New (stage) parameter for conductor's acoustics?

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During fine-tuning of the stage acoustics of the main auditorium of Casa da Musica, designed by Office for Metropolitan Architecture, in Porto (Portugal) we were confronted with conflicting comments with respect to the acoustic effect of different canopy positions. The well known stage parameters, ST and CS, did not point out a difference in results for the different canopy positions, while the conductor's experience did.
So we carried out several measurements and tried to find a parameter that could clarify the contradictory experiences of the musicians and the conductor. We needed a parameter that correlated with the 'transversely support over the stage' instead of or additional to the known parameters. It was also not clear to what degree the commonly used parameters describe the acoustics at the conductor's position.
This study aims at proposing a new (stage) parameter as well as trying to find out more about the 'conductor's acoustics'.
In the main auditorium (CdM) the newly defined parameter seems to describe the musicians' and conductor's experiences on the hearing 'ensemble' on stage even better than the known stage parameters. The same measurements have been carried out in other halls in order to check the validity of this new parameter.

1 Introduction

At the moment it is becoming more and more clear that we need to distinct between hall and stage acoustics. The solid base of knowledge on stage acoustics [1,2,3] is being extended by several researches. Finding a good ‘balance’ within the symphonic orchestra is essential. This is valid not only for the musicians, but also for the conductor.

Consulting experience for Casa da Musica in Porto [4] indicated lack of a parameter to fine-tune the stage acoustics as well as lack of a parameter describing the experience of the conductor.

This study is aimed to define a new parameter that will be useful to fine-tune the stage acoustics and to describe the acoustics at the conductor’s position.

In order to define as well as to validate this parameter measurements have been carried out in Casa da Musica in Porto and in the recently built temporary hall ‘Muziekgebouw aan de A2’ in Leidsche Rijn (the Netherlands).

2 Concert halls and stages

The main auditorium in Casa da Musica in Porto (Portugal), which is generally considered to be an excellent hall, opened in 2005 and was designed by Office for Metropolitan Architecture in cooperation with the acoustical consultant L.C.J. van Luxemburg. The architectural concept of a transparent shoebox-shaped hall in combination with program requirements challenged the acoustics in many ways. The architecture and acoustics have been tuned astonishingly to each other.

The shoebox-shaped auditorium has a volume of approximately 17000 m^3 and a capacity of 1250 seats. The stage is rectangular with a width of 22 m and a depth of 11 m, behind the stage an elevated balcony is designated for the choir. Vertical placed QRD diffusers and a visual transparent canopy (8 m x 12 m) control the stage acoustics.

Quite recently, we were able to validate our estimations for the new parameter with measurements in a temporary concert hall: Muziekgebouw aan de A2 in Leidsche Rijn (the Netherlands). This temporary hall will be used, while the original concert hall (Vredenburg Utrecht, the Netherlands) is being renovated. The new hall has a volume of approximately 22500 m^3 and a capacity of 1700 seats. The stage has a rectangular shape with a width of 23 m and a depth of 16 m. The height of the ceiling reflectors varies between 10.5 and 11.5 m.

3 Stage parameters and acoustics

Objective (measurable) stage parameters can be correlated to subjective categories. The objective parameters can be derived from the measured impulse response p(t). The impulse response for stage acoustics (figure 1), with source and receiver on the stage (‘stage – stage’), contains less reflected sound relative to the direct sound in comparison to the impulse response for the concert hall (‘stage – hall’).

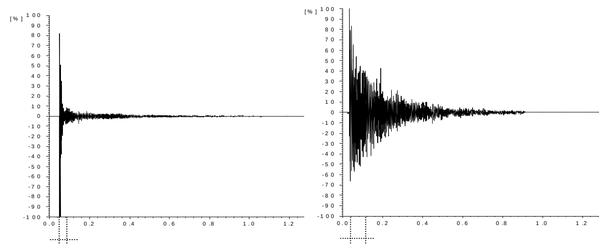

Fig. 1 Two different impulse responses p(t);
left: stage – stage, right: stage – hall

The sound on the stage can be divided into the direct sound, the ‘early sound’ as well as the ‘late sound’. The time interval for direct sound (first sound arriving at receiver without being reflected) is not very clear. The upper time limit for direct sound varies between 5 ms and 10 ms in literature, e.g. [5,2]. Especially for the low frequencies it is very difficult to distinguish between the direct and ‘early’ sound. The ‘early sound’ consists of sound being reflected (e.g. by wall, ceiling) and arriving within 40 ms after the direct sound [6]. The early sound provides information of the sound, produced by the other instruments not being part of the direct sound (due to directional characteristics of the instruments as well as objects between source and receiver). This part of the sound is important for the musicians and conductor for the playing ensemble (and to find balance within the orchestra) [7].

