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ACOUSTIC CONDITIONS OF THE SAN FRANCISCO WAR MEMORIAL OPERA HOUSE AND ITS RENOVATION

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1. INTRODUCTION

The War Memorial Opera House is one of the most culturally significant performing arts venues in San Francisco. The San Francisco Opera organization (which includes the performers, designers, systems and facilities) is known worldwide for the quality of its performances. The Loma Prieta earthquake which occurred just south of San Francisco in October 1989 was the impetus for the major renovation to the War Memorial Opera House currently in progress. This paper will report on the history of the San Francisco Opera House and the current renovation. It will also touch on some of the peripheral facilities and projects resulting from the renovation.

Paoletti Associates has enjoyed a long-standing professional relationship with the San Francisco Opera organization, and the San Francisco War Memorial Board of Trustees, having been involved in a number of various studies for them over the past 20 years. They recognize the importance of acoustics, and they are quite concerned about the historical and cultural reputation of their performing arts facilities.

We presented a paper at the British Institute of Acoustics in 1982 on the Zellerbach Rehearsal Building which is part of the Civic Center's performing arts complex, primarily used by the San Francisco Opera. We worked on a noise control study for the scenery workshop which is a remote facility of the Opera's on the peripheral of the City. We were also involved in the expansion of the orchestra pit and various small remodelling projects at the Opera House.

2. HISTORICAL BACKGROUND

The War Memorial Opera House, San Francisco, is a landmark structure (see Figure 1) and is included in the San Francisco Civic Center Historic District listed in the National Register of Historic Places. The overall historic philosophy of this project is that any restoration or rehabilitation should have minimal impact on the remaining historic fabric of the building.

The continual expansion and upgrades at the Opera House stems from the fact that when the building was originally constructed, it was not conceived as a repertory home for the Opera, hence, it did not have the support facilities and systems necessary to accommodate a permanent tenant.

The San Francisco Opera organization never ceases to amaze in its size and complexity. Of course, not many of the Opera patrons seated in the house watching a performance realize the enormity of the facility or the number of working staff supporting each production behind the scenes. In addition to the Opera House building which sits amongst other major performing arts facilities within the Civic Center of San Francisco, there are the following facilities which directly support Opera productions:

- The Zellerbach Rehearsal Building ('81), across the street from the Opera House, adjacent to Davies Symphony Hall. This is a 20,000 sq. ft. facility with two (2) lower level rehearsal rooms (one for symphony and one for opera use) below a full size replica of the Opera House stage and orchestra pit which is used for full dress rehearsals.

- Opera House rear stage extension ('79), for storage, dressing rooms, rehearsal and office space.

- Scenery Workshop/Warehouse - 80,000 sq. ft. remote facility for construction and storage of scenery.

- Warehouse - 36,000 sq. ft. remote facility for dead storage.

- Costume Shop - 25,000 sq. ft. remote facility for fabrication and storage of costumes.

3. THE WAR MEMORIAL OPERA HOUSE RENOVATION

The Loma Prieta earthquake caused some degree of damage to many structures throughout San Francisco. The War Memorial Opera House received mostly cosmetic damage in the form of hairline cracks and some plaster falling internally. Concerns for the potential for more falling plaster resulted in a horizontal net suspended below the complete ceiling of the main hall as a precautionary measure. The net is also a detrimental visual accoutrement to the building's ornate beaux-arts interior design. This led to a detailed structural and seismic analysis of the building (along with most other major civic buildings in the City) resulting in the decision to not only repair the cosmetic damages but perform a major seismic upgrade to the structure. Since the Opera House would have to go through a construction modification, it was decided that a much-needed upgrade of the technical performance systems should be done at the same time, and additional restrooms (a historical deficiency) should also be provided.

