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Massive Secure Construction

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Contents

PART V. MASONRY, CONCRETE, STONE, AND MASSIVE CONSTRUCTION

Massive construction is often described through thickness, density and permanence. Those characteristics matter, yet they do not establish the performance of a secure room. Masonry units contain webs, cells, mortar and grout. Concrete contains joints, cracks, ties, sleeves and structural connections. Historic stone conceals rubble, flues, timber pockets and later alteration. Each system can provide formidable direct airborne isolation while simultaneously supporting leakage, vibration and flanking through discontinuities that occupy only a small proportion of the visible boundary.

Part V therefore proceeds from configuration and evidence rather than material reputation. Chapters 15 and 16 examine unit masonry, joints, linings, openings, cracks and flanking. Chapters 17 and 18 treat concrete walls, precast and tilt-up systems, slabs, foundations and vibration transmission. Chapter 19 addresses natural and engineered stone, historic massive construction and conservation-compatible isolation. Every chapter distinguishes product compliance, structural adequacy, laboratory performance, field performance, occupied speech security and formal authority disposition.

Chapter 15. Concrete Masonry Units, Brick, Clay Tile, Grouting, and Parging

15.1 Masonry as a heterogeneous acoustic and evidentiary system

A masonry wall presents itself to the eye as a continuous, heavy plane; that visual impression is useful to the architect but insufficient to the acoustical engineer; the sound field encounters units, face shells, webs, cells, mortar, grout, reinforcement, coatings, movement joints, openings, frames, floor edges, bond beams and adjoining structure. Each constituent possesses its own density, stiffness, damping, geometry and continuity; the completed wall is consequently a spatially heterogeneous wave-bearing system rather than a homogeneous slab whose performance can be inferred from nominal thickness alone. The distinction is particularly important when the wall contains hollow units or selective grouting because the apparent solidity of the finished surface conceals a periodic internal architecture.

The evidentiary object must therefore be named with precision. A statement that a wall is “200 mm block” records only one nominal dimension. It does not identify the unit specification, net area, density class, shell and web geometry, mortar bedding, reinforcement, grout schedule, parging, plaster, penetrations, support condition or actual condition at the time of test. ASTM C90-24a expressly requires acoustical properties to be specified separately when desired, even though it controls important attributes of dry-cast loadbearing concrete masonry units.[1] ASTM C129-26 makes the same point for nonloadbearing units.[2] Compliance with either product standard narrows

1 MB-0184. ASTM International, ASTM C90-24a.
2 MB-0126. ASTM International, ASTM C129-26.

the material description, but it does not supply a transmission-loss curve for the finished wall.

The same evidentiary restraint applies to brick and structural clay tile. ASTM C55-25 concerns solid dry-cast concrete building brick, whereas ASTM C62-23 and C216-26a concern fired-clay or shale brick under different use and appearance conditions.[3][4][5] ASTM C34-23 addresses structural clay loadbearing wall tile and explicitly limits its property requirements to the time of purchase; tests on extracted historic tile are outside its conformance purpose.[6] These boundaries matter because a concrete brick, a solid fired-clay brick, a hollow brick and a structural clay tile may share a rectangular outline yet possess markedly different internal geometry, elastic behaviour and failure modes.

Four propositions remain separate throughout this chapter; first, a product or laboratory specimen may satisfy a standard or achieve a measured sound-reduction curve; secondly, an installed wall may exhibit a different apparent field result because its workmanship, joints, openings and flanking paths differ. Thirdly, the occupied room may or may not protect speech under realistic source level, background, listener access and operating state; fourthly, the competent authority may accept or reject the configured facility for a specified purpose. Masonry mass contributes to the first three propositions, but it does not collapse them into one conclusion and cannot itself confer formal acceptance.

3 MB-0155. ASTM International, ASTM C55-25.
4 MB-0163. ASTM International, ASTM C62-23.
5 MB-0139. ASTM International, ASTM C216-26a.
6 MB-0142. ASTM International, ASTM C34-23.