The ‘commonly’ used stage parameters focus on the relation between the (early) reflections and the direct sound, for example the objective parameter STearly (Support). This parameter describes the ease of hearing other orchestra members and is mainly used to measure the influence of surfaces around the orchestra platform. According to Gade [3] an architecturally (and probably also subjectively) dramatic 20% reduction e.g. in height of ceiling or in distance between side walls, will result in STearly increasing only about 1 dB. In case of fine-tuning the stage acoustics the STearly makes it difficult to understand whether relative small changes improve the stage acoustics or not. Especially if the stage acoustics will have to be locally determined instead of averaged over the stage for all measurement positions.

4 Measurements

4.1 Casa da Musica

In order to fine-tune the stage acoustics of the main auditorium of Casa da Musica (CdM) the position of the canopy has been changed. The influence of the canopy has been measured for four different canopy positions (see figures 2-5) [4]. Due to logistics, the measurements have been carried out without music standards and chairs on the stage.

Fig. 2 CdM: canopy @ rear 8.6 m – front 8.6 m

Fig. 3 CdM: canopy @ rear 8.6 m – front 9.3 m

Fig. 4 CdM: canopy @ rear 8.6 m – front 10.0 m

Fig. 5 CdM: canopy @ rear 10.0 m – front 10.0 m

The STearly, measured at one meter from the source, has been derived from the impulse responses (software Dirac 4.0 & EASERA 1.0, e-sweep signal). The impulse responses have been measured at nine source positions and eight receiver positions. One receiver was always placed at one meter from the source (Rec 1, height 1.35 m), one receiver at the conductor's position (Rec 2, height 2.0 m to represent the conductor standing on a riser) and six receivers were distributed over the stage, based on a grid (Rec 3-8, height 1.2 m). Figure 6 shows the source and receiver positions. The source (height 1.35 m) is rotated four times in order to omit the influence of the source, not being fully omni-directional. For all these source and receiver positions we also determined the 'new' parameter (software Dirac 4.0), for which the results are discussed in paragraph 6.

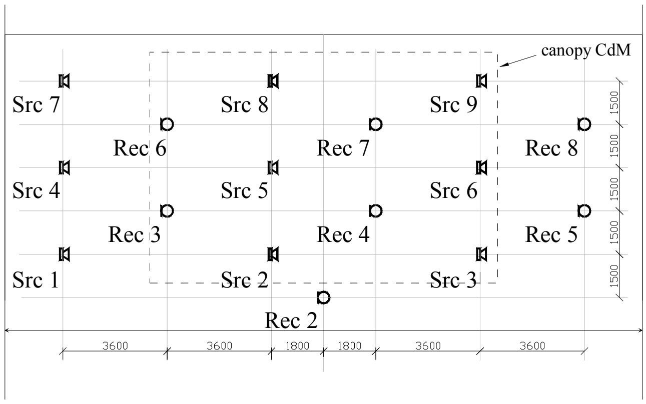

Fig. 6 Measurement positions

4.2 Muziekgebouw aan de A2

In order to validate the 'newly defined parameter', which is elucidated in paragraph 5, the same measurement methodology as for CdM was applied in the Muziekgebouw aan de A2 (MA2).

Two different stage configurations have been measured on this stage (figure 7 and 8). The differences between the two configurations are the orchestra surrounding (vertical placed QRD diffusers), the ceiling reflectors (CFG1: horizontal, CFG2: inclined) and the use of stage risers. Due to logistics, the measurements have been carried out without music standards and chairs on the stage.

