19th INTERNATIONAL CONGRESS ON ACOUSTICS
MADRID, 2-7 SEPTEMBER 2007

EVALUATION OF STAGE ACOUSTICS IN CONCERT HALLS BY INVESTIGATING PERFORMER'S PREFERENCE

PACS: 43.55.-n

Kim, Yong Hee; Seo, Chun Ki; Jeon, Jin Yong
School of Architectural Engineering, Hanyang University, Seoul 133-791, Korea
kimyonghee@gmail.com; arch114@sejongpac.or.kr; jyjeon@hanyang.ac.kr

ABSTRACT
The stage acoustics parameters ST_{Early} and ST_{Late} have been suggested to investigate performer preference of stage support in a concert hall. In this study, the performer preference was investigated on a stage of a fan-shaped multi-purpose hall with orchestra shell. Performers participated in performance evaluation tests as they played at different positions on the stage. Objective measurements using omni-loudspeaker and monaural microphone were also carried out at 15 positions on the stage in order to evaluate the stage acoustics. The results showed that ST_{Early} varies between –20.9 and –11.5 dB. It was found that the ST_{Early} does not correlate well with the performer preference on the stage.

INTRODUCTION
The acoustical design of concert halls has been mainly based on the listener's preference up to the late last century. In 1978, acoustical conditions preferred for ensemble were investigated by Marshall [1] on the synthesized reflections of sounds in anechoic room. At the similar time, Barron [2] carried out the subjective tests with a small orchestra and objective measurements in an actual concert hall with variable stage settings. In 1985 Marshall and Meyer [3] measured directivity of singer voices to evaluate auditory impression of singers. Based on these attempts, Gade [4-5] proposed the first parameter (ST1) for evaluation of stage acoustics based on both laboratory and field tests in 1989. During the 1990s, several stage components such as ceiling reflectors and the orchestra shell were studied [6–8]. Recently Jeon and Barron [9] carried out an objective evaluation of the stage acoustics in terms of Gade's stage support parameter using a scale model and computer simulation for a concert hall. Chiang et al. [10] tried to modify the stage support parameter through auditory experiments on a real stage using movable reflectors.

However, for architectural design purposes the imminent task is the establishment of the stage acoustical parameters. Although the Stage Support parameters [4-5, 10] have been proposed, these parameters do not directly linked to stage acoustical design. Marshall et al. [1] and Gade [4] derived preferred acoustical conditions for performers in laboratory experiments to model the performance and performer's perception. Barron [2], Chiang et al. [10] and Gade [5] carried out auditory experiments on real stages with only instrumentalists. From these previous studies, it seems that the experimental conditions such as actual or synthesized sound fields and types of performer subjects such as vocalist or instrumentalist can be adequately considered. Throughout verification and modification of the previous experimental settings, the stage acoustical design parameters should be further developed. Therefore, if reproduction of the stage sound field is realistic enough, the controlled experiments may give effective solutions in designing the stage enclosure.

In this study, experiments with vocalists and instrumentalists in a real hall were conducted in order to evaluate effectiveness of the current stage acoustical parameter, mainly Stage Support Early (ST_{Early}). In addition, contribution factors on performer's preference were investigated in different sound field.

STAGE SUPPORT

In this study, the stage parameters were used to objectively evaluate the sound field of a stage [4, 5]. ST_{Early} also known as ST1 is defined as a logarithmic ratio between direct sound energy (0 to 10 ms) and early reflection energy (20 to 100 ms) as shown in Eq. (1). From Gade's experiments [5], it was shown that the early reflections within 100 ms are the most important as stage support. ST2 is defined similar to ST_{Early} in consideration of early reflections within 200 ms based on ST_{Early}. Stage support late (ST_{Late}), includes late reflections beyond 100 ms as shown in Eq. (2). The stage support parameter is calculated from impulse responses measured at the stage. Distance between the sound source and receiver is 1 m and the measurement height is also 1 m from the stage floor.

$$ST_{Early} = 10\log\left(\int_{20ms}^{100ms} p^2 dt \Big/ \int_{0ms}^{10ms} p^2 dt\right) \text{ [dB]} \qquad \text{(Eq. 1)}$$

$$ST_{Late} = 10\log\left(\int_{100ms}^{\infty} p^2 dt \Big/ \int_{0ms}^{10ms} p^2 dt\right) \text{ [dB]} \qquad \text{(Eq. 2)}$$

