Acoustical Properties of Precast Concrete

This report is an up-date of and supersedes "Acoustical Properties of Prestressed Concrete," which was published in the March-April 1971 PCI JOURNAL. The report was developed by Shiner Associates, Acoustical Engineers, Skokie, Illinois, acting as consultant to the PCI Committees responsible for the *PCI Manual for Structural Design of Architectural Precast Concrete* and for the second edition of the *PCI Design Handbook.*

The Manual contains the full report and the Handbook will include an abridged version. Besides being reviewed by the supervising Manual and Handbook committees, the report also received reviews by other selected PCI Committees, by the Technical Activities Committee, and by a special group selected for a critical review of the Manual just prior to its publication.

The report gives an overview of the principles and criteria involved in evaluating the acoustical properties of precast and precast prestressed concrete walls, floors and roofs. The report is not applicable to sophisticated acoustical design problems. However, it can serve in selecting materials to meet code criteria for acoustical control and it does present the acoustical advantages inherent in walls, floors, and roofs made of precast or precast prestressed concrete.

CONTENTS

CHAPTER 1—GLOSSARY

Airborne sound—Sound that reaches the point of interest by propagation through air.

Background level—The ambient sound pressure level existing in a space.

Decibel (dB)—A logarithmic unit of measure of sound pressure or sound power. Zero on the decibel scale corresponds to a standardized reference pressure (0.0002 microbar) or sound power (10^{-12} watt).

Flanking transmission—Transmission of sound by indirect paths other than through the primary barrier.

Frequency (Hz)—The number of complete vibration cycles per second.

Impact insulation class (IIC)—A single figure rating of the overall impact sound insulation merits of floor-ceiling assemblies in terms of a reference contour (ASTM E492).

Impact noise—The sound produced by one object striking another.

Loudness—The intensive attribute of an auditory sensation dependent on the sound pressure and frequency of the wave form.

Noise—Unwanted sound.

Noise reduction coefficient (NRC)—The arithmetic average of the sound absorption coefficients at 250, 500, 1000, and 2000 Hz expressed to the nearest multiple of 0.05 (ASTM C423).

Noise reduction (NR)—The difference in decibels between the space-time average sound pressure levels produced in two enclosed spaces by one or more sound sources in one of them.

Preferred noise criteria (PNC)—A series of curves, used as design goals to specify satisfactory background sound levels as they relate to particular use functions.

Reverberation—The persistence of sound in an enclosed or partially enclosed space after the source of sound has stopped.

Sabin—The unit of measure of sound absorption (ASTM C423).

Sound absorption coefficient—The fraction of randomly incident sound energy absorbed or otherwise not reflected (ASTM C423).

Sound pressure level (SPL)—The squared ratio, expressed in decibels, of the sound pressure under consideration to the standard reference pressure of 0.0002 microbar.

Sound transmission class (STC)—The single number rating system used to give a preliminary estimate of the sound insulation properties of a partition system (ASTM E413).

Sound transmission loss (TL)—The ratio, expressed on the decibel scale, of the airborne sound pressure incident on the sound barrier that is transmitted by the barrier and radiated on the other side (ASTM E90).

Structure borne sound—Sound that reaches the point of interest over at least part of its path by vibrations of a solid structure.

CHAPTER 2—GENERAL

The basic purpose of architectural acoustics is to provide a satisfactory environment in which desired sounds are clearly heard by the intended listeners and unwanted sounds (noise) are isolated or absorbed.

Under most conditions, the architect/engineer can determine the acoustical needs of the space and then design the building to satisfy those needs. Good acoustical design utilizes both absorptive and reflective surfaces, sound barriers and vibration isolators.

Some surfaces must reflect sound so that the loudness will be adequate in all areas where listeners are located. Other surfaces absorb sound to avoid echoes, sound distortion and long reverberation times. Sound is isolated from rooms where it is not wanted by selected wall and floor-ceiling constructions. Vibrations generated by mechanical equipment must be isolated from the structural frame of the building.

Most acoustical situations can be described in terms of (1) sound source, (2) sound transmission path, and (3) sound receiver.

Sometimes the source strength and path can be controlled and the receiver made more attentive by removing distraction or made more tolerant to disturbance. Acoustical design must include consideration of these three elements.

CHAPTER 3—APPROACHING THE DESIGN PROCESS

Criteria must be established before the acoustical design of a building can begin. Basically a satisfactory acoustical environment is one in which the character and magnitude of all sounds are compatible with the intended space function.

Although a reasonable objective, it is not always easy to express these intentions in quantitative terms. In addition to the amplitude of sound, the properties such as spectral characteristics, continuity, reverberation, and intelligibility must be specified.

People are highly adaptable to the sensations of heat, light, odor, sound, etc. with sensitivities varying widely. The human ear can detect a sound intensity of rustling leaves, 10 dB, and can tolerate, if even briefly, the powerful exhaust of a jet engine at 120 dB, 10^{12} times the intensity of the rustling sound.

CHAPTER 4—DEALING WITH SOUND LEVELS

The problems of sound insulation are usually considerably more complicated than those of sound absorption. The former involves reductions of sound level, which are of greater orders of magnitude than can be achieved by absorption.

These large reductions of sound level from space to space can be achieved only by continuous, impervious barriers. If the problem also involves structure borne sound, it may be necessary to introduce resilient layers or discontinuities into the barrier.

Sound absorbing materials and sound insulating materials are used for different purposes. There is not much sound absorption from an 8-in. concrete wall; similarly, high sound insulation is not available from a porous, lightweight material that may be applied to room surfaces. It is important to recognize that the basic mechanisms of sound absorption and sound insulation are different.