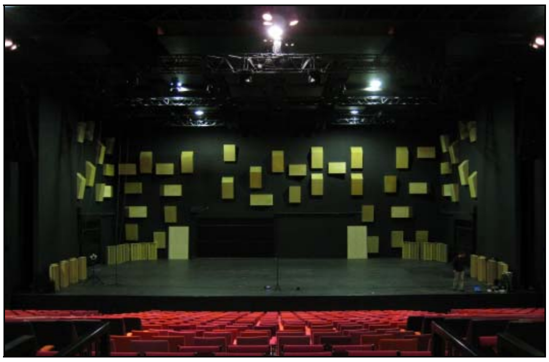

Fig. 7 MA2: configuration 1

Fig. 8 MA2: configuration 2

5 Defining new parameter

The results for STearly showed hardly any difference for the four different canopy positions in Casa da Musica [4]. According to the Just Noticeable Difference (JND) a difference between the four configurations should not be audible. This is in line with the musicians' experience. According to the conductor's experience, the canopy positions actually do differ (noticeably) from each other from (stage) acoustical point of view. This lead to the idea of taking a close look on the existing stage parameters as well as trying to find a 'new' parameter that would correspond with the experience of conductor and that would provide information about the sensitivity of the musician's position on the stage in order to fine-tune the stage acoustics.

As explained earlier in this paper, the (very) early sound is important for musicians for playing 'ensemble' in the symphonic orchestra. Especially for fine-tuning the stage acoustics the influence of the (very) early sound is interesting, because these (small) changes in the stage environment will most likely influence the sound in range of 40 ms. By comparing the very early sound to the 'late' early (40 - 80 ms) and late reverberant (80 - ∞) sound, an impression of the (relative) amount of early energy can be obtained. Because playing in a symphonic orchestra is a matter of finding the right 'balance' (between different types of instruments as well as between different types of energy!). Most of the existing stage parameters take the direct sound into account. However, the energy of the direct sound influences the objective parameters considerably.

By taking these considerations into account, we wanted to define a parameter that consists of the very early sound without the direct sound, compared to the 'late' early and late reverberant sound. However, by omitting the direct sound this parameter will no longer provide information about the sound (timbre etc.), but instead it will help us to fine-tune the stage acoustics, because of a more detailed view on the contribution of the very early reflections.

The upper time limit for direct sound is not very easy to determine, because of the frequency dependency of the impulse response. The Forward Integration Curve (figure 9) gives a clear view of a plateau that occurs several ms after the first energy arrives. This plateau is in fact the 'pause' between the direct sound and the first reflections. For the frequencies 500, 1000 and 2000 Hz, this plateau is clearly to determine.

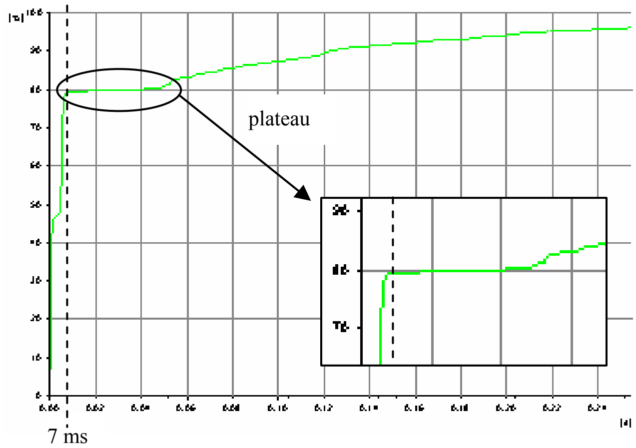

Fig. 9 Plateau visible in Forward Integration Curve

We checked the amount of energy by calculating the Definition for different time limits: 5 - 10 ms. After comparison of the Definition between different time limits (D*y*-D*x*), we concluded that for the frequencies 500, 1000 and 2000 Hz an upper time limit of the direct sound (a lower time limit for the plateau) of 7 ms is acceptable for our parameter. The smallest difference in Definition occurs between D*8* and D*7* for 500 – 2000 Hz (average of D*8*-D*7* = 0.00 ± 0.01). A difference of 0.00 between D*y* and D*x* means, that no energy has been transmitted from time limit '*x*', in this case 7 ms (so the plateau/'pause' has started).