Figure 15-1. Concrete masonry configurations and concealed mass distribution

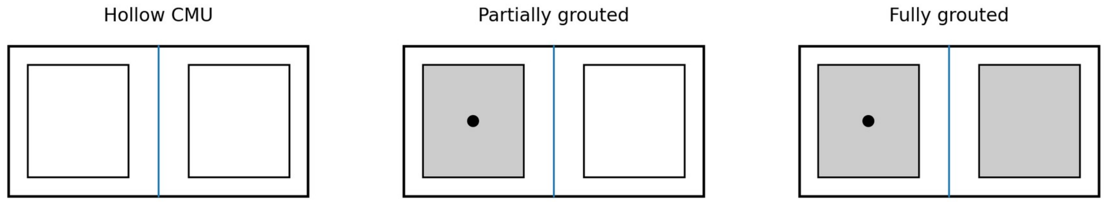

Figure 15-1. Hollow, partially grouted and fully grouted concrete masonry configurations. Author's original schematic. The visible wall can conceal materially different distributions of air, grout, reinforcement, mass and stiffness.

A defensible assessment therefore begins with a configuration schedule rather than a headline rating. The schedule identifies the product standard, unit dimensions, gross and net areas, density class, mortar type, bedding pattern, grout type, grouted-cell locations, bond beams, reinforcement, coatings, linings, openings, support condition and source of each datum; the engineer then distinguishes what was specified, what was observed, what was measured and what remains inferred. This discipline prevents a product certificate from being mistaken for an as-built wall record and prevents an as-built wall record from being mistaken for a field test.

Table 15-1. Product standards and the bounded propositions they establish. Product compliance does not establish completed wall acoustic performance.

Document	Primary proposition	Does not establish
ASTM C90 / C129	CMU product attributes	Completed wall TL or field isolation
ASTM C140/C140M	Unit sampling and physical tests	Grout continuity or room performance
TMS 402 / 602	Structural design and construction	Speech security or accreditation
ASTM E90 / E413	Laboratory curve and rating	Installed field result
ASTM E336	Configured field attenuation	Formal authorisation

Worked example 15.1. Percentage solid and the limits of a unit calculation

Consider a nominal concrete masonry unit with gross bed area

$A_g = 0.390 \times 0.190 = 0.0741\ m^2$.

Suppose measurement in accordance with the applicable unit test method gives net solid area

$A_n = 0.0348\ m^2$.

The percentage solid is

Equation 15.1

$p_s = 100(A_n)/(A_g) = 100(0.0348)/(0.0741) = 47.0\%$.

Here, p_s is percentage solid, A_n is net solid area in square metres and A_g is gross bed area in square metres. The dimensional check is straightforward because the area units cancel. The result assists with unit classification and with an initial estimate of unit material volume. It does not identify the wall surface mass by itself because mortar, webs, face shells, grout, reinforcement, moisture and construction tolerances remain. Nor does it predict sound isolation, which depends upon frequency, wall size, restraint, damping, leakage and other paths. ASTM C140/C140M-26a supplies the appropriate unit-testing framework, not a wall acoustic test.[7]

15.2 Product standards, project specifications and the proof hierarchy

The practical value of a product standard lies in the questions it answers reliably. ASTM C90-24a distinguishes dry-cast loadbearing concrete masonry units and identifies density classifications and physical requirements. ASTM C129-26 does corresponding work for dry-cast nonloadbearing units. ASTM C140/C140M-26a then supplies procedures for sampling, dimensions, compressive strength, absorption, density and other unit characteristics.[8][9][10] None of those documents measures the airborne transmission loss of a completed wall. A project that requires acoustic performance must therefore add an assembly-level requirement, identify the test method and preserve the tested configuration.

This hierarchy should appear explicitly in the specification; the product clause identifies acceptable units and any required density or geometry; the execution clause identifies bedding, joint filling, grout placement, reinforcement, coatings, penetrations and tolerances; the performance clause identifies the acoustic measurand, test method, frequency range, reporting requirements, field condition and decision rule. A submittal is incomplete when it contains only a product data sheet and an STC number copied from a wall of uncertain construction. The reviewer needs the

7 MB-0131. ASTM International, ASTM C140.
8 MB-0184. ASTM International, ASTM C90-24a.
9 MB-0126. ASTM International, ASTM C129-26.
10 MB-0131. ASTM International, ASTM C140.

complete test report, specimen dimensions, unit identity, wall area, mortar, grout, surface treatment, perimeter condition and any attached lining.

