SSA ACOUSTICS, LLP

ACOUSTIC EVALUATION & DESIGN GUIDELINES

TACOMA MUSICAL PLAYHOUSE
Tacoma, WA

January 15, 2010

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INTRODUCTION

This report aims to provide our evaluation of the existing Tacoma Musical Playhouse and provide preliminary guidelines and recommendations to be considered during the design of the new playhouse.

It is our understanding that the sole function of the space is to conduct musicals which include both orchestra and vocals. This requires sound energy to be balanced between direct and reflected sounds path that help increase the clarity of speech and fullness of music.

Our initial evaluation included conducted measurements consisting of reverberation times and sound loudness of varying sources such as the orchestra as well a female and male vocalists. The evaluation also included determining the equalization of sound energy from the orchestra over the seating area relative to the vocalists on stage.

Recommendations and material selections have also been provided for review and consideration in the design of the space. Typical recommendations included removing the existing absorption on the walls and ceiling and replacing it on the backwall and back portion of the ceiling. Diffusion is recommended on the side walls. A single proscenium reflector is also recommended.

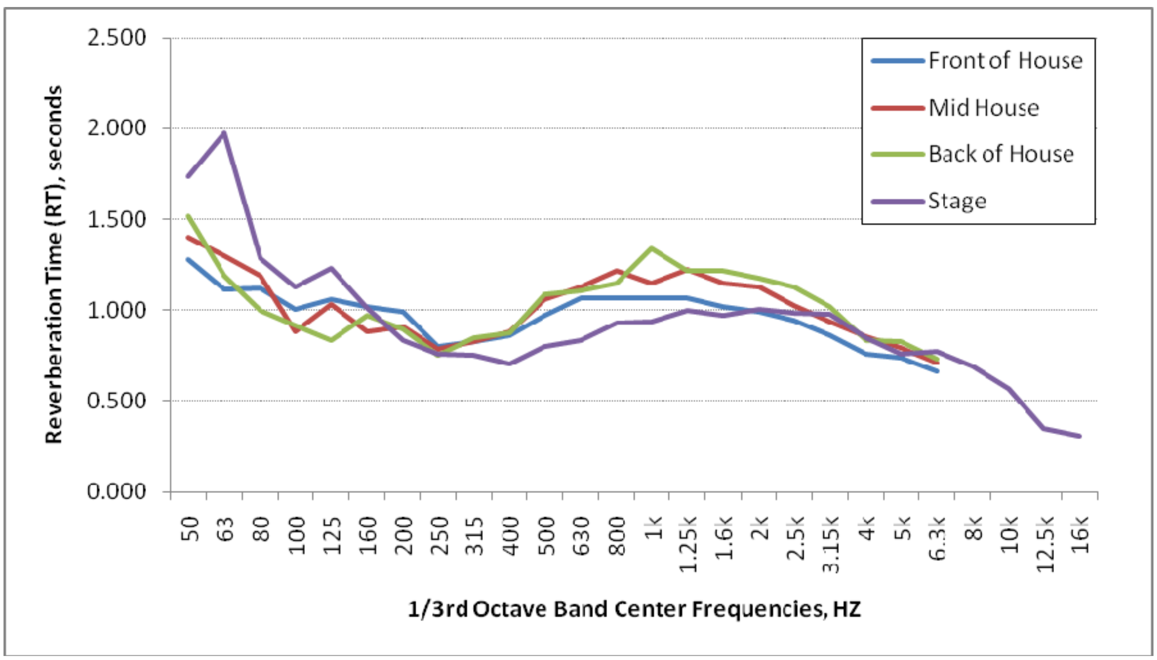
The element that requires immediate attention is the orchestra pit. Currently the opening from the pit is too small and should be adjusted so that the apron is no more than 50% the depth of the pit. The pit should also provide at 16sqft per musician.

EVALUATION

A site visit has been conducted to evaluate the existing conditions at the Tacoma Musical Playhouse. At this time measurements of existing sound levels from the orchestra and from male and female vocalists were conducted.

The purpose of this evaluation was to determine the existing acoustic environment and establish the performance and the ability of sound to even distribute throughout the space. In order to properly quantify this performance, measurements were made at specific locations throughout the playhouse. Measurements included reverberation time (RT60) as well as measurements of loudness of orchestra and vocals at the same specific locations. The following chart presents the results of reverberation times measurements for the house and stage area. The house was separated in to front, mid and back of house sections with three separate measurements to account for left, center and right house.

