Standard materials may be used in concert hall construction, but for acoustical reasons they are often handled in special ways.
To some designers and specification writers it may seem strange to think of all concert hall construction materials as “acoustical” materials, but such is the case. All interior wall, floor, and ceiling surfaces, and all finishes and furnishings have an effect on the acoustical environment in which concerts are performed. In addition, the way the hall is constructed and the design of the HVAC system play a part in eliminating noise disturbance during a concert. Standard materials may be used, but for acoustical reasons they are often handled in special ways.

In concert hall acoustics design there are two basic disciplines—room acoustics and noise control—whose needs and solutions are different, though they must often be achieved in the same wall, floor, or ceiling detail. Sometimes the same materials are used for different reasons, and their materials’ specifications are similarly separated. One discipline is the design of the auditorium itself: the volume, shaping, finishes, and furnishings necessary to achieve the best acoustical environment for the natural (unamplified) sounds of musical instruments. This discipline is called “room acoustics.”

If it is a place for listening, a big room’s acoustical environment is its hallmark. For a concert hall, “good acoustics” involves

- good distribution of sounds to all the seats, which depends on proper shaping and finishes of all interior surfaces
- natural sound diffusion and envelopment
- a sense of intimacy for the audience and a sense of ensemble for both musicians and audience
- proper reverberation times throughout all frequencies, which depend on the room's volume and the total sound absorption of all materials.
The two acoustical disciplines: room acoustics and noise control.

freedom from the acoustical faults of echoes, flutter, and focus
freedom from disturbing noises

Many halls in which classical music is performed have proscenium stages, lofts, and backstage areas used when other types of programs are presented. Symphony concerts in these halls usually require special orchestra shells designed to put the orchestra in the same room with the audience, eliminating sound energy loss and late arrival of sounds from the back of the stage. Halls planned for concert programs only, such as Boston's Symphony Hall, among many others, have a platform for the orchestra in the same room with the audience, without any backstage, loft, or proscenium arch.

"Noise control," the elimination of distracting sounds from the concert hall, is the other basic discipline in auditorium acoustics. The typical sources of disturbing noises are other activities within the building; the building’s mechanical systems; and airplanes, trains, and other traffic outside the building.

When the proper “envelope” (the room's shape and volume) has been established, with the proper interior finishes and furnishings, the room acoustics have been established. The floor, wall, and ceiling structures enclosing that envelope must then be designed to achieve the necessary noise control. The design process must recognize the two acoustical disciplines throughout the project's creative and construction document phases.

The degree of noise control required is usually set when the room acoustics criteria are established. Typically, the allowable background (ambient) noise levels are set at Noise Criterion 25 (NC-25), a single number rating representing a series of allowable levels across eight octaves of the hearing range. Sometimes an even lower Noise Criterion is used, especially where sound recording is anticipated. While the NC levels are used most specifically for controlling noise from the HVAC systems, they are also used as a basis for controlling other transmitted noises. These controls must be developed in relation to each other so that the total of transmitted noises through the room's envelope and through the HVAC system together do not exceed the design criteria.

“Hard” Acoustical Finishes and Furnishings

The volume and shape of a concert hall are established in the drawings and details in a project's contract documents. Most of the surfaces of that shape will be hard, sound-reflective materials, individually described further in the specifications. Some typical hard materials and relevant room acoustics concerns are described below.

Plaster. Plaster is a traditional material for ceilings and walls in concert halls. It is used in large areas and on broad surfaces, as well as in specially shaped details. Plaster is usually used with extra thickness—up to 1½ to 2 inches—because the stiffness and mass are necessary to resist panel vibration, which causes low frequency absorption, and to achieve good reflections at all frequencies. Since the necessary stiffness requires more mass than is typical in most of today's building details (gypsum board, for example), a stronger supporting structure may also need to be specified.