CHAPTER 5—SOUND TRANSMISSION LOSS

Sound transmission loss measurements are made at 16 frequencies at one-third octave intervals covering the range from 125 to 4000 Hz. The testing procedure is ASTM Specification E90, Laboratory Measurement of Airborne-Sound Transmission Loss of Building Partitions. To simplify specification of desired performance characteristics the single number Sound Transmission Class (STC) was developed.

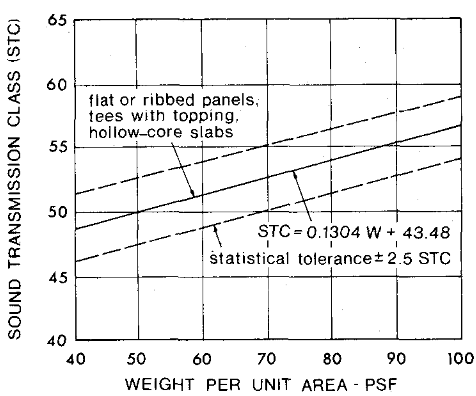


Fig. 1. Sound transmission class as a function of weight of floor or wall based on experimental data.

Airborne sound reaching a wall, floor or ceiling produces vibrations in the element and is radiated with reduced intensity on the other side. Airborne sound transmission loss of walls and floor-ceiling assemblies is a function of their weight, stiffness, and vibration damping characteristics.

Weight is concrete's greatest asset when it is used as a sound insulator. For sections of similar

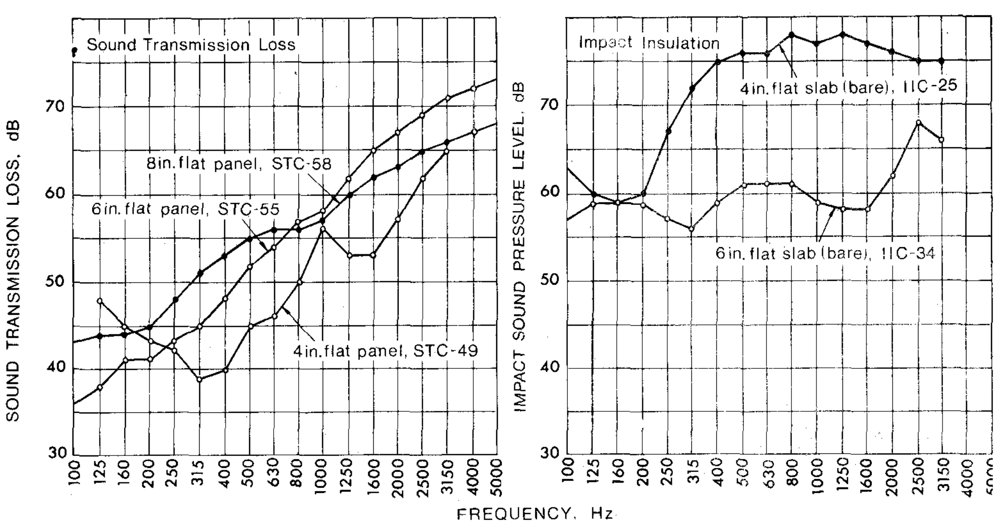


Fig. 2. Acoustical test data of solid flat concrete panels. Total weight: 4-in. panel = 54 psf; 6-in. panel = 75 psf; and 8-in. panel = 95 psf.

design, but different weights, the STC increases approximately six units for each doubling of weight as shown in Fig. 1.

Precast concrete walls, floors, and roofs usually do not need additional treatments in order to provide adequate sound insulation. If desired, greater sound insulation can be obtained by using a resiliently attached layer(s) of gypsum board or other building materials. The increased transmission loss occurs because the energy flow path is now increased to include a dissipative air column and additional mass.

The acoustical test results of both airborne sound transmission loss and impact insulation of 4, 6, and 8-in. flat panels, a 14-in. double tee, and 6 and 8-in. hollow-core slabs are shown in Figs. 2, 3, and 4.

Table 1 presents the ratings for various precast concrete walls and floor-ceiling assemblies. The effects of various assembly treatments on sound transmission can also be predicted from results of previous tests as shown in Table 2. The improvements are additive, but in some cases the total effect may be slightly less than the sum.