Figure 1 - Existing Reverberation Time (RT60)

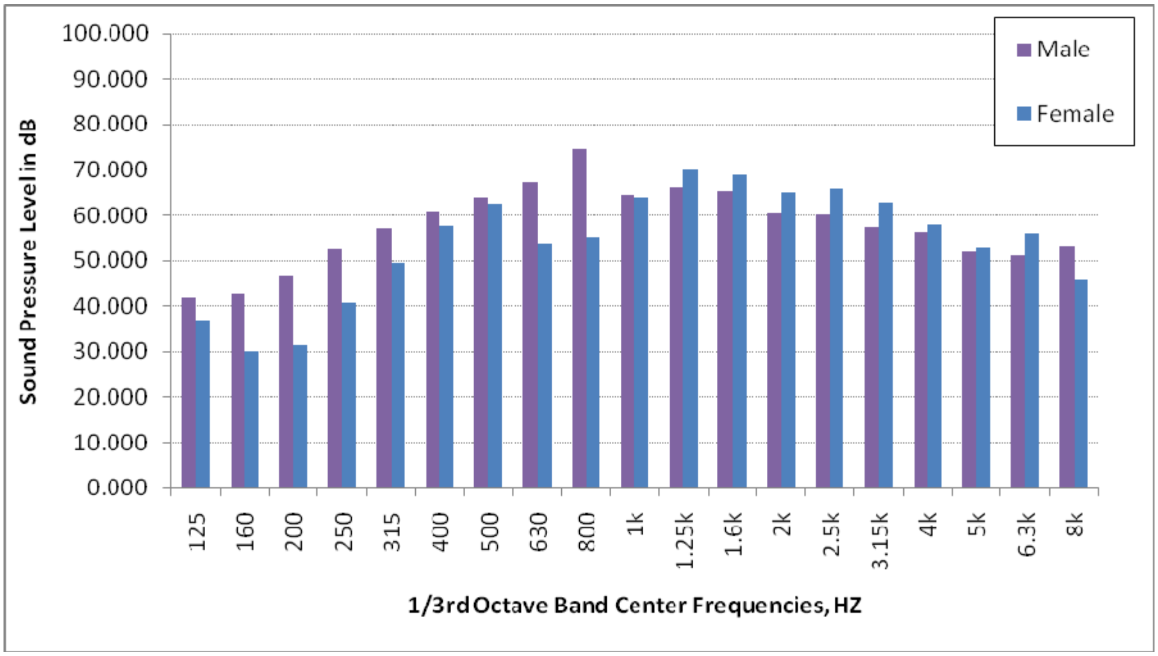


From the chart above, we notice that the reverberation times for all areas of the house follow the same trend. The house has a slightly longer reverberation time than the stage. Ideally the stage and house should exhibit similar results. Additionally the low frequency response (~125 Hz) of the space is slightly lower than what would be recommended. The mid frequency (~1000 HZ) portion of the spectrum is also slightly lower than what we would recommend. High frequencies (4000 Hz) are in the range we would expect to see for a performance space such as this.

Observations of the space during our site visit indicated the use of glued on ceilng tile which has been painted over. The extent of this tile appears to be the walls (sides and back) and the ceiling. The large quantity of absorption seems to have brought the reverberation time down to a reasonable level but has left the performance space un-balanced with the low and mid frequencies being reduced further than would be typically recommended. Initial recommendations will be discussed further in this report.

Measurements were acquired of both female and male vocalists in an effort to capture spectral sound pressure levels for use in modeling the house and distribution of sound energy. Measurements were acquired at a distance of approximately 5 feet for duration of 1.5 minutes for the sample song performed. The following table provides the results of both female and male which illustrates the difference in spectral content between vocalists.

Figure 2 - Spectral Measurements of Vocalists



As expected male spectral content is slightly higher at lower frequencies than females, however at the mid to higher frequencies female vocales exceeded that of male vocals. Overall sound level of male vocals was approxaimtely 80 dbA while female vocals were slightly less at 77 dbA.