The acoustics of a concert hall require very diffuse reflections throughout the room. To enhance the reverberance and give a sense of sound envelopment, the side walls and sometimes the ceiling are often shaped to scatter sounds. Plaster is often used to create these shapes, which may be large architectural forms or smaller decorative and functional forms. Many of the architectural shapes used in concert hall interior surfaces are repeated enough to permit precasting. This casting is often done in fiberglass-
reinforced gypsum (FRG). When large, flat surfaces of FRG are designed, they must be specified to be stiff like thick plaster.

**Gypsum board.** Gypsum board is seldom used in concert hall design because it has too much low frequency absorption resulting from natural panel vibration in response to sound pressure pulses. When gypsum board is used in walls and ceilings, as in civic auditoriums and most churches, the designer should specify double layers of \( \frac{3}{4} \)-inch-thick gypsum board, laminated for stiffness and installed on a furring system designed with extra stiffness.

**Wood and wood paneling.** Wood, often used in concert hall design for aesthetic reasons, must be installed with care. Thin wood paneling with air space behind it (i.e., on furring) will allow unwanted low frequency absorption through panel vibration—much as thin plaster and gypsum board do. Such paneling must be backed with solid construction such as plaster or thick gypsum board, to which it can be laminated. Large areas—and small surfaces repeated enough to be acoustically significant—require this treatment. Solid wood used in moldings and other details usually is not a concern; in fact, it may make the paneling stiffer.

When plywood and gypsum board are bent over curved wall or ceiling framing, they are stressed so that they cannot vibrate diaphragmatically. So bent, they are as stiff as thick plaster, and will not exhibit much low frequency absorption unless the whole curved system is not rigidly supported.

**Masonry.** Masonry materials such as stone, brick, block, and concrete usually are thick and massive enough to reflect low frequencies. Some porous, precast masonry units, however, absorb middle and upper frequencies due to their porosity; if used over large areas these materials will significantly affect the reverberation times of the room. The porosity can be sealed and painted, of course, but only on the recommendation of an acoustical consultant who has assessed all finishes and furnishings in the room.

**Metals and metal paneling.** In addition to absorbing low frequencies, diaphragmatic movement of metal materials might also cause rattles, so they, too, should be laminated to solid core material.

**Glass.** Glass is seldom used in concert halls, since these rooms are usually internal spaces surrounded by public hallways and functional spaces, and because windows could be a path of unwanted noise transmission. Glass might be used for decorative design and lighting, but only large, flat areas would be of concern. Small glass decorative elements might actually provide some useful sound diffusion.

**“Soft” Acoustical Finishes and Furnishings**

The people attending a concert probably constitute the most absorptive surface in a concert hall. The other absorptive surfaces will be the treatments for controlling echoes, and sound foci from rear walls, balcony faces, and similar surfaces. These areas must be limited, however, or else the room could become too “dead”—not “live” enough to give the music the desired reverberance.

Since the audience is the major sound absorber, comparing the room volume to the number of seats planned is useful. The reverberation time in the room is related directly to the volume of the room and, inversely, to the total sound absorption in the room. The volume/seat ratio that has been found to be appropriate, through comparison of many good symphony halls, can range from 250 to 350 cubic feet per seat. This is only a rule of thumb for room size, however. Proper sound distribution, diffusion, envelopment, intimacy, and
the right reverberation times must still be achieved, along with freedom from noise disturbance, echoes, focus, and flutter. Some of the typical, soft (absorptive) materials used, and their relevant concerns in concert halls, are described below.

**Seating.** Seating absorption should match the absorption of people so that when people are absent, as in rehearsals and low attendance, there will not be a noticeable change in the reverberation times of the hall. Designers should specify seats upholstered on the cushion and back rest, and possibly on the rear of the seat back. The seat fabric should be a very breathable woven fabric stretched over a thick, breathable, open-cell foam padding.

**Carpet.** Carpet is usually limited by acoustics to aisle runners, and is typically a commercial grade with a thin, tight loop pile of synthetic fibers. It should be laid with little or no padding.

**Walls and balcony faces.** Where rear walls follow the seating curve there is the real possibility of reflections back to the front of the room, focused and strengthened by the curve, and with a time delay that makes them distinct echoes. Balcony faces can do the same thing. Where a sound reinforcing system is used, even if only for announcements, the rear walls and the balcony face can cause serious echoes. A low wall at a cross aisle can have the same effect.