ST_{Early} includes stage support for controlling one's self performance with early reflections and hearing other player's sounds (ensemble). On a real stage, the stage support value increases as the measuring position is close to side wall or rear stage wall. And the maximum value is usually observed at 4 m away from the stage side reflectors [9]. In addition, clarity at stage (CS) is defined as in Eq. 3 similar to C80.

$$CS = 10\log\left(\int_{0ms}^{80ms} p^2 dt \Big/ \int_{80ms}^{\infty} p^2 dt\right) \text{ [dB]} \qquad \text{(Eq. 3)}$$

In addition to stage parameters, room acoustical parameters such as RT, Ts, and IACC were also considered. RT and Ts were averaged at the mid-frequency bands (500 Hz to 1 kHz). For IACC (Interaural cross correlation), both the early (within 80 ms, $IACC_{E3}$) and late (after 80 ms, $IACC_{L3}$) values were considered from 500 Hz to 2 kHz [10].

OBJECTIVE EVALUATION

Description of the hall

Field measurements and auditory tests were carried out in a multi-purpose hall with orchestra shell (See Fig. 1). The hall has about a 3,000 seat capacity with a typical fan-shaped plan. The audience area includes 2nd and 3rd floor rear balconies. The hall volume is about 36,000 m^3 and the stage floor area is about 270 m^2. The unoccupied reverberation time of the audience area at the mid-frequency bands is about 1.7 s on average.

(a) (b)

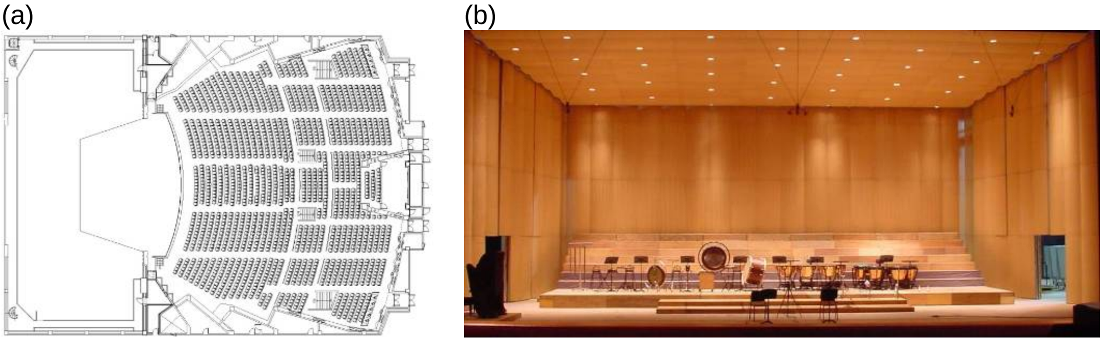

Figure 1. Floor plan and stage of the hall

Measurement procedure

Omni-directional sound source (B&K Type 4295) was located at 1 m from the microphone (AKG 414B). A logarithmic swept-sine signal was used for acquirement of responses. Various stage sound fields are measured according to different positions on the stage [7]. The sound source was located at 15 positions at intervals of 3 m from the frontal center of stage to rear stage and side stage, and four impulse responses were measured from every direction around each source position in order to extract representative stage parameters at each position. Additionally the binaural measurement using dummy head was carried out using the same procedure with monaural measurement. In this case the dummy head was located at each position toward the sound source. Fig. 2 shows the measurement positions and equipment used in this experiment.

(a) (b)