Measurements of the orchestra were acquired at a distance of approximately 10 feet from the members playing as well as for several locations around the house. Similar to the reverberation time measurements, the house was divided into three sections from front to back and from left to right. This was conducted in an effort to determine the overall loudness from the band at varying locations in the seating area and to establish the equalization of sound at these locations. At a distance of approximately 10 feet from the orchestra members, sound levels were at a level of approximately 92 dBA. The following chart illustrates the spectral components of sound levels.

At the areas of the house towards the opposite side of the orchestra sounds levels were approximately 5 dB less at 87 dBA with emphasis on the higher frequency sound levels. This is likely a direct result of the percussion being situated back where the direct line of sight is blocked from the seating area. Across the back row of the house sound levels were similar at low frequencies and higher frequencies were more attenuated. Largely in part due to the absorption on the surfaces and reflections. High frequencies were reduced by approximately 9 dB towards the left of the house as opposed to the right side. A reduction of this level is almost a 50% difference in sound level. Center locations and locations directly in front of the orchestra received the most balanced sound distribution compared when compared to source sound levels. In these locations it is primarily the direct sound energy that is dominating rather than useful reflections from the sidewalls and ceiling surfaces.

DESIGN CRITERIA

The acoustic experience by the audience within the playhouse will be controlled by three factors: sound volume, equalization, and reflected sound. To design any space we must consider the intended use, but, adjusting these three factors we can achieve the desired results.

Sound Loudness

Little clarification is needed regarding amplitude, or sound loudness, with regards to room acoustics. In a perfect environment, one can perceive a difference in loudness as small as one decibel. In a performance space, the sound heard by the audience will be made up of directly radiated sound, and reflected sound from the floor walls and ceiling. This combination of sources is needed to achieve a full, rich sound from the stage.

Direct sound is the unobstructed sound we receive from an object. Similar to standing in the middle of a field, that has a surface that is 100% absorptive; it is the only path of sound we would receive. Reflected sound is the sound that reaches our ears after being reflected off of various surfaces within the auditorium.

Although the audience receives both direct and reflected sound, it is the direct sound that determines the loudness they perceive. This is caused by two reasons, 1) sound is lower in amplitude from the reflected path because it travels a greater distance 2) sound is partially absorbed and diffused by a reflecting surface. The sound level is reduced or increased by 6 decibels with each halving or doubling of distance. For these reasons, reflected sound normally plays a small role in the overall perceived sound level.

Most sound environments we experience are made up of direct and reflective sound. We are conditioned to receiving sound from reflected paths and can perceive subtle differences between these direct and reflected sources. It helps us to define our environment. This relationship between direct and reflected sound must be preserved in a performance space for sound to seem natural. It is therefore important that the relative difference in sound level between the direct and reflected paths be maintained.

Equalization

This quality further defines the sound by evaluating the frequency spectrum received at the listener. With listeners experiencing sound from 20 Hertz to 20,000 Hertz, it is important to experience the full range of the sound without some frequencies being reduced by materials from which they are reflected. In other words, equally radiating the full spectrum of sound from the stage to the listener from both the direct and reflected paths. If the equalization of a performance arts center is correct, sound from the stage, in which all frequencies are equally loud, will reach the audience in exactly that same amplitude relationship.

Lower frequencies tend to radiate uniformly in all directions, while higher frequencies tend to radiate more directly in a straight path. Reflective surfaces then focus more high frequency sound and thereby change the frequency composition heard by a listener. This requires the reflective surfaces of the house to be carefully designed to avoid changing the equalization of the performance sound.

The house should not favor high frequencies, and should have a mellow, warm feeling composed of the entire frequency spectrum. Without this balance, the house will tend to sound *harsh* and have a "*brightness"* to the sound that will dominate the spectrum. This will be passed on to the musicians and performers causing them to over compensate and to adjust their performance from becoming overbearing. The instruments will have to avoid "digging in" and applying more -

pressure to generate sound and yet avoid overshadowing other elements of the music. Equalization is the single most important factor in the acoustics in the house. Sound systems can be adjusted to provide better equalization for specific locations within a space but, nothing can substitute for good room acoustics in the design.

Fullness

Refers to the amount of reflected sound relative to the direct sound. The more reflected sound energy, the more full the house will be. For slow, romantic music performed by large groups, fullness is required, whereas smaller groups less fullness is typically required.