Now our new parameter can be described as the quotient (Q) of the energy$_{7\text{-}40\ \text{ms}}$ (very early sound without the direct sound) and the energy$_{40\text{-}\infty\text{ms}}$ ('late' early and late reverberant sound), Eq.(1). By applying the logarithmic function ($LQ_{7\text{-}40}$) a value in dB will be derived from the $Q_{7\text{-}40}$, Eq.(2).

$$Q_{7-40} = \frac{\int_{7}^{40} p^2(t)dt}{\int_{40}^{\infty} p^2(t)dt} \quad [-] \qquad (1)$$

$$LQ_{7-40} = 10\log\left(Q_{7-40}\right) \quad [\text{dB}] \qquad (2)$$

6 Results

6.1 Casa da Musica

The results for STearly showed hardly any difference for the four different canopy positions in Casa da Musica [4]. The average value (250-2000 Hz, all measurement positions) for STearly is -11.7 ± 0.1 dB. Gade defines for the Support -12 ± 1 dB (STearly) as optimum values for stage acoustics [2]. The results for the $LQ_{7\text{-}40}$ (average 500-2000 Hz) for the four different canopy positions are indicated in table 1, 2 and 3.

source	8.6 – 8.6	8.6 – 9.3	8.6 – 10	10 – 10
Src 1	-3.1	-3.7	-3.6	-3.9
Src 2	**-8.4**	**-9.4**	**-11.2**	**-10.5**
Src 3	**-6.4**	**-6.1**	**-7.2**	**-8.1**
Src 4	-2.2	-2.4	-3.3	-3.4
Src 5	-5.4	-5.6	-5.6	-7.6
Src 6	-4.7	-5.0	-4.9	-3.8
Src 7	-2.3	-2.6	-2.1	-2.6
Src 8	-3.6	-3.7	-4.0	-4.6
Src 9	-3.1	-2.4	-2.4	-3.2
average	**-4.3**	**-4.5**	**-4.9**	**-5.3**

Table 1. $LQ_{7\text{-}40}$ [dB] for Rec 2

source	8.6 – 8.6	8.6 – 9.3	8.6 – 10	10 – 10
Src 1	-1.0	-1.2	-0.7	-1.9
Src 2	-3.8	-4.6	-5.5	-5.2
Src 3	-3.3	-3.6	-3.6	-5.3
Src 4	0.3	0.3	0.4	0.0
Src 5	-3.0	-4.1	-3.0	-4.0
Src 6	-4.3	-4.3	-4.1	-4.8
Src 7	0.7	1.4	0.6	0.1
Src 8	-2.1	-2.3	-2.1	-2.5
Src 9	-3.2	-2.6	-3.4	-3.3
average	**-2.2**	**-2.3**	**-2.4**	**-3.0**

Table 2. $LQ_{7\text{-}40}$ [dB] for Rec 3

receiver	**8.6 – 8.6**	8.6 – 9.3	8.6 – 10	**10 – 10**
Rec 2	**-4.3**	-4.5	-4.9	**-5.3**
Rec 3	**-2.2**	-2.3	-2.4	**-3.0**
Rec 4	**-3.4**	-3.2	-3.6	**-3.7**
Rec 5	**-1.1**	-1.1	-1.2	**-1.0**
Rec 6	**-1.6**	-1.9	-1.8	**-1.9**
Rec 7	**-2.4**	-2.8	-2.5	**-2.4**
Rec 8	**-0.8**	-0.9	-0.8	**-0.8**

Table 3. $LQ_{7\text{-}40}$ [dB], average over all source positions

The conductor (Rec 2), as well as some musicians in front of the stage below the canopy (Rec 3 and Rec 4), experienced differences in stage acoustics by changing the position of the canopy, in contrast with the musicians to the rear and side of the stage (Rec 5 and Rec 8). The horizontal position of the canopy at 8.6 m is being advised. The canopy at 8.6 m provides (obviously) more (very) early sound, compared to the late sound, than the canopy at 10 m (Rec 2: $\Delta LQ_{7\text{-}40} = 1.0$ dB).

The conductor also had some difficulties to hear the violins and the celli (Src 2 and Src 3). According to table 1 the contribution of the (very) early sound on these positions ($LQ_{7\text{-}40}$) is much lower compared to the other positions.