TMS 402/602-22 establishes the current United States design and construction framework for masonry structures, with published errata that must be considered when the standard is used.[11] Its companion Masonry Designers' Guide explains structural application through worked examples and quality-control discussion, but remains guidance rather than a substitute for the standard.[12] The secure-room designer should not attempt to convert structural code compliance into an acoustic conclusion. Structural design determines capacity and serviceability; acoustic design adds source, path, receiver and evidentiary requirements that the structural code was not written to decide.

Industry technical notes are valuable when their status is kept visible. CMHA TEK 13-01D assembles masonry STC relationships and detailing advice, while TEK 13-02A discusses transmission, absorption, layout and sealing.[13][14] The Brick Industry Association's Technical Note 5A addresses clay masonry sound insulation.[15] These documents can guide preliminary selection, expose common construction errors and direct the reader to test standards. They are not independent governmental acceptance criteria, and simplified mass-based equations should not displace frequency-resolved evidence where protected speech is at issue.

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11 MB-1180. The Masonry Society, TMS 402-22 Building Code Requirements for Masonry Structures and TMS 602-22 Specification for Masonry Structures.
12 MB-1179. The Masonry Society, Masonry Designers' Guide - 2022.
13 MB-0422. Concrete Masonry & Hardscapes Association, TEK 13-01D, Sound Transmission Class Ratings for Concrete Masonry Walls.
14 MB-0423. Concrete Masonry & Hardscapes Association, TEK 13-02A, Noise Control With Concrete Masonry.
15 MB-0367. Brick Industry Association, Technical Note 5A, Sound Insulation - Clay Masonry Walls.

A useful proof hierarchy therefore proceeds from product identity, through construction records, to assembly testing, field verification and operational assessment; the hierarchy is cumulative rather than substitutive. A field test cannot retroactively establish which unit lot was used; a certificate cannot establish whether head joints were filled; a photographic record cannot determine a transmission curve; an STC value cannot establish whether a quiet receiving corridor permits recognition of names and numbers. Each evidence class answers a different question.

Worked example 15.2. Estimating unit-derived surface mass

Take a unit course with gross face dimensions 390 mm by 190 mm and wall thickness 190 mm; let the measured net volume of concrete in one unit be 0.00670 m^3, and let oven-dry concrete density be 1,850 kg/m^3. Unit mass is

$$m_u = \rho V_n = 1{,}850 \times 0.00670 = 12.40 \text{ kg}.$$

If the modular face area per unit is 0.400 × 0.200 = 0.0800 m^2, the unit-derived contribution to wall surface mass is

$$m'_u = \frac{m_u}{A_m} = \frac{12.40}{0.0800} = 155 \text{ kg/m}^2.$$

Here, ρ is concrete density, V_n is net concrete volume, m_u is unit mass and A_m is modular face area; the units reduce to kilograms per square metre; mortar, grout, reinforcement, coatings and moisture have not yet been included. The estimate is suitable for a preliminary mass balance and uncertainty budget, but it is not a substitute for weighing representative units or documenting the installed wall.

15.3 Face shells, webs and cell geometry

A hollow CMU obtains its structural form from two principal face shells joined by webs; the shell thickness, web thickness, taper, cell shape and end configuration determine more than net area; they establish bending panels, force-transfer ribs, local cavities and repeated discontinuities. At low frequency the wall may move in global modes influenced by its overall mass, dimensions and boundary restraint; at higher frequency, face shells, webs and cells participate in local and periodic behaviour that a homogeneous mass-law model cannot reproduce.

The face shells receive airborne pressure directly; their response is coupled through webs, mortar joints and any grout to the opposite side; a web is therefore both a structural necessity and a vibration bridge; increasing web area can increase surface mass and stiffness, but may also strengthen mechanical transmission between shells. The net result depends on frequency and damping. A statement that one unit is “more solid” than another does not tell the reader whether the relevant transmission trough moves upward, downward or merely changes depth.