Clarity

For this project this quality will be one of the most crucial to design to. In this space there is a combination of vocals, both spoken and singing, as well as for musical performances. The ability to clearly understand the content of speech is essential. Clarity is the acoustical opposite of fullness and is obtained when reflected sound energy is low relative to direct sound energy. Higher clarity is required when listening to speech and is particularly important when performing orchestra music. In general, greater clarity requires shorted reverberation times.

Brightness

This describes the perceived loudness of higher musical frequencies (those above 2000 Hz). When a room is in good balance with other frequencies and are not overpowering. A bright acoustic environment enables performers to clearly hear themselves enhancing their ensemble. However without this balance, the playhouse will tend to sound *harsh* and have a with a sound that will dominate the spectrum. This will be passed on to the musicians causing them to adjust their performance from becoming overbearing. The string instruments will have to avoid “digging in” and applying bow-pressure to avoid overshadowing other elements of the music. Equalization is the single most important factor in the acoustics in the PAC. Sound systems can be adjusted to provide better equalization for specific locations within a space but, nothing can substitute for good room acoustics in the design.

Warmth

In performance arts spaces this describes the relative loudness of lower frequencies (less than 250 Hz) to the loudness of mid frequencies. The Bass Ratio (BR) has been widely used as a measure to describe warmth. The Bass Ratio is the reverberation at low frequencies divided by the reverberation at mid frequencies. For a performance space this should be greater than 1.0. It should be noted that to reflect and diffuse sound with long wavelengths (low frequencies) will require large surfaces with substantial mass and rigidity. Reflectors for musical performances require a mass equivalent to 4 pounds per square foot.

Reverberation Time

Reverberation time (RT60) is one of the most important characteristics in design a performance space. It is defined as the time required for a sound source to decay 60 dB once the source noise has stopped. This descriptor can have a serious effect on what the listener perceives within the space. Excessively high reverberation times can reduce speech intelligibility, prevent ensemble cohesion and also reduce timing and clarity. It is directly related to the volume of the space and the type of material surfaces. Some materials will provide an acoustically absorptive surface reducing reverberation while others are hard and reflective.

Shaping

The primary method to control these factors is room shaping. This allows control of the length of time direct and reflected sound takes to arrive at a listener. It also allows for sound to be directed to different areas of the house by adjusting the angle on wall surfaces. The following guidelines support the recommendations we have developed for the PAC:

- The reverberation time RT should be 1.2 to 1.4 seconds at mid-frequencies (500 and 1000 Hz), 1.3*RT seconds at 125 Hz, and 0.8*RT seconds at 4000 Hz. At high frequencies, too much reverberation usually means “harsh” or “rasping” listening conditions. At low frequencies, too much reverberation usually sounds “boomy,” whereas too little sounds “shrill.” Currently mid-frequencies are approximately at the range that is recommended. However, the lower frequencies would be recommended to increase as they are actually reduced more than would be recommended.

- The first method to controlling reverberation is to adjust the volume of the space. For the playhouse the recommended volume-per-seat ratio should be approximately 200 to 240 ft^3 per person. Based on the approximate volume of the space at roughly 65,000 cubic feet, the house will be able to accommodate approximately 270 to 325 audience seats.

- The average ceiling height in the house can be directly related to the reverberation time where the height of the ceiling in feet, divided by 20 approximates the mid-frequency reverberation time. Currently the average ceiling height is approximately 20 feet resulting with a mid-frequency reverberation time of 1.0 seconds. This is slightly lower than would be recommended for a space with both orchestra and vocals. Current performance is acceptable for a lecture hall but should offer slightly more reverberation.

- The ceiling currently provides absorption over the entire area. Absorption is in the form of glued on ceiling tiles. This material is not currently providing an equal level of absorption over the spectrum. The ceiling should implement sound-reflecting materials such as thick wood or gypsum board to promote useful reflections at the front of the space. This can be achieved by removing some of the ceiling tile and allow the ceiling to effectively re-direct sound to the seating area. Towards the rear portion of the ceiling absorption should be employed to control reverberation. Absorption should cover an equivalent area of approximately 1800 sqft. This is equivalent to the entire width of the house extending from the back, a distance of approximately 30 feet. Details will be provided as the design progresses to further illustrate this concept. Absorption should be in the form of 2 inch theater board or theater blanket provided by Owens Corning.