Thus began a rather complex $72 million dollar renovation of which only a relatively minor portion of funds would come from FEMA (Federal Emergency Management Agency) for actual seismic repair. Approximately $44 million dollars would come from a City Bond for seismic upgrade, $24 million dollars from private funds (via CROH, the Committee to Restore the Opera House) for technical and performance system upgrades, and approximately $4 million dollars from the City Hotel Tax and City budgets allotted for the Opera and Ballet. A very significant planning, financial, and logistics exercise ensued since the San Francisco Opera (and the San Francisco Ballet, the other major tenant of the War Memorial Opera House) would have to cancel performances or vacate the building for at least one full season while the repairs were made. The decision was made to utilize temporary quarters while the Opera House was being repaired (i.e. "the show must go on").

The City of San Francisco, through the War Memorial Board of Trustees (which is responsible for maintaining and managing all of the City's Civic Performing Arts facilities) and the City's Chief

Executive Officer, mandated that the two joint tenants (the Opera and Ballet, both actual users of the facility) would have major involvement in the project. The City's Bureau of Architecture was responsible for much of the work to be done, and Skidmore, Owings and Merrill, Architect were hired by the Committee to Restore the Opera House (CROH) for the technical upgrades. In essence, the work is basically split at the proscenium line with the Bureau of Architecture responsible for front of house and Skidmore, Owings and Merrill responsible for the back of the house.

4. ACOUSTICAL CONDITIONS

In order to document, both technically and historically, the existing acoustical conditions of the War Memorial Opera House, measurements were made to establish a baseline for ambient sound levels that should not be exceeded as a consequence of the upgrades and renovations. Measurement parameters were chosen to allow data resolutions that reflect the acoustical effects of room attributes such as size, shape, and finishes. These measurements are objective and repeatable, allowing for future calculation and analysis (if required), to determine the acoustical impact of any future change in room attributes. It is important to emphasize that existing conditions with regard to background noise are less than optimum, and must be carefully considered as renovations are made to the building.

Our measurements and subjective evaluation clearly indicated that background sound levels are higher than desirable for a major performance space of the international caliber of the War Memorial Opera House. Measured values in the range of NC 25 to NC 30 predominate in the low frequencies (i.e. below 500 Hz) and even exceed NC 30 at 125 Hz. This low frequency noise is the result of mechanical equipment and "breakout" associated with ductwork above the ceiling of the hall being transmitted to the audience area via large open lighting slots. Some exterior automobile traffic noise is transmitted from the exterior via worn out gaskets around doors leading to the hall.

Compared to most modern performance spaces with similar use, the background sound levels found in the Opera House would be considered extremely high. NC 15 - 20 is typically the technical design criteria. Fortunately, the measured spectrum shape is relatively smooth. For the most part, the existing background sound level measured in the hall currently tends to mask some of the other extraneous low frequency noises. However, it seriously detracts from one's ability to adequately hear well in a space as large as the Opera House, where sound energy produced on stage is finite, and its dynamic range above the room ambient must be maximized.

Using TEF analysis, we examined and documented a wide variety of parameters that help to describe acoustical quality including reverberance, early-late energy ratios, loudness, clarity, spaciousness, and intimacy. Two areas which we were asked to study that are potentially impacted by proposed changes include Organ Lofts (which will have new restrooms projecting into them), and the side rear seating areas at the Dress Circle, where massive seismic shearwalls will be added directly behind the last row of seats.

Organ Lofts. The existing Organ Lofts are presently empty except for minimal storage. There are lighting instruments and loudspeakers located within the organ bay openings. The interior finish surfaces of the organ loft are wood floor and plaster walls and ceiling, with heavy velour curtains behind the organ bay openings. The proposed revisions (adding restrooms) to the orgah loft volume has the effect of reducing the overall interior volume of the loft, as well as introducing massive sound-reflective surfaces closer to the grilles of the organ bay openings.