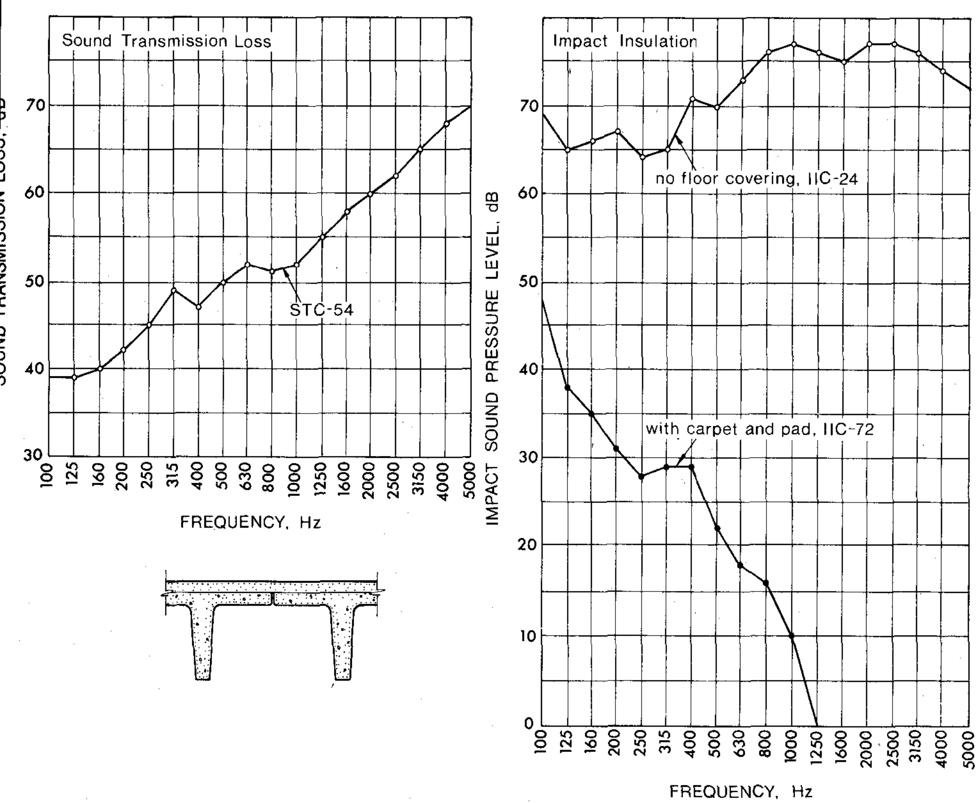


Fig. 3. Acoustical test data of 14-in. precast double tee system with 2-in. concrete topping. Total weight = 75 psf.

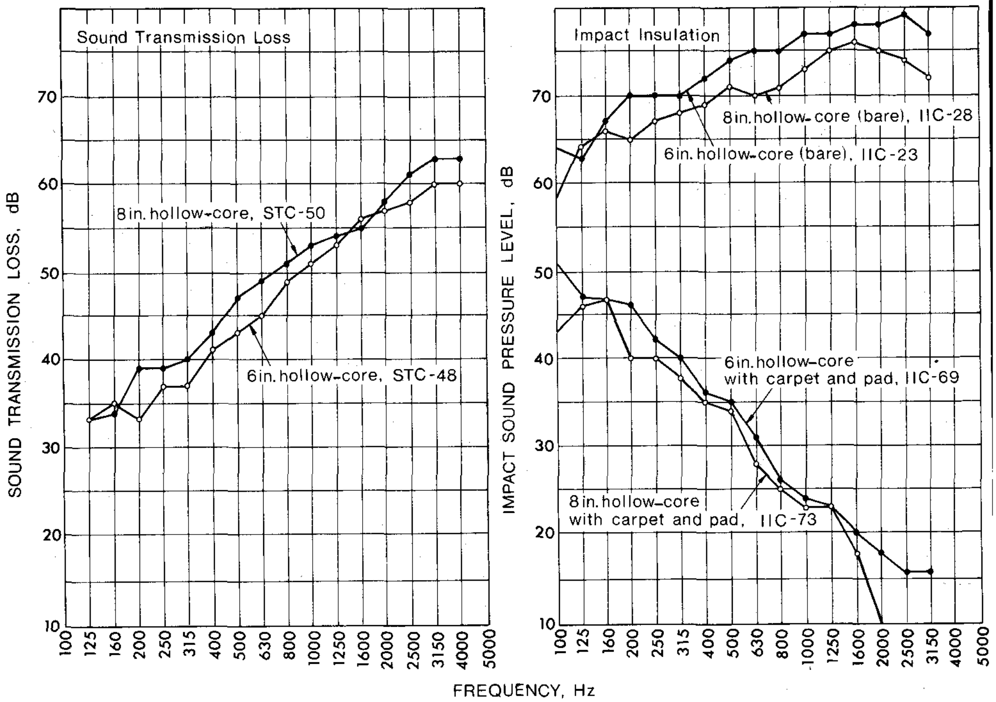


Fig. 4. Acoustical test data of hollow-core panels. Total weight: 6-in. hollow-core = 45 psf and 8-in. hollow-core = 57 psf.

CHAPTER 6—IMPACT NOISE REDUCTION

Footsteps, dragged chairs, dropped objects, slammed doors, and plumbing generate impact noises. Even when airborne sounds are adequately controlled there can be severe impact noise problems.

The test method used to evaluate systems for impact sound insulation is described in ASTM Specification E492, Laboratory Measurement of Impact Sound Transmission Using the Tapping Machine. As with the airborne standard, measurements are made at 16 one-third octave intervals but in the range from 100 to 3150 Hz. For performance specification purposes the single number Impact Insulation Class (IIC) is used.

In general, thickness or unit weight of concrete does not greatly affect the transmission of impact sounds as shown in the following table:

Thickness, in.	Unit weight of concrete, pcf	IIC
5	79	23
	114	24
	144	24
10	79	28
	114	30
	144	31

Table 1. Airborne sound transmission and impact insulation class ratings from tests of precast concrete assemblies.

Assembly No.	Description	STC	IIC
	Wall Systems		
1	4 in. flat panel, 54 psf	49	—
2	6 in. flat panel, 75 psf	55	—
3	Assembly 2 with wood furring, 3/4 in. insulation and 1/2 in. gypsum board	58*	—
4	Assembly 2 with 1/2 in. space, 1 5/8 in. metal stud row, 1 1/2 in. insulation and 1/2 in. gypsum board	63*	—
5	8 in. flat panel, 95 psf	58	—
6	14 in. prestressed tees with 4 in. flange, 75 psf	54	—
	Floor-Ceiling Systems		
7	14 in. prestressed tees with 2 in. concrete topping, 75 psf	54	24
8	Assembly 7 with carpet and pad, 76 psf	54	72
9	Assembly 7 with resiliently suspended acoustical ceiling with 1 1/2 in. mineral fiber blanket above, 77 psf	59	51
10	Assembly 9 with carpet and pad, 78 psf	59	82
11	8 in. hollow-core prestressed units, 57 psf	50	28
12	Assembly 11 with carpet and pad, 58 psf	50	73
13	8 in. hollow-core prestressed units with 1/2 in. wood block flooring adhered directly, 58 psf	51	47
14	Assembly 13 except 1/2 in. wood block flooring adhered to 1/2 in. sound-deadening board underlayment adhered to concrete, 60 psf	52	55
15	Assembly 14 with acoustical ceiling, 62 psf	59	61
16	4 in. flat slabs, 54 psf	49	25
17	5 in. flat slabs, 60 psf	52*	24
18	6 in. flat slabs, 75 psf	55	34
19	8 in. flat slabs, 95 psf	58	34*
20	10 in. flat slabs, 120 psf	59*	31
21	5 in. flat slab concrete with carpet and pad, 61 psf	52*	68
22	10 in. flat slab concrete with carpet and pad, 121 psf	59*	74