- Side wall surfaces should use sound reflecting and diffusive surface with as many irregularities as possible to enhance useful reflections and avoiding flutter echo and focusing of sound energy. Significant reflective surfaces should be adjusted for angle and distance from the source to prevent an excessive delay between direct path sound and reflected path sound (ITDG or initial-time-delay gap). Currently glued on ceiling tile is installed and removing more sound energy that is needed. The side walls will actually provide useful reflections to the side seating areas. However, considering the sidewalls are parallel to each other, diffusion should be installed to reduce the chance of flutter echo.

- For the function of this space the recommended design for initial time delay should not exceed approximately 20 ms or 23 feet. This will provide an excellent listening environment for both speech and music. The following chart provides the path length difference as it relates to expected listening conditions.

Table 1

South Path Difference, ft	Time Delay Gap, ms	Listening Conditions
<23	< 20	Excellent for speech and music
23 to 34	20 to 30	Good for speech, fair for music
34 to 50	30 to 45	Marginal (blurred)
50 to 68	45 to 60	Unsatisfactory
> 68	> 60	Poor (echo if strong enough)

- The orchestra pit should be designed so music can be blended and balanced with sound from the stage. For preliminary planning purposes, the pit should allow for approximately 16 sqft per musician. The current drawings for the proposed pit space indicates an area of approximately 315 square feet. This will allow for approximately 19 musicians. The backwall of the pit should provide removable or retractable sound absorption to allow the conductor to control the overall sound loudness. Absorption should be a minimum of two inches in thickness.

Currently the space offers good sound reinforcement from the side walls with ITDG gaps at or less than 20 ms along the side seating areas. Along the front center area of seating, ITDG is well below the recommended design goal.

The current shaping of the space with the low ceiling and distant sidewalls will support the function of the space with some added materials to control echo, reverberation and destructive reflections. The following aims to provide the initial recommendations necessary to achieve the goals of the project.