Cell geometry introduces air volumes with openings at unit ends, webs and joints. In an ungrouted wall, cells may communicate vertically or be segmented by mortar droppings and bond beams. The air is not necessarily an independent cavity in the ideal double-leaf sense because the two face shells are connected by webs at short intervals. Nevertheless, local air compliance and shell motion can shape resonant response. Numerical and experimental research on hollow brick and hollow concrete units demonstrates that periodic internal geometry and anisotropy require more careful modelling than a single equivalent slab when detailed prediction is sought.[16][17]

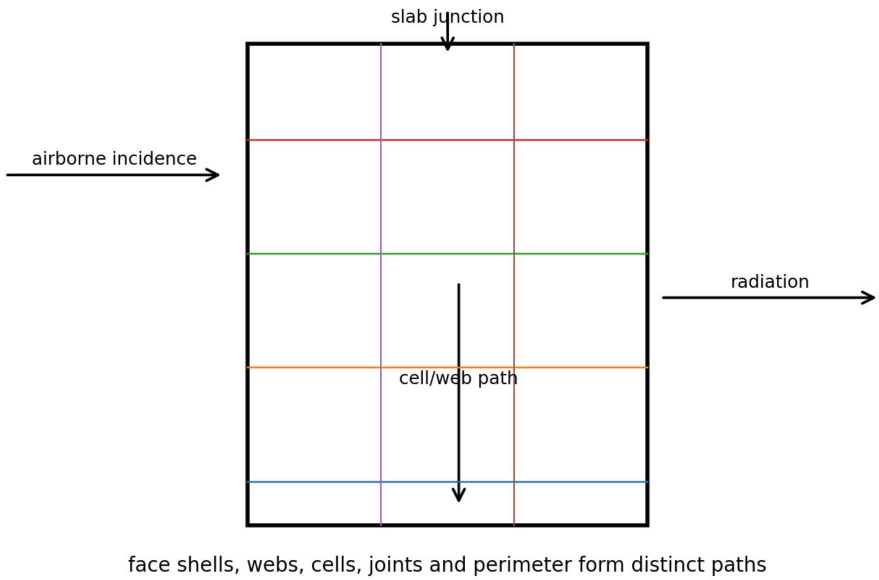

Figure 15-2. Parallel acoustic and structural paths through a hollow masonry unit wall. Author's original schematic. Face-shell bending, web force transmission, cell pressure and mortar-joint leakage contribute in different proportions by frequency.

Orientation matters. A special unit laid with cells in a different direction may present a different net section and different local resonances. ASTM C140/C140M-26a recognises orientation in mechanical testing for relevant unit types.[18] Acoustic documentation should likewise record the installed orientation, especially for unusual units, horizontally cored products or historic hollow tile. A photograph of the exposed face cannot supply that information after concealment.

The engineer should resist false precision in geometric models; manufacturer drawings describe nominal mould geometry, while cured

16 MB-0956. J. A. Díaz-Cereceda et al., "Sound Transmission Loss Analysis Through a Multilayer Lightweight Concrete Hollow Brick Wall by FEM and Experimental Validation".
17 MB-1008. M. Villot et al., "A Homogenised Vibratory Model for Predicting the Acoustic Properties of Hollow Brick Walls".
18 MB-0131. ASTM International, ASTM C140.

units vary and joints alter continuity; a useful model may begin with measured unit mass and dimensions, then test sensitivity to shell and web thickness. Where a local feature controls, laser scanning, cut specimens or high-resolution photographs may be justified; where doors, joints or ducts already dominate, detailed unit homogenisation may add complexity without changing the decision. The degree of modelling should follow the unresolved question.

Worked example 15.3. Surface mass including mortar and reinforcement

Continue the preceding unit estimate of 155 kg/m². Suppose bed and head mortar together contribute 9.5 kg/m², and reinforcement averaged over the wall contributes 2.2 kg/m². The ungrouted wall estimate is

$m' = 155+9.5+2.2 = 166.7$ kg/m².

If uncertainty components are $u_u = 5.0$ kg/m² for units, $u_m = 1.5$ kg/m² for mortar and $u_s = 0.4$ kg/m² for steel, and they are treated as uncorrelated for this screening estimate, combined standard uncertainty is

$u_c = \sqrt{u_u^2+u_m^2+u_s^2} = \sqrt{25+2.25+0.16} = 5.24$ kg/m².