*Estimated values

Structural concrete floors in combination with resilient materials effectively control impact sounds. One simple solution consists of good carpeting on resilient padding. Table 2 shows that a carpet and pad over a bare concrete slab will increase the impact noise reduction from 43 to 56 points.

The overall efficiency varies according to the characteristics of the carpeting and padding such as resilience, thickness and weight. So-called resilient flooring materials, such as linoleum, rubber, asphalt vinyl, vinyl asbestos, etc., are not entirely satisfactory directly on concrete, nor are parquet or strip wood floors when applied directly.

Impact sounds may also be controlled by providing a discontinuity in the structure such as would be obtained by adding a

Table 2. Typical improvement for wall, floor, and ceiling treatments used with precast concrete elements.

Treatment	Increase in Ratings: Airborne (STC)	Increase in Ratings: Impact (IIC)
Wall furring, 3/4 in. insulation & 1/2 in. gypsum board attached to concrete wall	3	0
Separate metal stud system, 1 1/2 in. insulation in stud cavity & 1/2 in. gypsum board attached to concrete wall	5 to 10	0
2 in. concrete topping (24 psf)	3	0
Carpets and pads	0	43 to 56
Vinyl tile	0	3
1/2 in. wood block adhered to concrete	0	20
1/2 in. wood block and resilient fiber underlayment adhered to concrete	4	26
Floating concrete floor on fiber-board	7	15
Wood floor, sleepers on concrete	5	15
Wood floor on fiberboard	10	20
Acoustical ceiling resiliently mounted	5	27
if added to floor with carpet	5	10
Plaster or gypsum board ceiling resiliently mounted	10	8
with insulation in space above ceiling	13	13
Plaster direct to concrete	0	0

Example: The performance of a 2 in. concrete topping, carpet and pad added to 8 in. hollow-core prestressed floor units is calculated as follows:

Materials	STC	IIC
Bare slab	50	28
2 in. concrete topping	3	0
Carpet and pad	0	50
Totals	53	78

resiliently-mounted plaster or drywall suspended ceiling or a floating floor consisting of a second layer of concrete cast over resilient pads, insulation boards or mastic. The thickness of floating slabs is usually controlled by structural requirements, however, 8 psf is adequate in most instances.

CHAPTER 7—ABSORPTION OF SOUND

A sound wave always loses part of its energy as it is reflected by a surface. This loss of energy is termed sound absorption. It appears as a decrease in sound pressure of the reflected wave. The sound absorption coefficient is the fraction of energy incident but not reflected per unit of surface area. Sound absorption can be specified at individual frequencies or as an average of absorption coefficients (NRC).

A dense non-porous concrete surface typically absorbs 1 to 2 percent of incident sound and has an NRC of 0.015. There are specially fabricated units with porous concrete surfaces which provide greater absorption.

In the case where additional sound absorption of precast concrete is desired, a coating of acoustical material can be spray applied, acoustical tile can be applied with adhesive, or an acoustical ceiling can be suspended.

Most of the spray applied fire retardant materials used to increase the fire resistance of precast concrete and other floor-ceiling systems can also be used to absorb sound. The NRC of the sprayed fiber types range from 0.25 to 0.75. Most cementitious types have an NRC from 0.25 to 0.50.

If an acoustical ceiling were added to Assembly 7 of Table 1 (as in Assembly No. 9), the sound entry through a floor or roof would be reduced 5 dB. In addition, the acoustical ceiling would absorb a portion of the sound after entry and provide a few more decibels of quieting. Use of the following expression can be made to determine the intra room noise or loudness reduction due to the absorption of sound:

$$NR = 10 \log_{10} \frac{A_o + A_a}{A_o}$$

where

NR = sound pressure level reduction, dB

A_o = original absorption, Sabins

A_a = added absorption, Sabins

Values for A_o and A_a are the products of the absorption coefficients of the various room materials and their surface areas.

A plot of this equation is shown in Fig. 5. For an absorption ratio of 5, the decibel reduction is 7 dB. Note that the decibel reduction is the same, regardless of the origi-

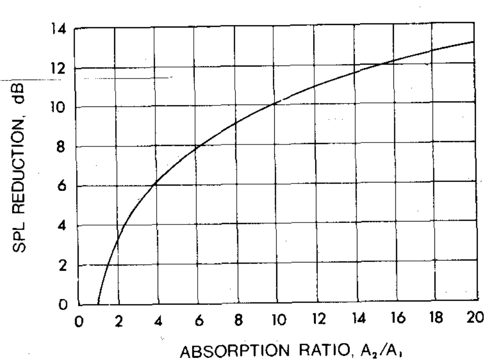


Fig. 5. Relation of decibel reduction of reflected sound to absorption ratio.

nal sound pressure level and depends only on the absorption ratio. This is due to the fact that the decibel scale is itself a scale of ratios, rather than difference in sound energy.