In their current form, the organ loft and the grille openings are "frequency selective" (see Figure 2). Depending upon the location of the sound source, the frequency (more accurately, wavelength) of the incident sound, and the particular organ bay position evaluated, some energy will be reflected (and/or scattered) by the grille and returned to the room, and other energy will be admitted into the organ loft through the grille and the velour drapes. The energy which is transmitted through the grille may be considered "lost" or absorbed from the energy within the hall. While the existing loft space can be considered a semi-coupled volume to the main house, the effect of changing the overall volume of the loft has an undetectable effect on the overall reverberation time in the main house, due to the immense volume of the audience chamber.

Our measurements for the organ loft were conducted to determine the sound energy reflection and absorption characteristics provided at the organ bay openings. We carried out a series of measurements with the TEF analyzer, measuring the sound energy on both sides of organ loft grilles (this was done for each of the three bays, house left side). We then evaluated the change between the direct sound incident to the bay openings, and the sound which actually passed into the organ bay.

The accompanying graph represents the averaged frequency response difference for the 3 house left organ bays. The Y-axis represents amplitude in decibels and the X-axis indicates frequency in Hertz plotted on a logarithmic scale. The "0" decibel line represents unity, indicating that there was no measured change between the sound energy measured at the front of the bay opening to that measured behind the curtain. This means that the sound was neither reflected by the grille nor absorbed by the curtains. This is more apparent in the lower frequencies, which due to their long wavelengths, respond to the loft openings as if the grille work was non-existent. At mid and high frequencies, the openings act as a frequency-selective absorber and reflector caused by the size of the grille openings and surface variations.

Dress Circle Shearwalls. Concrete shearwalls will be added at the side/rear of the Dress Circle seating area. From an acoustical standpoint, the shearwall will serve to place a hard sound reflective boundary surface closer to audience seats than presently exists. To determine the acoustical significance of this proposed construction, and to help provide future recommendations with regard to possible architectural finishes, we conducted Polar ETC measurements at a representative seating location (seat J17) near the proposed shearwall (see Figure 3). The accompanying figures provide a graphical representation of the significant reflected sound energy arrivals and their relative time offset in both the horizontal and median planes.

Our analysis looked at the direction, time difference, and relative strength (or amplitude) of sound energy reflections relative to the direct sound. Significant sound reflections from behind the listening location arrive approx. 85 milliseconds or more after the direct sound, thus contributing to the "definition" of the sound source. At this particular seat, the primary reflective energy comes from the wall corner cove formed by the entry door and the ceiling. A smaller amount of sound energy comes from the back wall due to the reduction in exposed wall area caused by the angle and seating rake of the Dress Circle. We anticipate that adding the shearwall will cause the reflected sound to arrive earlier in time to the listener (since the shearwall will be closer in distance), and at a higher amplitude.

Although this increased energy return from the wall surface will not be detrimental to the clarity of the direct sound, it will present a change in both the sound level and the directional impression.

We recommended that the face of these shearwalls from at least ear height (or seat back) to the ceiling be treated with a sound-diffusing acoustical treatment. Such treatment will maintain the useful early sound energy (as opposed to using an absorptive finish which would greatly reduce reflected sound) but will "scatter" the reflected sound. This will reduce the increased intensity of the reflected sound while maintaining the general spatial impression which exists in the nearby seating area.

5. THE SEATING RENOVATION

A separate project is the renovation of all of the 120 seats on the Orchestra Level of the Opera House. Because this study had been authorized and funded separately prior to the earthquake in '89, it continues as a stand-alone project. Newly upholstered seats can certainly impact the acoustics of a hall, and therefore must be integrated and coordinated with the rest of the projects.

The original seats were custom designed. They were very thick, plush and comfortable, with fully upholstered backsides of the seat backs. The pitch of the seat backs were fairly shallow and the row to row seat spacing was only 36 inches. Therefore, over the years many of the seat backs became worn and the upholstery split, as patrons, stepping past those seated, maneuvered to their seats. The cushioned seat bottoms, which did not retract when unoccupied, have also worn significantly and sag to the point of affecting sightlines.