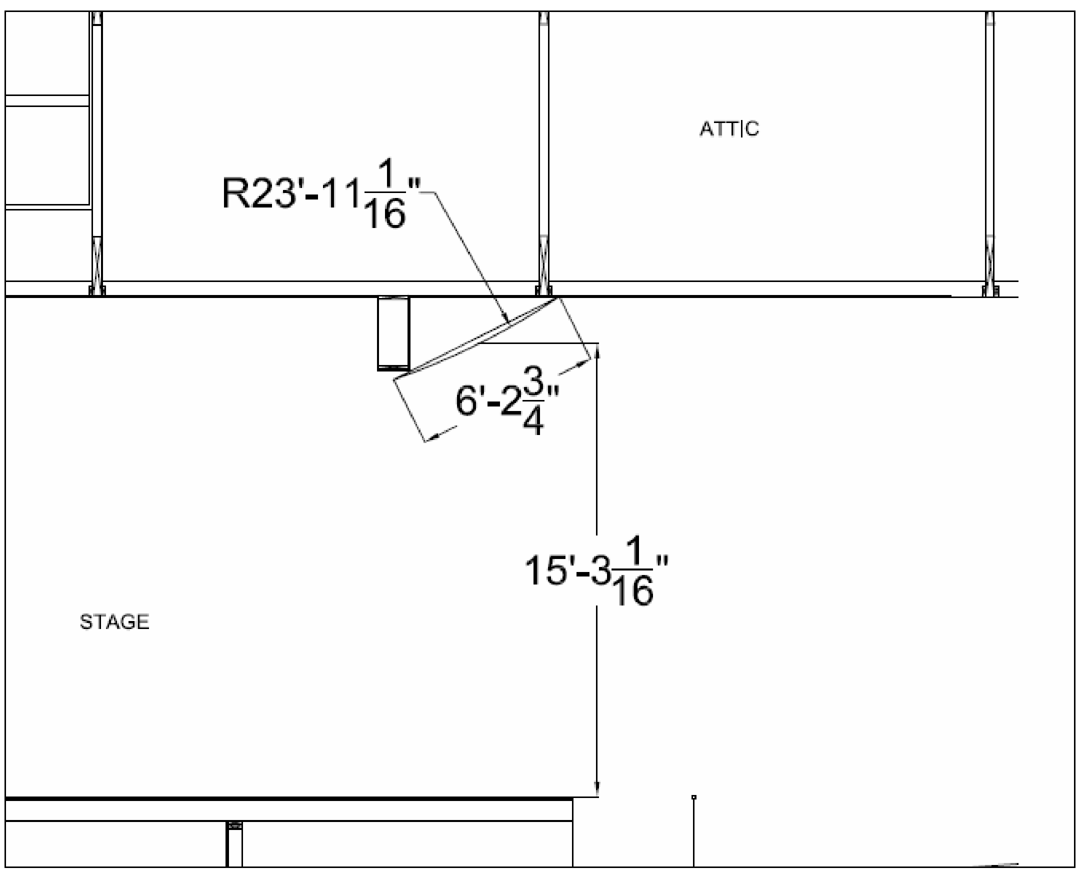
RECOMMENDATIONS

We recommend allowing space for a large single reflector to be installed proscenium opening. This will assist in directing sound energy from the orchestra pit to the audience. Additionally it will provide useful reflections to project sound from the stage to the seating area. This will prove beneficial for directing early sound energy outward over the audience area. As an alternative to the single large reflector, a series of smaller reflectors will perform equally well. To perform effectively as a reflector for music, the reflector should provide for a mass of 3 to 5 pounds per square foot. This can be achieved with two layers of ½ inch or 5/8 inch GWB. With the reflectors in place the recommended ITDG can be achieved in the front area of the house.

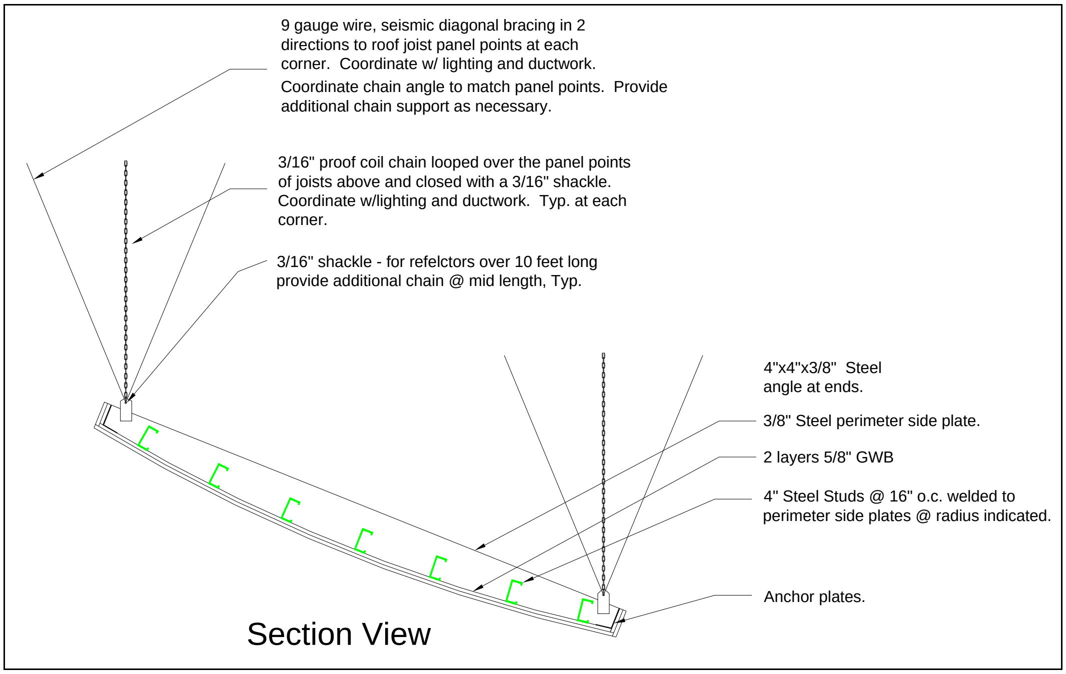
The proscenium reflector should be added as illustrated in the figure below. This will help direct sound energy to the back seating area. Reflector should have the following properties:

<u>ROW 1</u>

Radius:	~24 feet
Chord Length:	~ 6 feet
Angle:	~27 degrees
Height:	~15 feet
Distance from Proscenium Opening:	~2.5 feet



The following detail has also been included providing typical construction details that can apply to the ceiling reflectors.