While a decibel difference is an engineering quantity which can be physically measured, it is also important to know how the ear judges the change in sound energy due to sound conditioning.

Apart from the subjective annoyance factors associated with excessive sound reflection, the ear can make accurate judgments of the relative loudness between sounds. An approximate relation between percentage loudness, reduction of reflected sound and absorption ratio is plotted in Fig. 6.

The percentage loudness reduction does not depend on the original loudness, but only on the absorption ratio. (The curve is drawn for loudness within the normal range of hearing and does not apply to extremely faint sounds.)

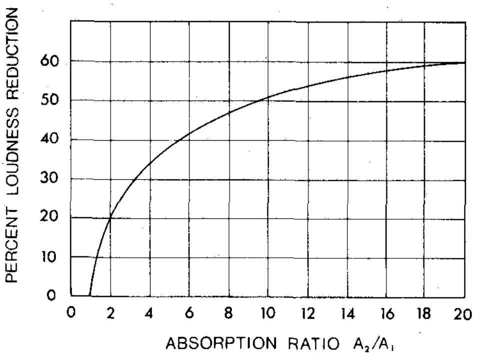


Fig. 6. Relation of percent loudness reduction of reflected sound to absorption ratio.

Referring again to the absorption ratio of 5, the loudness reduction is read from Fig. 6 as approximately 40 percent.

CHAPTER 8—ACCEPTABLE NOISE CRITERIA

As a rule, a certain amount of continuous sound can be tolerated before it becomes noise. An "acceptable" level neither disturbs room occupants nor interferes with the communication of wanted sound.

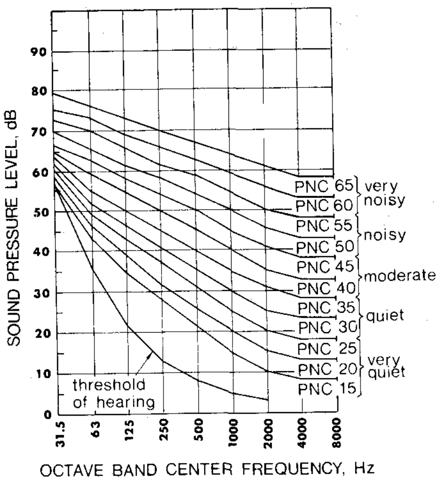
The most generally accepted and commonly used noise criteria today are expressed as the Preferred Noise Criteria (PNC) curves Fig. 7.[1] These values are the result of extensive studies based on the human response to both sound pressure level and frequency and take into account the requirements for speech intelligibility.

The figures in Table 3 represent general acoustical goals. They can also be compared with anticipated noise levels in specific rooms to assist in evaluating noise reduction problems.

A low background level obviously is necessary where listening and speech intelligibility is important. Conversely, higher ambient levels can persist in large business offices or factories where speech communication is limited to short distances.

Table 3. Recommended category classification and suggested noise criteria range for steady background noise as heard in various indoor functional activity areas.[1]

Type of space (and acoustical requirements)	PNC curve
Concert halls, opera houses, and recital halls (for listening to faint musical sounds)	10 to 20
Broadcast and recording studios (distant microphone pickup used)	10 to 20
Large auditoriums, large drama theaters, and churches (for excellent listening conditions)	Not to exceed 20
Broadcast, television, and recording studios (close microphone pickup only)	Not to exceed 25
Small auditoriums, small theaters, small churches, music rehearsal rooms, large meeting and conference rooms (for good listening), or executive offices and conference rooms for 50 people (no amplification)	Not to exceed 35
Bedrooms, sleeping quarters, hospitals, residences, apartments, hotels, motels, etc. (for sleeping, resting, relaxing)	25 to 40
Private or semiprivate offices, small conference rooms, classrooms, libraries, etc. (for good listening conditions)	30 to 40
Living rooms and similar spaces in dwellings (for conversing or listening to radio and TV)	30 to 40
Large offices, reception areas, retail shops and stores, cafeterias, restaurants, etc. (for moderately good listening conditions)	35 to 45
Lobbies, laboratory work spaces, drafting and engineering rooms, general secretarial areas (for fair listening conditions)	40 to 50
Light maintenance shops, office and computer equipment rooms, kitchens, and laundries (for moderately fair listening conditions)	45 to 55
Shops, garages, power-plant control rooms, etc. (for just acceptable speech and telephone communication). Levels above PNC 60 are not recommended for any office or communication situation.	50 to 60
For work spaces where speech or telephone communication is not required, but where there must be no risk of hearing damage	60 to 75



Preferred noise criteria curves	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
PNC-15	58	43	35	28	21	15	10	8	8
PNC-20	59	46	39	32	26	20	15	13	13
PNC-25	60	49	43	37	31	25	20	18	18
PNC-30	61	52	46	41	35	30	25	23	23
PNC-35	62	55	50	45	40	35	30	28	28
PNC-40	64	59	54	50	45	40	35	33	33
PNC-45	67	63	58	54	50	45	41	38	38
PNC-50	70	66	62	58	54	50	46	43	43
PNC-55	73	70	66	62	59	55	51	48	48
PNC-60	76	73	69	66	63	59	56	53	53
PNC-65	79	76	73	70	67	64	61	58	58

Fig. 7. Preferred noise criteria (PNC) curves.

Often it is just as important to be interested in the minimum as in the maximum permissible levels of Table 3. For example, in an office or residence, it is desirable to have a certain ambient sound level to assure adequate acoustical privacy between spaces, thus minimizing the transmission loss requirements of unwanted sound (noise).