We are currently preparing acoustical specifications for the newly renovated seats. Although they are to be similar in every way to the original seats, they will have a slightly steeper rake to the seat back to allow more clearance for patrons (the row to row seat spacing remains the same). Current fire codes often require fire protection for the cushion materials and upholstery on the seat backs and bottom, which could affect the acoustical absorption of the seat. Although additional fire protection is not required for this project, the cushioning material will be of a new synthetic fill. The new seats will all be self rising when unoccupied.

The seating renovation work also includes incorporation of current ADA (Americans with Disabilities Act) requirements for accessibility for handicapped patrons, assistive hearing systems, and other conditions for the physically challenged.

6. OTHER STUDIES

Other projects related to the basic Opera House renovation include:

Front of House Elevators. A year prior to the '89 earthquake, the main front-of-house elevators were outfitted with new electrical motors, which are located in small rooms on the fifth floor level, adjacent to the entrance doors to the balcony. When the elevators are in operation (potentially anytime during a performance), the whine of the motor can be heard in the balcony. Noise levels were measured in the balcony up to 10 dB above the ambient during an elevator passby. Both airborne (due to minimal sound isolation at the ungasketed standard door to the elevator equipment room) and structureborne (due to inadequate vibration isolation) noise transmission contribute to the excessive noise levels in the balcony.

Orpheum Theatre Orchestra Pit. During the season that the Opera is out of the Opera House, they are expecting to perform in other venues in San Francisco. One of these theatres is the 2500 seat Orpheum Theatre. The orchestra pit is very shallow in depth and limited in size to approximately 25 musicians. It is totally unsuitable for the minimum 65 musicians needed by the Opera. A detailed study is in progress to create a new orchestra pit suitable in every way for the musicians: comfortable, cool, and quiet, with good acoustics.

Civic Auditorium. In addition to the Orpheum Theatre, the Opera is also expecting to perform in Civic Auditorium, a large volume, high ceiling "barnlike" structure usually seating about 4500 with a very poor reputation, acoustically. The Opera has proposed a truly exciting scheme to transform the flat floor, single U-shaped balcony Civic Auditorium into a thrust stage theatre form with box seats for a portion of the patrons, and a two level stage, with the orchestra located above and behind the performers on stage. Flanking the stage are two large rear projection screens (each larger than the original Opera House proscenium opening). We have not yet embarked on assisting the Opera with this work in the Civic Auditorium; however, it is expected to be a very challenging assignment. No doubt, some very sensitive electronic voice enhancement techniques may be required to successfully accommodate the 180 degree spread of seating in this large venue.

7. ACKNOWLEDGEMENTS

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- S. Leonard Auerbach and Associates, Theatrical Consultants
- Turner Construction Company

