 7 m, the total volume of the room ranges from 750 m^3 to 2500 m^3 (Fig. 2). Moreover, on the basis of these volumes, the values of V^* range from about 10 m^3/performer to 30 m^3/performer: the lowest values deals with the highest values of N and vice versa (Fig. 3).

In case of a big room volume (V>2500 m^3) and of a higher room (H>7 m), it is possible to increase the ST_{Early} by hanging sound reflectors on the ceiling. In this case the values of H to be used in equation 3 and in Fig. 2 will be the height of the reflectors (H_{ref}).

The sound level in the room diminishes with low values of T_0 (0,6 s – 1,4 s) and high values of V^* (fig. 5). A reduction of T_0 from 1,4 s to 0,6 s reduces the sound level of about 2-3 dB; an increase of V^* from 10 m^3/performer to 30 m^3/performer reduces the sound level of about 4 dB. In order to reduce the sound level it seems important to increase as much as possible V^*.

From an analysis of equation 3 it has to be stressed that small variations of the distance between source and receiver SR=1 m (± 0,1 m) produce significant changes in ST_{Early} of about ± 1,5 dB. Variations of these entities may be observed during measurements as it is not easy to check the centre of the source and because microphone and source as to be moved in different positions. In this respect it seems important that [5] put more emphasis on the evaluation of the distance SR=1 m.

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