These undesirable sounds may be from an exterior source such as automobiles or aircraft, or they may be generated as speech in an adjacent classroom or music in an adjacent apartment. They also may be direct impact-induced sound such as foot-falls on the floor above, rain impact on a lightweight roof construction or vibrating mechanical equipment.

Thus, the designer must always be ready to accept the task of analyzing the many potential sources of intruding sound as re-

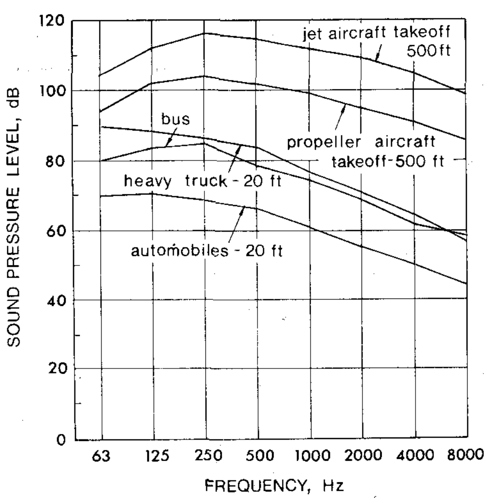


Fig. 8. Sound pressure levels (exterior noise sources).

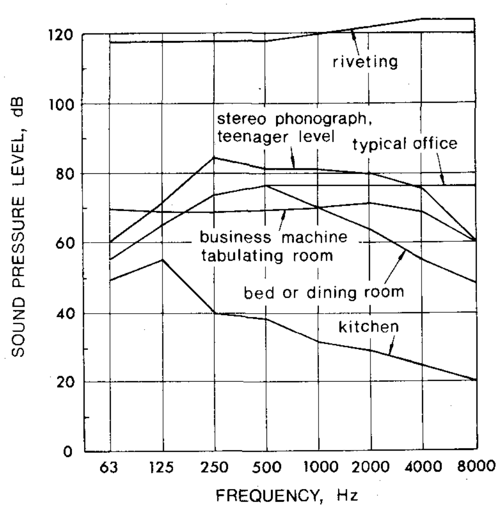


Fig. 9. Sound pressure levels (interior noise sources).

lated to their frequency characteristics and the rates at which they occur. The level of toleration that is to be expected by those who will occupy the space must also be established. Figs. 8 and 9 are the spectral characteristics of common noise sources.

With these criteria, the problem of sound isolation now must be solved, namely the reduction process between the high unwanted noise source and the desired ambient level. For this solution, two related yet mutually exclusive processes must be incorporated, i.e., sound transmission loss and sound absorption.

CHAPTER 9—ESTABLISHMENT OF NOISE INSULATION OBJECTIVES

Often acoustical control is specified as to the minimum insulation values of the dividing partition system. Municipal building codes, lending institutions and the Department of Housing and Urban Development (HUD) list both airborne STC and impact IIC values for different living environments. For example, the HUD minimum property standards[2] are:

Location	STC	IIC
Between living units	45	45
Between living units and public space	50	50

Some community ordinances are more specific, listing the sound insulation criteria with relation to particular ambient environments:[3]

	Grade I Suburban	Grade II Residential Urban & Suburban	Grade III Urban
Ambient level	PNC 20-25	PNC 25-30	PNC 35 +
Walls	STC 55	STC 52	STC 48
Floor-Ceiling Assemblies	STC 55	STC 52	STC 48
	IIC 55	IIC 52	IIC 48

Once the objectives are established, the designer then should refer to available data, e.g., Fig. 1 or Table 1, and select the system which best meets these requirements. In this respect, concrete systems have superior properties and can with minimal effort comply with these criteria.

When the insulation value has not been specified, selection of the necessary barrier can be determined analytically by (1) identifying exterior and/or interior noise sources, and (2) by establishing acceptable interior noise criteria.

Design Example

Assume a precast prestressed concrete office building is to be erected adjacent to a major highway. Private and semiprivate offices will run along the perimeter of the structure. The first step is to determine the degree of insulation required of the exterior wall system;

	Sound Pressure Level, dB							
Frequency (Hz)	63	125	250	500	1000	2000	4000	8000
Bus traffic Source noise (Fig. 8)	80	83	85	78	74	68	62	58
Private office Noise criteria —PNC 35 (Fig. 7)	55	50	45	40	35	30	28	28
Required insulation	25	33	40	38	39	38	34	30

The 500 Hz requirement, 38 dB, can be used as the first approximation of the wall STC category. However, if windows are planned for the wall, a system of about 50-55 STC should be selected (see following composite wall discussion). Individual transmission loss performance values of this system are then compared to the calculated needs.

	Sound Pressure Level, dB					
Frequency (Hz)	125	250	500	1000	2000	4000
Required insulation	33	40	38	39	38	34
6-in. precast solid concrete wall (Fig. 2)	38	43	52	59	67	72
Deficiencies	—	—	—	—	—	—

The selected wall should meet or exceed the insulation needs at all frequencies. However, to achieve the most efficient design conditions, certain limited deficiencies can be tolerated. Experience has shown that the maximum deficiencies are 3 dB at two frequencies or 5 dB on one frequency point.

CHAPTER 10—COMPOSITE WALL CONSIDERATIONS

Doors and windows are often the weak link in an otherwise effective sound barrier. Minimal effects on sound transmission loss will be achieved in most cases by a proper selection of glass, Table 4.[4] Mounting of the glass in its frame should be done with care to eliminate noise leaks and to reduce the glass plate vibrations.

Table 4. Acoustical properties of glass.