The reported screening value is therefore 166.7 ± 5.2 kg/m² at standard-uncertainty level; moisture and hidden grout would require additional terms; the mass balance supports prediction and comparison, not a claim of wall conformance.

15.4 Hollow CMU transmission mechanisms

The attraction of a hollow CMU wall lies partly in its substantial mass without the material quantity of a solid wall; that economy creates a complex acoustic structure; below the first significant panel and room resonances, the wall responds as a finite supported element. Through the middle frequencies, global bending, shell modes and web coupling interact; at higher frequencies, distributed porosity, cracks, joints and local radiation can become conspicuous. The resulting curve need not follow the smooth six-decibel-per-octave rise associated with the ideal limp mass law.

An open-textured unit may absorb sound at its exposed surface, but absorption and transmission are different quantities. Surface pores can dissipate some incident energy while also permitting air communication into the material or cells. Painting, plastering or parging may decrease absorption yet improve transmission loss by closing pores. CMHA guidance recognises this trade and warns that open-textured surfaces should not be evaluated by weight alone.[19] The correct treatment depends upon whether the room requires internal absorption, boundary isolation or both.

Mortar bedding is integral to the hollow-wall model; face-shell bedding can leave the central web region unbedded by design, while full bedding changes contact area and force transfer; head joints may be filled fully, partially or inadequately. The acoustical consequence of a poor head joint is not merely a slight reduction in average mass; it can create a connected air path whose transmission coefficient exceeds that of the surrounding field by orders of magnitude. The defect therefore deserves parallel-path analysis rather than a percentage-mass correction.

The perimeter also controls the wall’s loss factor. Research on heavyweight single-leaf walls shows that making all perimeter joints resilient can reduce sound reduction above coincidence by reducing energy flow from the panel

19 MB-0423. Concrete Masonry & Hardscapes Association, TEK 13-02A, Noise Control With Concrete Masonry.

into the surrounding frame, even though low-frequency behaviour may improve.[20] The result is a useful warning against a universal maxim that “resilient is always better”. A CMU wall rigidly bonded at some edges and separated at others requires a configuration-specific model. Joint restraint, structural load and fire requirements cannot be inferred from an acoustic preference alone.

Laboratory curves for hollow walls should be inspected for plateaux, dips and unexpected high-frequency flattening; a plateau may reflect coincidence, local shell behaviour or another transition; a flattening may indicate leakage or laboratory limit; the curve should be compared with unit geometry, wall dimensions, mortar state and test-opening details. Replacing the curve with an STC number discards precisely the information needed to distinguish those mechanisms.

Worked example 15.4. Ideal mass-law comparison as a bounded screen

For a limp, infinite, non-porous panel at normal incidence, a common screening expression is

Equation 15.2

$R \approx 20 \log_{10}(m'f) - 47$,

where R is transmission loss in decibels, m' is surface mass in kilograms per square metre and f is frequency in hertz. At f = 500 Hz, an ungrouted wall estimate of $m' = 167$ kg/m² gives

$R \approx 20 \log_{10}(167 \times 500) - 47 = 51.4$ dB.

20 MB-1003. Jukka Keränen and Valtteri Hongisto, “Effect of Resilient Joints on the Airborne Sound Insulation of Single-Leaf Heavyweight Constructions”.

If full grouting raises surface mass to 310 kg/m², the same expression gives

$R \approx 20 \log_{10}(310 \times 500) - 47 = 56.8$ dB.

The predicted difference is 5.4 dB; the calculation is dimensionally conventional because the constant embeds the reference units; it omits finite size, oblique incidence, stiffness, coincidence, shells, webs, restraint, damping, porosity, leakage and flanking; its legitimate use is to show the approximate scale of a mass change. It must not be reported as the wall's tested transmission loss.

15.5 Partially grouted masonry and periodic non-uniformity

Partial grouting creates a wall that is neither hollow nor continuously solid; selected cells contain grout and usually reinforcement; intervening cells remain hollow; bond beams may produce horizontal bands of continuous grout; the finished wall therefore contains a two-dimensional pattern of mass and stiffness whose spacing is set by the structural design. Acoustic behaviour can vary with propagation direction and frequency because the pattern interacts with structural wavelengths.