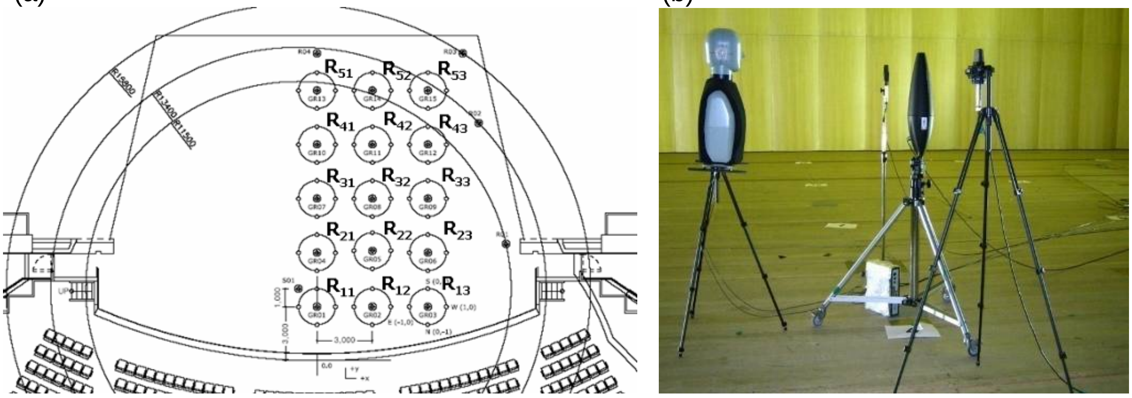

Figure 2. Measurement positions and equipment

Table I. Stage and room acoustical parameters at each position

Position		Stage acoustical parameter				Room acoustical parameter			
		ST_{Early} [dB]	ST2 [dB]	ST_{Late} [dB]	CS [dB]	RT [s]	T_s [ms]	$IACC_{E3}$	$IACC_{L3}$
***R11**	**A**	**–19.9**	–16.1	–16.9	16.2	1.46	9.0	0.99	0.36
R12		–19.5	–16.2	–17.5	16.7	1.32	8.7	0.99	0.19
***R13**	**B**	**–18.4**	–16.0	–18.0	17.5	1.21	8.7	0.98	0.21
R21		–15.6	–13.3	–15.8	15.3	1.37	10.7	0.99	0.37
R22		–16.2	–14.0	–16.7	16.0	1.18	10.0	0.98	0.27
***R23**	**C**	**–15.9**	–13.9	–17.0	16.7	1.15	9.7	0.98	0.27
***R31**	**D**	**–13.6**	–11.9	–15.4	14.9	1.28	10.3	0.99	0.47
R32		–13.4	–12.0	–16.2	15.1	1.11	9.8	0.98	0.31
R33		–12.7	–11.5	–16.6	15.8	0.99	10.9	0.96	0.33
R41		–11.5	–10.5	–15.9	15.2	1.30	11.1	0.98	0.48
R42		–11.9	–11.2	–17.5	16.3	1.07	10.9	0.97	0.33
***R43**	**E**	**–11.3**	–10.5	–17.3	16.2	0.98	10.2	0.95	0.33
R51		–13.2	–12.6	–18.1	17.8	1.57	10.5	0.92	0.41
R52		–13.0	–12.4	–18.8	18.2	1.32	9.5	0.93	0.21
R53		–13.2	–12.7	–20.0	19.4	1.04	9.5	0.89	0.29

* The five positions which were selected for the field auditory test

Measurement results

Table I shows the room acoustical parameters at each position. All stage parameters were averaged from 250 Hz to 4 kHz. The ST_{Early} ranged from –19.9 to –11.3 dB and the mean ST_{Early}

was –14.6 dB while the ST2 ranged from –16.2 to –10.5 dB. The range of ST2's distribution is smaller than that of ST_{Early}'s distribution. The mean of ST2 was –13.0 dB. The data shows that higher ST_{Early} and ST2 values were recorded when the sound source was close to the side and rear walls. The ST_{Late} ranged from –20.0 to –15.4 dB, and the CS from 15.1 to 19.4 dB. ST_{Early} was highly correlated with ST2 (R=0.98). The correlation between ST_{Late} and CS was also negatively high (R=–0.98). On the other hand, there was no correlation between ST_{Early} and ST_{Late} (R=–0.01).

RT ranged from 0.98 to 1.57 s. T_s was very small ranging from 8.7 to 11.1 ms due to the dominant direct sound. Similarly $IACC_{E3}$ was very high at every position. But $IACC_{E3}$ decreased slightly at the locations within 4 m of the side and rear walls. $IACC_{L3}$ ranged from 0.19 to 0.48. The $IACC_{L3}$ values increased as the measurement position become close to the rear wall. At the same distance from the stage front, the stage center gives higher RT and $IACC_{L3}$ values (R11, R21, R31, R41, and R51) while it gives lower ST_{Early} values. A possible explanation for this is that due to the fan-shape of the area where the distance between the side walls increases as one move from the rear to the front of the stage. T_s was correlated with $IACC_{L3}$ (R=0.70), ST_{Early} (R=0.76) and ST2 (R=0.82). $IACC_{E3}$ has strong relationships with ST_{Late} (R=0.81) and CS (R=–0.80). These indicate that not only amount of early or late sound energy but binaural or directional aspect is important.

