Planetarium Acoustical Analysis

Introduction

During the construction of the planetarium, the owner’s representative had concerns regarding the echo that he heard whenever he entered the planetarium. He was extremely uncertain about the outcome of the space, and was in need of some assurance that the echoes would be gone when the planetarium was finished.

For a long time during construction, the planetarium consisted mostly of hard surfaces, included lath and plaster for the surface of the dome, concrete floors, and gypsum board covered metal stud walls. Because of this the echo heard in the room was substantially greater than would be heard after the finishes were in and the seats were filled with students.

The planetarium is a domed structure, and therefore can reverberate more than usual because the shape allows for more deflections of sound. Concave ceiling and wall surfaces often require treatment to prevent annoying sound reflections which reduce intelligibility of direct sound, such as what the owner heard. Sound energy can be concentrated in certain areas (focusing is more noticeable for low frequencies because most materials are less sound absorbing at those frequencies) or reflected along smooth concave surfaces (creep echo).

The planetarium was designed with a sound-transparent liner for the sky images to be projected on. This allows sound to transmit through the screen and be reflected or absorbed by the material behind it (in this case, gypsum board).

The planetarium space is planned for use both as a classroom/lecture hall and as a cinema for films concerning astrology. The owner was most concerned that during lectures any other noises would be easily heard and accentuated, and that during films the audio would be hard to understand because the echoes he heard were so long. A reverberation time analysis would have been beneficial to assure the owner that the acoustical quality of the planetarium would be acceptable.

On the outside corners of the structure, on the other side of the hallway that runs around the perimeter of the planetarium, are three mechanical rooms that serve the planetarium mechanically and electrically, and also provide audio visual systems. The owner was also concerned that the noise from these rooms would be easily heard through the mechanical room walls, the hallway, and the walls to the planetarium. A sound transmission class rating of the mechanical room walls would be able to alleviate any concerns regarding the noise that would be audible in the planetarium.
Acoustical Analysis

Reverberation Time

Reverberation time is the time required for the sound level in the room to decay 60 dB, or in other words, it is the time needed for a loud sound to be inaudible after turning off the sound source.

The calculation of reverberation time using the Sabine equation assumes that the sound in the room be diffused. In practice, reverberation time equations are good enough to describe the sound build up and attenuation in the room. The optimum reverberation time for different rooms depends on the volume of the space, the type of the room, and the frequency of the sound. In general terms, the optimum reverberation time for rooms with speech programs is less then the optimum reverberation time for rooms with music performance.

The sound absorption coefficient describes the efficiency of the material or the surface to absorb the sound. The ratio of the absorbed sound energy to the incident energy is the sound absorption coefficient. For architectural purposes, sound absorbing materials and constructions can be divided into four types of materials depending on the way the absorption is mainly performed: Turning the sound energy into heat such as fiberglass and carpet, vibrating with a specific frequency when the sound hits the surface such as lightweight panels and 5/8" gypsum board (These materials absorb the sound effectively on a narrow band of frequencies), turning the sound energy into heat in the neck of the cavities such as sound blocks (This construction has a good absorption on low frequencies), and allowing the sound to go through such as some types of grid systems and lay-in ceiling with sound leakage above it.

The most common way to measure sound absorption coefficient is to lay a piece of the material in a reverberant room (a room which has very long reverberation time) then measure the RT so the coefficient can be derived from Sabin equation (the original version of RT calculation). There is a standard that details this procedure. The value of the coefficient for the same material varies with the type of the mounting in the test room.

A reverberation time calculation was performed to determine the adequacy of the finish materials in the planetarium to absorb or reflect sound. Because the space is intended to be used as both a lecture hall and a cinema, the optimum reverberation time was determined to be between 0.7 seconds and 1.2 seconds at 500 Hz. The midpoint of that range, 0.95 seconds was used to maintain an appropriate time for both usage types. From that information optimum reverberation times were determined for both high and low frequencies (1.24 seconds at 125 Hz and 0.76 seconds at 4000 Hz).
From these reverberation time values, optimum sabin values could be found through the equation $a = 0.05V/t$ where $V$ is the volume of the space and $t$ is the optimum reverberation time that was found above.

The actual sabin values for the planetarium space were determined next by calculating the surface area of each material used within the space to include walls, the domed roof, floor, seats, and audience. The walls are designed to be covered entirely with sound absorbing acoustical panels, the dome will be covered with gypsum board, the floor will be carpeted, and the seats will be upholstered. The sound absorption coefficients of each material were multiplied with each respective surface area to determine the sabin value. The values were next summed to produce an overall sabin value at each frequency (125 Hz, 500 Hz, and 4000 Hz).

The calculated sabin values were similar to the optimum values, and the corresponding reverberation times were 1.3 seconds at 125 Hz, 0.95 seconds at 500 Hz, and 0.80 Hz at 4000 Hz. The expected reverberation times match the optimum times extremely closely. This concludes that the planetarium space will perform as required for both a lecture hall and a cinema (See Appendix D for calculations).

**Sound Transmission Class Rating**

Sound transmission class (STC) is a single number used to characterize the airborne isolation properties of a partition. The STC is determined from the measured TL of a partition at different frequencies. These measured values are then compared with standardized STC contours.

A transmission loss calculation was performed to determine the ability of the walls of the mechanical rooms to prevent sound from entering the planetarium space. The mechanical room walls are constructed of metal studs with 3” acoustical batt insulation between the studs and two layers of 5/8” gypsum board on each side of the studs. Each room has one flush solid core wood door with a hollow metal frame.

To calculate the transmission loss, the transmission loss values for each material were used to calculate the composite transmission loss of the entire wall. Composite transmission loss is calculated from $\text{TL} = 10 \log \frac{\sum S}{\sum tS}$ where $S$ is the surface area of the material and $t$ is the sound transmission coefficient of the material.

The composite transmission loss of the wall for rooms 101C and 101F was 40 dB and 41 dB for room 101E at 500 Hz. TL values were obtained for 6 frequencies in order to create a curve to obtain an STC rating. The transmission loss calculations can then be transferred to a sound transmission class graph where the curve for these values can be compared to a standard STC curve. A high STC rating means better the sound insulation of the wall. The STC rating for all three rooms is 42, which is very good.
penetration from the mechanical rooms into the planetarium space will not be an issue (See Appendix D for calculations).

**Conclusion**

Despite the owner’s concerns for the acoustical quality of the planetarium, the space will be acoustically adequate for its intended purposes. In fact, the space is extremely close to its optimal performance. The owner can be assured that when the space is completed, there will be no noticeable echo when the room has an audience, and little, if any, mechanical room noise will transfer into the planetarium space. No revisions need to be implemented into the design.