The ceiling surface should provide approximately 1/2 of the ceiling area with absorption achieving an NRC of no less than 0.80. Absorption should begin from the back wall and extend forward no more than approximately 30 feet and extend to both sides following an arc close to that of the seating area. Absorption can be installed on the back portion of the ceiling or on the sides of the ceiling in a horseshoe pattern. Materials meeting the design requirements for absorption include 2 inch thick theater board available through Owens Corning (catalog cut enclosed).

The rear curved walls located on either side currently indicate a radius of approximately 15 feet. For these walls to more effectively redirect sound energy to the main seating area the shaping should be adjusted. The curve should be increased to have a radius of 19 feet. There are two options for these reflectors. The first is to maintain the use of a single reflector on either side as currently illustrated. The second includes splitting the reflector into two separate reflectors with smaller chord lengths. Each reflector would be angled at approximately 6 degrees from the side wall with chord lengths of approximately 10 feet. They can be oriented to allow for a scalloped orientation. The side reflectors would also benefit from a slightly outward angle from top to bottom with the top being further out from the wall than the bottom. This should be at an angle of approximately 7 degrees which will help redirect sound downward towards the audience.

The rear wall is currently curve and will provide destructive reflections back to the stage area. It is recommended that the back wall be fully treated with absorption in the form of heavy draperies with 200 percent fullness. This will reduce destructive reflections back to the stage area and the performers.

The floor and seating area should provide absorption. Seating is recommended to be a fabric, not vinyl, cushion which will provide similar absorptive properties to that od a full audience. This will help maintain a similar performance whether the house is full or only partially full. The floor should be treated with commercial grade carpeting in the isles only. Carpeting need not extend into the seating area. The front of the house near the stage should also receive carpeting. carpeted in the aisles and not around the seating area.

The orchestra pit currently illustrates a stage apron that extends more than 11 feet over the pit with an opening of approximately 4 feet. The overall depth of the pit is approximately 15 feet. The recommend apron depth should be not more than 50% the depth of the pit. The following figures illustrate the current and recommended configurations.