SUBJECTIVE EVALUATION

Auditory test procedure

The five different positions (A to E) among the measured 15 positions were selected for performer's evaluation of the stage acoustics determining about 2 dB interval of ST_{Early} values (see Table II). Subjects played blindfold at each position so as not to notice visual circumstance of the position. They were asked the overall preference by ranting each position as a soloist position. A total of four players participated in the test. They consisted of two vocalists (soprano), one violinist and one clarinettist as shown in Fig. 3. The test was conducted individually except for the vocalists. The players gave their performances three times at each position before giving a ranking. In addition, they evaluated the subjective impressions as a five-point scale in a semantic differential test. The evaluation terms are shown in Table III.

Table II. Description of the five stage positions for the field auditory test

Initial	Position	ST_{Early} [dB]	Descriptions
A	R11	–19.9	Frontal center, close to soloist position
B	R13	–18.4	Frontal side, cello or violin position, outer orchestra shell
C	R23	–15.9	Frontal side, cello or violin position, inner orchestra shell
D	R31	–13.6	Stage center, wood-wind position
E	R43	–11.3	Rear side, contrabass or percussion position

Figure 3. The four subjects (Two soprano, one violinist and one clarinetist)

Table III. Description of the test questions for evaluation of subjective impression

Subjective impression	Descriptions
Support	Effect of stage environment which supports hearing oneself
Blending	Degree of well-blended one's performance
Size	Acoustically perceived hall size
Directivity	Degree of spreading when one makes a sound
Reverberance	Perceivable reverberation when one note or tone stops
Overall preference	Overall preference for one's performance

Auditory test results

Fig. 4 shows the test results of preference ranking for the soprano subjects. The most common preference was found to be at the stage center (D) which had a ST_{Early} value of –13.6 dB. Positions C and E which are near to the reflective surface of orchestra shell were not preferred for vocalists in spite of high early energy levels. Position E was the second most preferred for instrumental players. This difference between the preferred positions of the vocalists and the instrumentalists indicates that the vocalists perceive early reflections as negative components, while instrumentalists perceive early reflections as positive. This preference might be influenced by their usual performance position; orchestra arrangement for instrumentalists and solo or operatic singing position for vocalists.

The preference rankings of the stage support parameters for the sopranos are weakly and negatively correlated with ST_{Early} ($R_{Soprano1}$=–0.22, $R_{Soprano2}$=–0.28), while the preference rankings of instrumental players are positively correlated with ST_{Early} ($R_{Volinist}$=0.78, $R_{Clarinettist}$=0.60). These results support the observation that the vocalists perceive early reflection negatively, while instrumentalists perceive it positively. However, ST_{Late} is positively correlated with subject preference for both vocalists and instrumentalist. ($R_{Soprano1}$=0.81, $R_{Soprano2}$=0.46, $R_{Volinist}$=0.45, $R_{Clarinettist}$=0.46). This can be explained by the fact that all performers perceived late reflection positively including reverberations.