(a) Sound Transmission Class (STC)

Type and Overall Thickness	Inside Light	Construction Space	Outside Light	STC
1/8″ Plate or float	—	—	1/8″	23
1/4″ Plate or float	—	—	1/4″	28
1/2″ Plate or float	—	—	1/2″	31
1″ Insulated glass	1/4″	1/2″ Air Space	1/4″	31
1/4″ Laminated	1/8″	.030 Vinyl	1/8″	34
1 1/2″ Insulated glass	1/4″	1″ Air Space	1/4″	35
3/4″ Plate or float	—	—	3/4″	36
1″ Insulated glass	1/4″	1/2″ Air Space	1/4″ Laminated	38
1″ Plate or Float	—	—	1″	37
2 3/4″ Insulated glass	1/4″	2″ Air Space	1/2″	39
4 3/4″ Insulated glass	1/4″	4″ Air Space	1/2″	40
6 3/4″ Insulated glass	1/4″	6″ Air Space	1/4″ Laminated	42

(b) Transmission Loss (dB)

Frequency (Hz)															
125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000
1/4 inch plate glass — 28 STC															
24	22	24	24	21	23	21	23	26	27	33	36	37	39	40	40
1 inch insulating glass with 1/2 inch air space — 31 STC															
25	25	22	20	24	27	27	30	32	33	35	34	29	31	33	36
1 inch insulating glass laminated with 1/2 inch air space — 38 STC															
30	29	26	28	31	34	35	37	37	38	38	40	41	40	41	44

Sound transmission loss of a door depends upon its material and construction, and the sealing between the door and the frame.[5] There is a mass law dependence of STC on weight (psf) for both wood and steel doors. The approximate relationships are:

For steel doors:

$$STC = 15 + 27 \log W$$

For wood doors:

$$STC = 12 + 32 \log W$$

where W is the weight of the door in psf

The relationships are purely empirical and a large deviation can be expected for any given door.

For best results, the distances between adjacent door and/or window openings should be maximized, staggered when possible and held to a minimum area. Minimizing openings retains the acoustical properties of precast concrete.

The design characteristics of a door or window system must be analyzed prior to specification. Such qualities as frame design, door construction and glazing thickness are vital performance criteria. Installation procedures must be exact and care given to the frame of each opening. Gaskets, weatherstripping and raised thresholds serve as both excellent thermal and acoustical seals and are recommended.

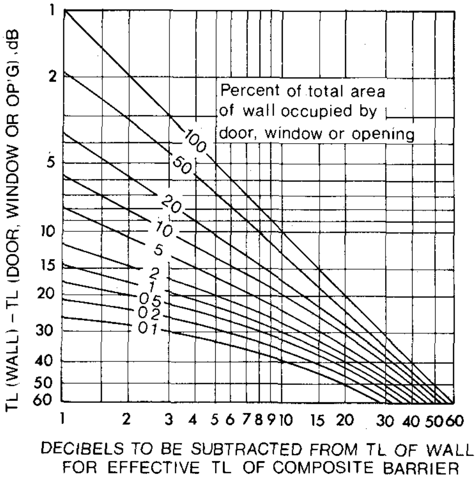


Fig. 10. Chart for calculating the effective transmission loss of a composite barrier.*

*For purposes of approximation, STC values can be used in place of TL values.

Fig. 10 can be used to calculate the effective acoustic isolation of a wall system which contains a composite of elements, each with known individual transmission loss data.

Design Example

To complete the office building wall acoustical design from Chapter 9, assume the following:

1. The glazing area represents 10 percent of the exterior wall area.
2. The windows will be double glazed with a 38 STC acoustical insulation rating.

The problem now becomes the task of determining the combined effect of the concrete-glass combination and a redetermination of criteria compliance.

	Sound Pressure Level, dB					
Frequency (Hz)	125	250	500	1000	2000	4000
6-in. precast solid concrete wall (Fig. 2)	38	43	52	59	67	72
Double glazed windows (Table 4)	30	28	35	38	41	44
Correction (Fig. 10)	−2	−6	−7	−11	−15	−19
Combined transmission loss	36	37	45	48	52	53
Insulation requirements	33	40	38	39	38	34
Deficiencies	—	3	—	—	—	—

The maximum deficiency is 3 dB and occurs at only one frequency point. The 6-in. precast concrete wall with double glazed windows will provide the required acoustical insulation.

Floor-ceiling assembly acoustical insulation requirements are determined in the same manner as for walls by using Figs. 2, 3 or 4, 7 and 9.

CHAPTER 11—LEAKS AND FLANKING

The performance of a building section with an otherwise adequate STC can be seriously reduced by a relatively small hole or any other path which allows sound to bypass the acoustical barrier. All noise which reaches a space by paths other than through the primary barrier is called flanking.

Common flanking paths are openings around doors or windows, at electrical outlets, telephone and television connections, and pipe and duct penetrations. Suspended ceilings in rooms where walls do not extend beyond the ceiling to the roof or floor above allow sound to travel to adjacent rooms.

Anticipation and prevention of leaks begins at the design stage. Flanking paths (gaps) at the perimeters of interior precast walls and floors are generally sealed during construction with grout or drypack.

In addition, all openings around penetrations through walls or floors should be as small as possible and must be sealed airtight. The higher the STC of the barrier, the greater the effect of an unsealed opening (see Fig. 10).

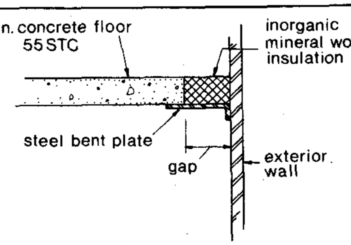
Perimeter leakage more commonly occurs at the intersection between an exterior curtain wall and floor slab. It is of vital importance to seal this gap in order to retain the acoustical integrity of the system as well as provide the required fire stop between floors.

