Acoustical Design of the Opera House of the New National Theatre, Tokyo, Japan

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Abstract: The NNT Opera House seats 1810, volume 14,500m², and reverberation time, with audience, 1.5s (stage curtain open). Measurements on CAD computer and 1:10 wooden models and full-sized materials samples were conducted over a 7-yr. period. The main floor is almost rectangular, the three balconies have modest fan shape and the balcony fronts at each level create a rectangular shape. The unique design has a large curved reflector in front of the proscenium and over the orchestra pit and curved reflecting surfaces at the fronts of the three side balconies to form, in combination, an "acoustic trumpet". These surfaces, the balcony faces and the ceiling distribute the singers voices uniformly over the seating areas from a large portion of the tremendous stage.

INTRODUCTION

An international architectural competition was established in 1985 by the national government of Japan for the design of the overall NNT Project which embodies the Opera House, other theaters and associated spaces. TAK Architects of Tokyo with Takahiko Yanagizawa, President, and architect in charge, won the competition. The characteristics specified to the acoustical consultant were: (1) approximately 1800 seats, (2) adequate visibility of performers' movements and expressions from all seats, (3) to be used primarily for presentation of opera and ballet in the manner of an Italian opera house; (4) reverberation time in the range of 1.4 to 1.6 seconds with full occupancy; (5) orchestra pit to accommodate up to about 120 musicians; (6) in the competition the architect chose a moderate fan-shaped plan, with parallel side-balcony fronts; (7) three balconies and a natural wood interior. The architect's choices were to minimize the distance between the front of the stage and the most remote listener while maintaining (2) above. Acoustics in this period was the responsibility of S. Masuda.

On receiving the commission of Acoustical Design Consultant for the NNT in 1989, L. Beranek met with the technical staff of the architect, headed by T. Hidaka to lay out the program. Beranek made a systematic effort to assemble drawings, photographs, details on materials and acoustical data measured by world-wide acoustical engineers for ten opera houses typical of those in regular use. The technical literature was reviewed to assist in establishing the important acoustical characteristics that should be determined at various stages of its design and after its completion. The results of these studies, including drawings, photographs, descriptions and acoustical data on the halls are combined in Beranek (1996).

Hidaka and staff made measurements of the acoustical parameters, including those recently developed, in ten European opera houses and theaters. The next stage was their formation of a CAD computer model. This was followed by construction of a 1:10 wooden model in which the audience was simulated, and where impulse signals were radiated from a tiny loudspeaker to spherical heads with 1/8-in. microphones used as "ears".

DESIGN AND MEASUREMENTS

The acoustical characteristics that appeared from the studies to be most meaningful, which were measured in existing halls, in models and in the completed hall, and the designs employed in NNT to accomplish them were:

A. Reflected sound waves from the surfaces of the hall including, direction and magnitude: The goal was to achieve projection of singers' voices uniformly over the audience at levels high enough to easily override the orchestral music from the pit. Because it is early sound that yields voice intelligibility, the CAD model could be used to determine the direction of the waves arriving at each position and the 10:1 model was employed to furnish information on the sequence of wave arrivals and strengths by use of sound-pressure/time plots. To achieve the desired goal, an architectural "acoustic trumpet" was devised as shown in Figs. 1 and 2. In Fig. 1, the drawings show by the letters "T" the positions of the seven curved surfaces and the shaping of the ceiling that combined to achieve the "trumpet". The architect's handling of this unique concept is shown in Fig. 2. The strength of the sound (often given by G, the sound level at a position in the hall compared to that measured from the same source in an anechoic room) is given in this paper by $\frac{\text{V}}{\text{EDT}} \times 10^2$ (Beranek, 1996a). Average level at 8 to 20 positions is usually determined.

B. Reverberation time (RT) occupied, and early decay time (EDT) unoccupied: If correct, these quantities both affect the clarity of the libretto and add a fullness of tone to the music. They were measured both in the 10:1 model and in the opera house at various stages of its completion. The goal of RT = 1.5s was achieved.

C. Bass strength (BR), the support that the hall (occupied) gives to the low notes of music in relation to the higher notes: We chose as a measure of BR the ratio of the sum of the RT's at 125 and 250 Hz to the sum at 500 and 1000 Hz. Achieving a ratio greater than unity was particularly difficult in NNT because of the architect's requirement that the interior surfaces of the hall be wooden. A satisfactory ratio was achieved by employing chairs that were lightly upholstered, modeled after those in the Vienna's Grosser Musikvereinssaal.

D. Intimacy, the initial-time-delay gap t₁: The hall should return the first sound reflection to the center part of the main floor within 20 ms after arrival of the direct sound. This was obtained from impulse responses and drawings.

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E. Spaciousness, measured by the quantity one minus the interaural-cross-correlation coefficient, (Hidaka, Beranek and Okano, 1995). Large spaciousness means that a considerable portion of the sound energy at listeners' ears arrives from near-lateral directions. The "acoustical trumpet" and the shaping of the balcony faces provided high values of \([1 - IACC_c]\).

F. Diffusion: Irregularities on the walls, balcony faces and ceiling give the sound a rich acoustical patina. These were provided everywhere including fine scale diffusion on the "T" surfaces and ceiling of Fig. 1.

G. Clarity, \(C_{red}\), the ratio of the early energy (0 to 80 ms) to the reverberant energy (80 to 3000 ms) in dB.

H. Quiet and freedom from echoes: The HVAC noise, hall unoccupied, is NCB-16. Echoes were prevented by tilting the rear wall 5° and employing sound absorption on the undersides of the first balcony. This treatment was duplicated for the wall at the rear of the third balcony.

CONCLUSIONS

The values of the measured quantities in the NNT opera house (given first) and those measured in the Vienna Staatsoper, a world standard, (in parentheses) are: \(R1_{med} = 1.5\ s\ (1.3\ s)\); \(EDT_{med} = 1.7\ s\ (1.4\ s)\); \(t_e = 28\ ms\ (15\ ms)\); \(C_{red} = 1.6\ dB\ (2.7\ dB)\); \([1 - IACC_{red}] = 0.65\ (0.6)\); \(BR = 1.15\ (1.1)\); \((V/EDT)\times10^2 = 85\ (80)\). These numbers indicate that the NNT has rich reverberation, clarity, spaciousness and warmth equal to those in the best houses, and excellent strength of sound. Reviews by music critics and statements from conductors, singers and attendees have indicated excellent acoustics, with the added remarks, "There was no holding back of the orchestra. Yet, every voice and every instrument were clear."

REFERENCES