A simple area-weighted model can estimate average mass, but it cannot fully describe periodic response; grouted cells stiffen local regions and strengthen the connection between face shells; hollow cells preserve lower mass and local cavity behaviour; at wavelengths much larger than the grout spacing, an equivalent-medium approximation may be useful. As wavelength approaches the structural periodicity, local and band-like effects can emerge. The design record must therefore preserve grout spacing and bond-beam locations, not merely the statement “partially grouted”.

Construction variability is unusually consequential. A drawing may require every third cell to be grouted, yet congestion, mortar droppings, interrupted placement or misidentified cells can change the pattern; a missed cell reduces mass and may interrupt reinforcement development; an unintended filled cell changes local stiffness. Neither condition is proved by a grout-cylinder strength result; grout strength testing addresses the sampled material; it does not image concealed placement.

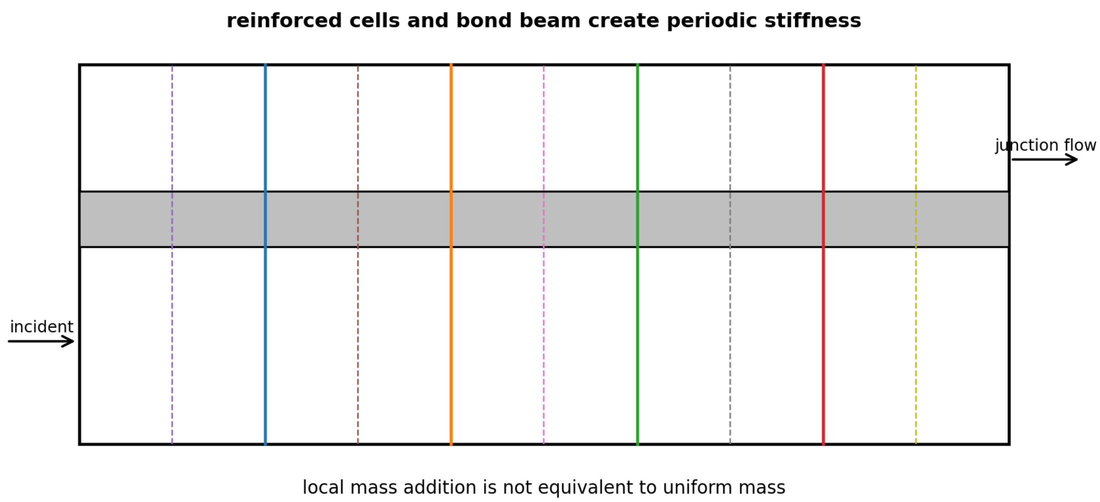

Figure 15-3. Periodic grout, reinforcement and bond-beam network in partially grouted masonry. Author's original schematic. The structural pattern also creates a spatially varying vibration path.

Acoustic prediction should be proportionate to the decision; for preliminary comparison, the wall can be divided into grouted and hollow regions and combined energetically; for a critical wall, finite-element or wave-based modelling may be appropriate, but only if geometry, material properties and damping are known well enough to justify it. Field measurement remains necessary where adjoining structure, openings and workmanship dominate; a sophisticated model cannot repair an unverified configuration.

Worked example 15.5. Area-weighted screening model for partial grouting

Assume 35 per cent of wall area behaves locally like a grouted region with R_g = 58 dB, while 65 per cent behaves like a hollow region with R_h = 50 dB at a frequency of interest. Convert to transmission coefficients:

$\tau_g = 10^{(-58/10)} = 1.58 \times 10^{-6}$, $\tau_h = 10^{(-50/10)} = 1.00 \times 10^{-5}$.

The area-weighted coefficient is

$\tau_c = 0.35\tau_g + 0.65\tau_h = 0.35(1.58 \times 10^{-6}) + 0.65(1.00 \times 10^{-5}) = 7.05 \times 10^{-6}$.

Thus

$R_c = -10 \log_{10}(7.05 \times 10^{-6}) = 51.5$ dB.