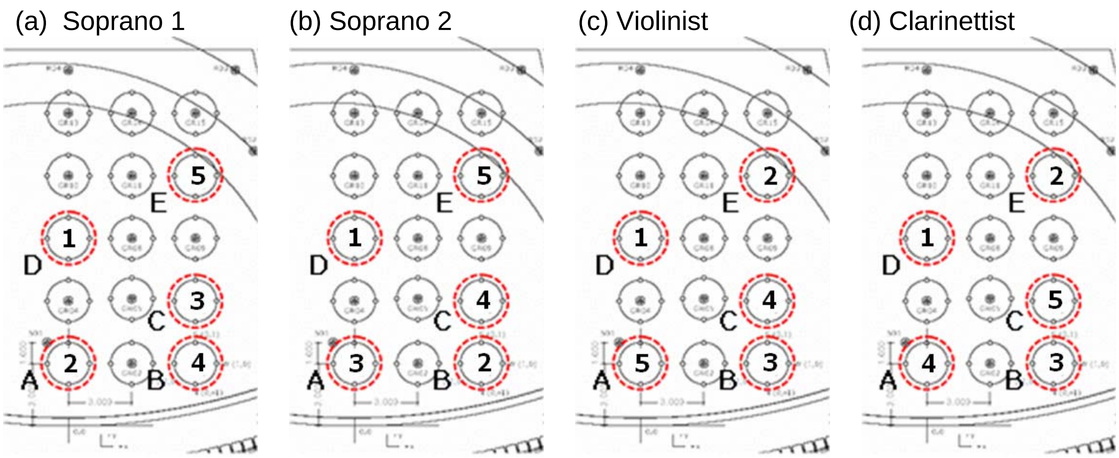

Figure 4. Results of preference ranking for each subject

However, ST_{Early} did not show a significant correlation (over than R=0.7) with the subjective test results of 5-point scale except for stage support of violist (See Table IV). Although the number of subjects who were participated in this study was small, the type of investigation on stage acoustics seems adequate for the solo performers group in real condition. Evaluation of the parameters for stage acoustics should be conducted with various ensemble or orchestral conditions and somewhat verified in the laboratory [4, 5].

Table IV. Correlation coefficients for the relationship between the rating results of subjective impression and ST_{Early}

Subjects	Stage support	Size	Directivity	Reverberance	Blending	Overall preference
Soprano 1	0.33	–0.63	–0.30	0.30	–0.13	–0.15
Soprano 2	0.68	0.62	–0.06	–0.17	–0.39	–0.58
Violinist	0.93*	0.17	–0.42	0.32	0.12	–0.42
Clarinetist	–0.05	0.01	0.54	0.38	0.66	0.54

* Significance level of 0.05

CONCLUDING REMARKS

In this study, stage acoustics were investigated objectively and subjectively in terms of stage support (ST_{Early}). The result shows that the ST_{Early} does not correlate well with performers' preference on the stage. The stage acoustical parameters in use such as ST_{Early} and ST_{Late} are based on the preference of instrumentalist [4, 5, 10]. To develop these into a general parameter for use in the acoustical design of stage, all types of performances should be further considered. In concert halls, vocal and instrumentalists are the main type of performances. However, determination of the preference of vocalists in the stage sound field is more difficult than determining the preference of instrumentalists because vocal sound source and binaural receiver work as one body. The acoustical modeling of the vocalist's perception of their performances has not been established. Thus, field auditory experiments remain as the most appropriate method for determining the preference of the vocalists.

Gade's research approach consists of evaluating parameters under limited laboratory experiments and verification during subjective field experiments [4, 5]. In the current study, stage support parameters were examined, but the other factors such as type of the performers and spectral characteristics of the instruments should also be considered. Proper stage parameters should be suggested and applied for better stage designs.

ACKNOWLEDGMENT

This work was supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD) (KRF-2006-511-D00413).

References: [1] A. H. Marshall, D. Gottlob, H. Alrutz: Acoustical conditions preferred for ensemble. Journal of the Acoustical Society America **64** (1978) 1437-1442

[2] M. Barron: The Gulbenkian Great Hall, Lisbon, II: an acoustic study of a concert hall with variable stage. Journal of Sound and Vibration **59** (1978) 481-502

[3] A. H. Marshall, J. Meyer: The directivity and auditory impressions of singers. Acta Acustica united with Acustica **58** (1985) 130-140

[4] A. C. Gade: Investigations of musicians' room acoustic conditions in concert halls. Part I: Method and laboratory experiments. Acta Acustica united with Acustica **65** (1989) 193-203

[5] A. C. Gade: Investigations of musicians' room acoustic conditions in concert halls. Part II: Field experiments and synthesis of results. Acta Acustica united with Acustica **65** (1989) 249-262

[6] J. H. Rindel: Design of new ceiling reflectors for improved ensemble in a concert hall. Applied Acoustics **34** (1991) 7-17

[7] J. O'keefe: A preliminary study of reflected sound on stages. 15th International Congress on Acoustics, Trondheim (1995)

[8] J. S. Bradley: Some effects of orchestra shells. Journal of the Acoustical Society America **100** (1996) 889-898

[9] J. Y. Jeon, M. Barron: Evaluation of Stage Acoustics in Seoul Arts Center Concert Hall by Measuring Stage Support. Journal of the Acoustical Society America **117** (2005)

[10] W. Chiang, S.-t. Chen, C.-t. Huang: Subjective assessment of stage acoustics for solo and chamber music performances. Acta Acustica united with Acustica **89** (2003) 848-856

[11] L. L. Beranek: Concert Halls and Opera Houses: Music, Acoustics, and Architecture. Springer Verlag, New York (2004)