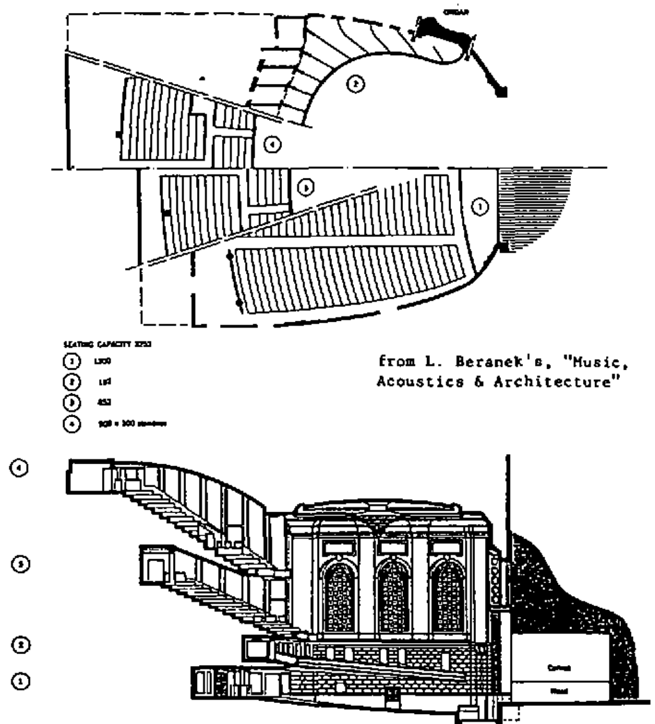

Figure 1

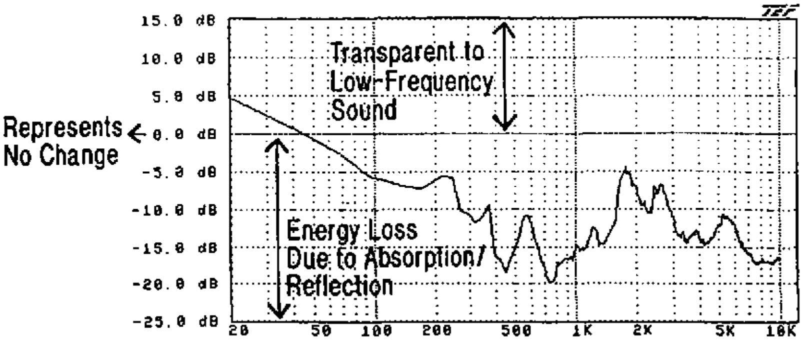

Figure 2 Frequency Response Difference – Organ Bay Grilles

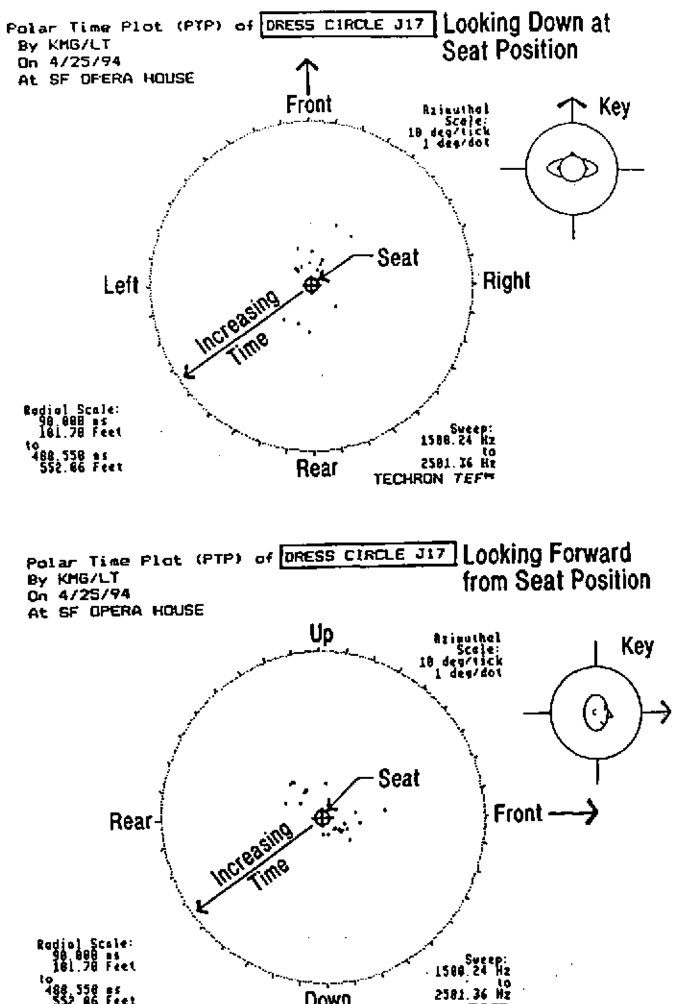

Figure 3 **Polar Energy Time Curve**