A linear average of 58 and 50 dB would give 52.8 dB and would be incorrect because sound-energy transmission is logarithmic; even the coefficient model remains simplified; it assumes the two regions act as independent parallel areas and ignores wave coupling, periodicity, restraint and flanking.

Worked example 15.6. Bond-beam contribution to average surface mass

A wall is 3.6 m high; a bond beam 200 mm high runs continuously at 2.4 m above the floor; if grouting that band adds 145 kg/m² relative to the hollow condition over the band area, its height-averaged surface-mass addition is

$\Delta m' = 145(0.200)/(3.600) = 8.06$ kg/m².

The dimensionless height ratio scales the local mass addition; the average is useful for dead-load and low-frequency screening, but the actual band remains concentrated; it can alter modal shapes and junction transmission differently from a uniform 8.06 kg/m² coating. The drawing location must therefore be retained in any detailed model.

15.6 Fully grouted CMU and the difference between intended and verified solidity

A fully grouted wall is intended to have its cells filled, commonly with reinforcement embedded according to the structural design; the resulting wall can possess much greater surface mass, greater continuity and different damping than the hollow unit wall. It may also couple more strongly into slabs, columns and adjacent walls; the gain in direct airborne isolation can therefore coexist with increased structure-borne transmission through the building frame; the complete room model must examine both.

ASTM C476-23 establishes material requirements for masonry grout, including conventional and self-consolidating categories.[21] ASTM C1019-26 establishes sampling and testing procedures.[22] Those standards are essential to material quality assurance, but they do not make concealed placement visible. A conforming sampled grout batch can coexist with a bridge, shadow void, blocked cell or interrupted lift elsewhere in the wall. The distinction between grout quality and grout completeness must be stated explicitly in specifications and reports.

Grout placement is a fluid-flow and construction-sequence problem; mortar fins can project into cells; reinforcement, ties, embedded items and cell offsets constrict flow; grout can bridge across an obstruction, leaving a void below, or segregate if proportions and handling are unsuitable. Excessive lift height or inadequate consolidation increases risk. Cleanouts and staged

21 MB-0152. ASTM International, ASTM C476-23.
22 MB-0108. ASTM International, ASTM C1019-26.

observation provide direct evidence before concealment; later investigations must rely upon records, non-destructive indications and controlled openings.

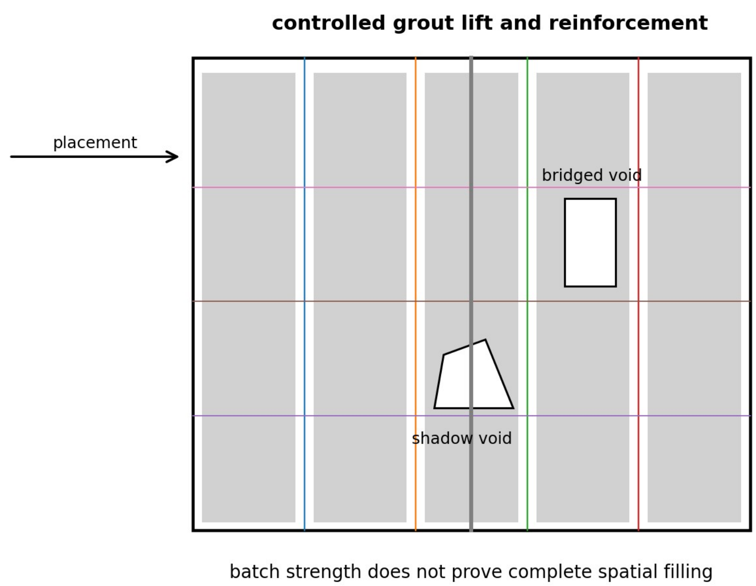

Figure 15-4. Grout lift, consolidation and concealed void mechanisms. Author's original schematic. Material test results do not independently prove complete filling throughout every cell.

The acoustic effect of voids depends upon size, location and connectivity; a small isolated void may make little difference to direct transmission yet matter structurally; a connected vertical void can reduce local mass over a substantial height. A void adjacent to an outlet or frame may join another weak path; the wall should therefore be investigated by mechanism rather than by an arbitrary percentage-complete threshold.