6.2 Muziekgebouw aan de A2

The results for STearly in Muziekgebouw aan de A2 show a bit more difference between the two different stage configurations than the results for CdM, CFG1: STearly = -13.9 dB and CFG2: STearly = -13.5 dB. The two measured configurations however are in an early phase of the fine-tuning process (relative large changes in the stage environment). The results for the $LQ_{7\text{-}40}$ (average 500-2000 Hz) for the two stage configurations are indicated in figure 10 and 11. Source position 7 is canceled for configuration 2 due to the positioning of the QRD diffusers.

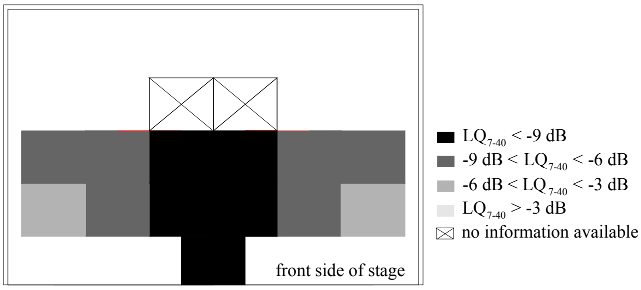

Fig. 10 $LQ_{7\text{-}40}$ [dB] for configuration 1

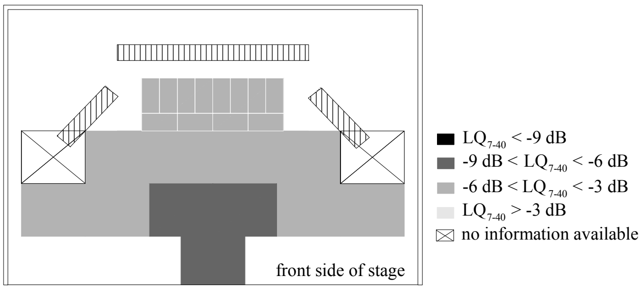

Fig. 11 $LQ_{7\text{-}40}$ [dB] for configuration 2

By enclosing the orchestra, like in configuration 2, the amount of (very) early reflections increases enormously (compared to the late energy). This (actually quite logical) change can now be confirmed with the $LQ_{7\text{-}40}$. The conductor as well as the orchestra experienced a clear improvement of the stage acoustics/'playing ensemble' in case of configuration 2.

7 Discussion

This research has established that the newly defined parameter $LQ_{7\text{-}40}$ seems to correspond more with the musicians' and conductor's experience in Casa da Musica than the well known stage parameters do and that $LQ_{7\text{-}40}$ is a useful tool for fine-tuning the stage acoustics. The measurement results in Muziekgebouw aan de A2 also indicate that $LQ_{7\text{-}40}$ is a good tool, that provides information about the amount of (very) early reflections, in order to fine-tune the stage acoustics. The obtained and discussed values however are only valid for these concert halls and their orchestras. So more research is necessary.

Furthermore, the measurement results have been acquired through measurements with an omni-directional sound source and receiver. The difference between the used method and 'reality' will be largest at high frequencies. Also must be considered that the measurements have been carried out on the stage without chairs and orchestra. In reality orchestra members and their equipment influence the sound distribution, resulting in a different amount of (early) reflections. The $LQ_{7\text{-}40}$ therefore should only be used as a tool to check differences between stage configurations. An optimum value for this parameter is not (yet?) available.

The $LQ_{7\text{-}40}$ provides us more insight into the acoustics at the conductor's position, but to understand more about the conductor's acoustics, further research is required. To validate (and fine-tune) the parameter $LQ_{7\text{-}40}$ more measurements in different halls (in different phases of the fine-tuning process) have to be carried out as well as determining the musicians' and especially the conductor's experiences.

8 Conclusion

As discussed earlier in paragraph 3 and 5, the time limits of 7 and 40 ms are being preferred for the newly defined parameter $LQ_{7\text{-}40}$ in order to gain more information about the (very) early reflections that are important for musicians as well as for the conductor.

The subjective perception of the musicians as well as the conductor seems to correspond with the objective measurement results of $LQ_{7\text{-}40}$: the differences in the four canopy positions (CdM) and the two different stage configurations (MA2) are audible, as well as measurable. The $LQ_{7\text{-}40}$ also provides information about the 'transversely support over the stage': it is now clear to what extent each source contributes to the stage acoustics (amount of (very) early reflections, compared to the late reflections) on a certain receiver position.

Acknowledgement

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