Figure 3 - Currently Proposed Pit Section

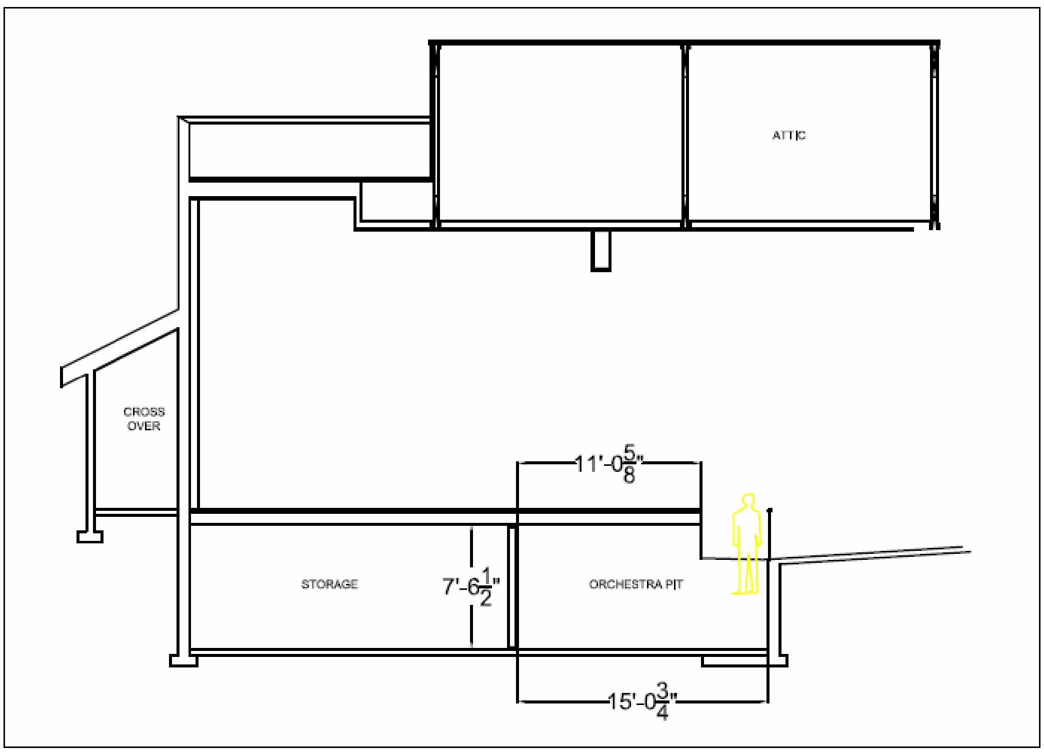
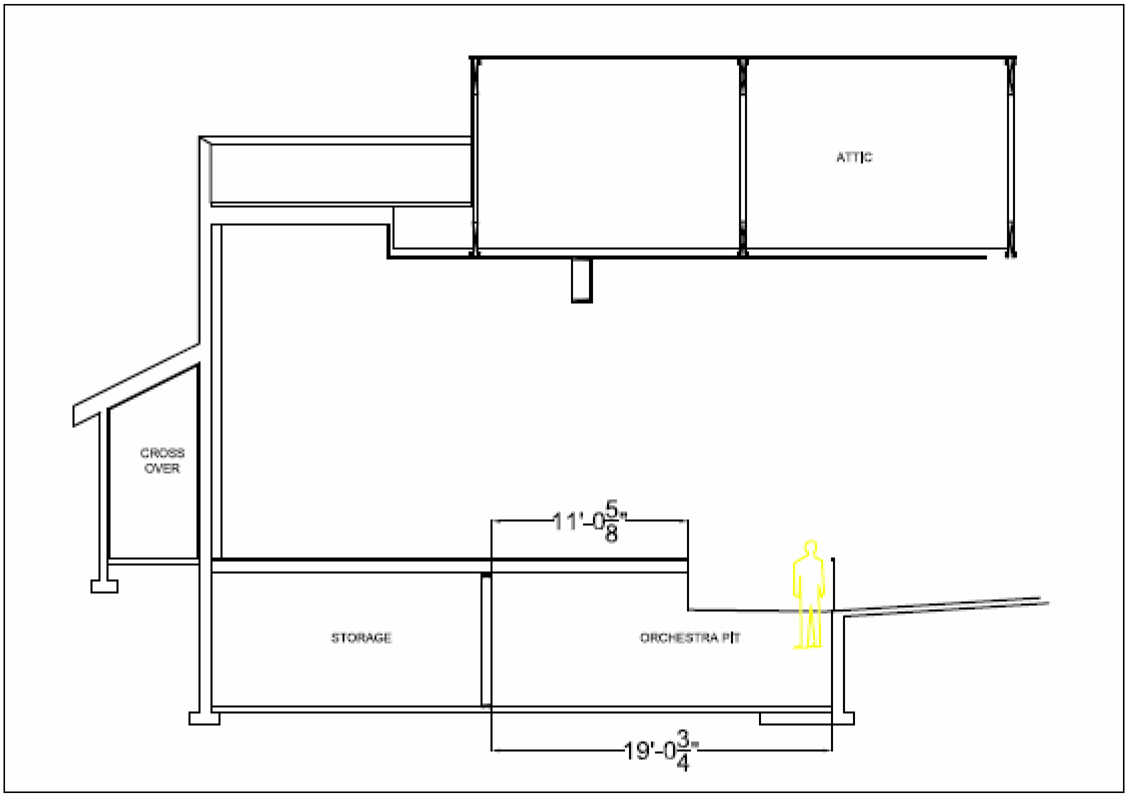


Figure 4 - Recommended Pit Section



This configuration will not only allow sound energy to exit the pit and fill the house but also provide a better line of sight between the conductor and musicians towards the back of the pit. In order to provide this opening and maintain stage depth adjustments to the back of stage and proscenium opening may be necessary. We will assist in this coordination as the design progresses,

SUMMARY

The information found in this report has provided our initial evaluation and preliminary recommendations. Guidelines and consideration haves also been provided to help address the design goals to be achieve that will support the function of the space. Catalog cuts of materials such as absorption are also included. Further detailing will be provided as necessary and details review relative to acoustical performance. Should there be any questions or significant changes been made, please contact us as soon as possible.

Sincere Regards,

John C. Keiffer
Acoustical Consultant