There are two approaches to treating the rear walls and balcony faces: make them very absorptive, or shape them to reflect up and to the side walls where their second reflections will be scattered and become part of the room’s reverberance. The acoustical consultant’s calculations of reverberation times and analyses of room shape will dictate whether such absorptive treatment is appropriate, or if it will add too much absorption to the room. Absorption of other finishes and furnishings will also be a factor.

Absorptive treatment, when called for, is typically in the form of semi-rigid fiberglass insulation board, of six to seven pounds per cubic foot density, covered with a breathable fabric. The fiberglass core should be at least one inch thick. Often the acoustical consultant will call for greater thickness, possibly three to four inches, in order to achieve desired absorption at low frequencies. The breathable fabric may be an open-weave material (such as Guilford’s FR701), grille cloth (as for loudspeakers), or wire screening. Sometimes these materials are used in combination with an open-design architectural screen such as a vertical wood batten, preferably having more than 50 percent open area with narrow battens, about one inch wide, and rounded on the corners.

**Draperies.** Draperies are generally absorptive, so they are seldom used in concert halls. Drapes should not be used around the platform in particular, since the orchestra needs all of the solid sound-reflective backup it can get. Occasionally the acoustical consultant will recommend drapes for the audience chamber in order to “adjust” the acoustics. (See acoustics story, page 88.)
Special and Design-Generated Conditions

Adjustable room acoustics. Adjusting the acoustical environment might be appropriate for two reasons: the architect, owner, and consultant might want to “fine tune” the room or, more likely, the owner may be planning more diverse presentations requiring a broad range of reverberation times and subsequent changes to the room’s volume and/or absorption. In either instance, standard materials with their special acoustical considerations, as discussed above, can be used. Some designers have made ceiling surfaces move downward to reduce volume and close off upper seating; some have used drapes that come out of wall pockets to cover reflective surfaces, with the drapes and hard surfaces hidden behind an acoustically transparent screen (grille cloth).

Another effective design uses ceiling bands and an attic space that can be closed off. These solid ceiling bands, which go across the room, should be from 10 to 15 feet wide and curved in section for best reflections. The spaces between the bands should be wide open and the roof deck above fairly close to the bands so that sound is reflected back into the room without much delay time. The designer should further provide a method of closing off this attic space with adjustable drapes, just behind the leading edge of each ceiling band. With the attic thus closed off, the room will be deader (i.e., about 40 to 45 percent of the “ceiling” will be absorptive), and the ceiling reflections will seem to occur sooner, resulting in an environment more appropriate for talking than music. With the absorption in the attic drawn back, the volume of the room is opened up to the height of the roof deck, providing more fullness of sound and a longer reverberation time. I recommend this and other approaches to adjustable acoustics only when multipurpose use is more critical than concert hall-quality acoustics.

Reveals, coves, and hidden recesses. As noted above, when there are spaces between ceiling panels, the sounds will go up between the panels into the ceiling plenum. Unless specifically designed by the consultant, this is not generally a good condition, and it should be properly detailed by designers and understood by specification writers. Leaving many “slots” and similar openings in the ceiling and/or wall designs can allow sound energy to escape the room. Nor is the sound likely to return to the room, especially if there is a large plenum volume with insulation on the underside of the deck above.

This design affects the low frequencies most. High frequencies are more beam-like; less high-frequency energy flows through a slot. Low frequencies, more like a flood of sound energy, ignore the width of the slot. Thus, where overlapping panels occur, sometimes in cove recesses or where there is a reveal between the meeting of two surfaces, these “voids” should be closed up to keep the useful sound energy in the room. Closing these voids is also important for noise control. Too often these reveals or slots are left open, and the
noise barrier achieved by the
construction of a 1½-inch solid
plaster ceiling panel, for example, is
compromised, allowing plenum or
other noises to enter the room more
easily. Obviously, the closure
specified must be just as good a
barrier as the ceiling panel or wall
being sealed up.