One way to achieve this seal is to place a 4 pcf density mineral wool blanket between the floor slab and the exterior wall. Fig. 11 demonstrates the acoustical isolation effects of this treatment.

In exterior walls, the proper application of sealant and backup materials in the joints between units will not allow sound to flank the wall.

If the acoustical design is balanced, the maximum amount of acoustic energy reaching a space via flanking should be less than the energy transmitted through the primary barriers.

Although not easily quantified, an inverse relationship exists between the performance of an element as a primary barrier and its propensity to transmit flanking sound. In other words, the probability of existing flanking paths in



	Combined Transmission Loss
No closure	14 STC
With steel bent plate closure	28 STC
With 4 in. thick safing insulation	30 STC
steel bent plate added	42 STC
With 6 in. thick safing insulation	38 STC
steel bent plate added	45 STC

Fig. 11. Effect of safing insulation seals.

a concrete structure is much less than in one of steel or wood frame.

In addition to using basic structural materials, flanking paths can be minimized by:

1. Interrupting the continuous flow of energy with dissimilar materials, i.e., expansion or control joints or air gaps.
2. Increasing the resistance to energy flow with floating floor systems or full height and/or double partitions with suspended ceilings.

CHAPTER 12—VIBRATION ISOLATION

The isolation of vibrations produced by equipment with unbalanced operating or starting forces can frequently be accomplished by mounting the equipment on a heavy concrete slab placed on resilient supports. A slab of this type is called an inertia block.

Inertia blocks can provide a desirable low center of gravity and compensate for thrusts such as those generated by large fans. For equipment with less unbalanced weight, a "housekeeping" slab is sometimes used below the resilient mounts to provide a rigid support for the mounts and to keep them above the floor where they remain cleaner and easier to inspect. This slab may also be mounted on pads of precompressed glass fiber or neoprene.

The natural frequency of the total load on resilient mounts must be well below the frequency generated by the equipment. The required weight of an inertia block depends on the total weight of the machine and the unbalanced force. For a long-stroke compressor, five to seven times its weight might be needed. For high pressure fans, one to five times the fan weight is frequently sufficient.

Simplified theory shows that for 90 percent vibration isolation a single resiliently-supported mass should have a natural frequency about one-third the driving frequency. For 99 percent isolation the natural frequency of a resiliently mounted mass is a function of the static deflection of the resilient supports; this makes determination of the natural frequency simple.

A floor supporting resiliently mounted equipment must be stiff and heavy. If the static deflection of a floor supporting resilient mounts approaches the static deflection of the mounts, the floor then becomes a part of the vibrating system and little vibration isolation is achieved.

Therefore, floors supporting heavy rotating or reciprocating equipment often must be stiffer than floors designed to meet ordinary structural design criteria with floor deflection not more than about 1/6 or 1/8 of mount deflections. This means that, in the initial planning stage, vibrating systems should be kept away from long spans and located close to vertical supports.

Sometimes, additional columns

may be installed directly under the equipment. For example, a 20 ft span, with the usual 1/360 of span deflection, will deflect 0.67 in. at maximum allowable load. This is the static deflection required of isolation mounts for 90 percent isolation of an 800 CPM machine.

To obtain 90 percent isolation on such a floor the static deflection of the resilient mounts has to be increased six to eight times. However, floors are seldom loaded to the design limits and loading at center of span can often be avoided. With a moderate floor load, good isolation is usually provided if the static deflection of the mounts is increased by an amount equal to 1/360 of the floor span.

CHAPTER 13—REFERENCES

1. Beranek, L. L., Blazier, W. E., and Figwer, J. J., "Preferred Noise Criterion and Their Application to Rooms," *Journal of the Acoustical Society of America,* V. 50, Nov. 1971, pp. 1223-1228.
2. HUD, "Minimum Property Standards—Doc. Nos. 4900.1, 4910.1, 4920.1," U.S. Government Printing Office, Washington, D.C., 1973.
3. Berendt, R. D., Burroughs, C. B., Winzer, G. E., "A Guide to Airborne, Impact and Structureborne Noise Control in Multifamily Dwellings," prepared for Federal Housing Administration, U.S. Government Printing Office, Washington, D.C., 1967.
4. Flynn, D. R., Lacher, M. B., Quindry, T. L., Sabine, H. J., "Acoustical and Thermal Performance of Exterior Residential Walls, Doors and Windows," National Bureau of Standards, U.S. Government Printing Office, Washington, D.C., 1975.
5. IITRI, "Compendium of Materials for Noise Control," U.S. Department of Health, Education & Welfare, U.S. Government Printing Office, Washington, D.C., 1975.
6. Beranek, L. L., *Noise Reduction,* McGraw-Hill Book Co., New York, N.Y., 1960.
7. Harris, C. M., *Handbook of Noise Control,* McGraw-Hill Book Co., New York, N.Y., 1957.
8. ASHRAE; *ASHRAE Systems Handbook for 1976,* American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., New York, N.Y., 1976.
9. Crede, C. E., Harris, C. M., *Shock & Vibration Handbook,* 2nd Edition, McGraw-Hill Book Co., New York, N.Y., 1976.
10. Belliston, Harold W., Litvin, Albert, "Sound Transmission Loss Through Concrete Walls," *Research and Development Bulletin,* Portland Cement Association, Skokie, Illinois. To be published in 1978.

Discussion of this report is invited.
Please forward your comments to
PCI headquarters by Sept. 1, 1978.