Wavelengths and diffusive ele-
ments. While major surfaces are
designed to achieve specific sound
distribution in a concert hall, sound
diffusion from many hard surfaces
detailed at different scales is also very
important. Some of the older concert
halls, like Boston's Symphony Hall,
the Grosser Musikvereinssaal in
Vienna, and Amsterdam's Concertge-
bouw, which are highly decorated
with moldings, pilasters, fancy
balcony faces, and other sound-
scattering elements, are still considered to
be some of the best
concert halls in the
world. The beam-like
high frequencies
react to the diffusive
elements in these
halls like light on a
many-faceted gem—
they are scattered and
diffused. Low-
frequency sounds
need much larger
surfaces to reflect
from. A surface can
therefore be large for
low frequencies and
highly textured for high frequencies. Generally, one must achieve a broad
range of scale of architectural
elements in design and in specifica-
tion of hard materials. Happily, these
ends are easier to attain now than they
were with the austere designs that
followed World War II.

Architectural Noise Control
Specifying appropriate barriers to
transmitted noise must be based on
some understanding of acoustical
barriers, their ratings, and the
conditions that compromise their
effectiveness. In moving from
concerns for room acoustics to basic
noise control, the designer must be
aware that the two disciplines occur
side by side where the interior
surfaces (reflection) and special
treatments (absorption) stop, and
where basic wall, floor, and ceiling
construction begins.

One of the most prevalent miscon-
ceptions about noise control is that
specifying more insulation provides a
greater noise barrier, as it does a
greater thermal barrier. Insulation by
itself is an insignificant barrier to
sound. Only when used in conjunc-
tion with other systems, such as steel
studs with combination layers of
gypsum board, can insulation
materials become effective noise
barriers.

Whole systems of construction
must be detailed and their compo-
nents specified together. Insulation
materials used for acoustical reasons,
whether in noise control or acoustics
absorption, should not be included—
and thus lost—in the thermal
insulation specifications. Thinking of
insulation materials in acoustics as
either (a) surface sound absorbers for
room acoustics or (b) sound attenu-
ators for noise control might help
designers get away from the falla-
cious concept of “insulating against
noise.”

Many standard details for wall,
floor, and ceiling construction have
been tested in laboratories for their
sound transmission loss at 1/3-octave
bands across more than eight octaves
of the hearing range. These values
have been given single-number
ratings according to ASTM proce-
dures. These ratings are called the
Sound Transmission Class (STC) for
each construction. STC ratings are
Penetrations for various mechanical, electrical, and plumbing services, which are hidden in ceilings and wall spaces, are the worst of these.

Mechanical Systems Noise Control

Many building systems create noise: plumbing, elevators, lighting and power, and—the most serious—the HVAC systems. The noise from these various sources is transmitted in three ways. It can be

- airborne, requiring special detailing and specification in the walls, floors, ceilings, and other architectural barriers
- structure-borne, requiring special vibration isolation details and isolators based on the MEP engineer's design and included in the project specifications
- duct- and pipe-borne, requiring identification through analysis and specification of adequate duct linings, sound attenuators, and isolators

Air-moving equipment for the HVAC system can be large and can generate low-frequency noise in the air handling units. The AHU system noise is much harder to control than ordinary activity noises and often requires construction specifically designed for low-frequency noise attenuation. In addition, very low velocity air speeds must be used in ducts so there will be no air hiss at the supply registers. All of these sources and paths must be controlled to meet noise criteria within the concert hall.

Decision Making

Every time four walls and a ceiling enclose a new space, a new acoustical environment is created; the designer has “committed acoustics.” Most of the time designers know basically what to expect acoustically. For concert halls, however, the acoustical environment is a driving force in the design process, demanding that nothing be left to chance.

Probably the most significant step in achieving good acoustics in a new concert hall comes long before the specification of interior surfaces and wall and ceiling constructions. That step is the choice of an acoustical consultant with concert hall design experience. The consultant should be part of the team from the very first design concepts to the owner’s acceptance of the plan. A consultant can provide much technical material and expertise on room acoustics and noise control, helping the designer and specifications writer make the decisions that will ultimately make for beautiful music.