A fully grouted wall is often described as equivalent to concrete. The comparison is imprecise. The CMU wall contains unit shells, mortar joints, interfaces between grout and unit, reinforcement and construction lifts; those interfaces alter stiffness, cracking and damping; a mass-law screening calculation may approach that of a concrete wall of similar surface mass, but detailed vibration and cracking behaviour need not. Chapter 17 treats concrete as its own material and construction system.

Table 15-2. Hollow, partially grouted and fully grouted CMU configurations, dominant uncertainties and minimum evidence.

State	Mass and stiffness pattern	Principal uncertainty
Hollow	Periodic shells, webs and cells	Cell continuity, porosity and joints
Partially grouted	Alternating filled and hollow regions	Actual grouted-cell map and voids
Fully grouted	High nominal continuity	Placement, consolidation and hidden bridges

Worked example 15.7. Grout volume for a controlled lift

A wall segment is 8.0 m long and contains 20 cells to be grouted in a lift 1.2 m high. The clear average cell area is 0.0125 m^2. The theoretical grout volume is

$V_t = 20 \times 0.0125 \times 1.2 = 0.300\ m^3$.

Allow 8 per cent for absorption, spillage, irregularities and test samples:

$V_b = 1.08V_t = 0.324\ m^3$.

Here, V_t is geometric volume and V_b is planned batch volume; the factor is project-specific and should not be adopted without experience and specification review. A delivered quantity substantially below the geometric need is evidence of a possible filling problem, but a matching quantity does not prove correct distribution because grout may be lost, overfill one region or remain in pumps and delivery hoppers.

Worked example 15.8. Void fraction from a bounded mass balance

A documented wall zone should contain 0.480 m^3 of grout. The dry density of representative cured grout is estimated at 2,150 kg/m^3. The expected dry grout mass is

$m_e = 0.480 \times 2{,}150 = 1{,}032$ kg.

A carefully isolated demolition and weighing exercise recovers material whose corrected dry mass is 935 kg. If loss and sampling corrections are accepted for this illustration, inferred void fraction is

$$\varphi_v = 1-\frac{935}{1,032} = 0.094,$$

or 9.4 per cent. The dimensional check is a mass ratio; the inference remains bounded by uncertainty in nominal volume, density, retained debris and recovery completeness; it should prompt spatial investigation rather than a claim that every tenth cell is empty.

15.7 Unit density class, aggregate and moisture state

Concrete masonry density is not a decorative descriptor. It influences unit mass, elastic modulus, thermal response, fastener behaviour, handling, fire performance and acoustic response. ASTM C90-24a identifies normal-weight, medium-weight and lightweight classifications for dry-cast loadbearing units, while ASTM C129-26 recognises lightweight and normal-weight aggregates in nonloadbearing units.[23][24] The acoustic specification should record the actual density classification and, where prediction requires it, representative measured density rather than a generic catalogue range.

Two units of equal external dimensions can have different surface mass because of aggregate density, shell geometry and percentage solid; their dynamic properties may also differ; lightweight aggregate can introduce greater internal damping or porosity, yet lower surface mass. A normal-weight unit may yield a higher mass-law screen but a different coincidence or local-shell response; it is therefore unsound to declare either class

23 MB-0184. ASTM International, ASTM C90-24a.
24 MB-0126. ASTM International, ASTM C129-26.

universally superior. Selection should be based on the complete frequency curve, structural design, fire requirements, attachment needs and the weak paths of the room.

Moisture complicates comparison. Concrete masonry units absorb and desorb water, and the installed moisture content depends upon manufacture, storage, weather, mortar, grout and building conditions; added moisture increases mass temporarily and can change material stiffness and damping; it also influences shrinkage and cracking. Laboratory tests conducted at one conditioning state should not be transplanted uncritically to a wet construction site or a dry occupied building; the test report's conditioning statement is part of the evidence.

The practical submittal should include unit lot, density classification, absorption data, dimensions and mass. For high-consequence construction, representative units may be weighed and measured. This does not require a research laboratory. A calibrated scale, dimensional procedure and documented sample plan can establish whether the delivered units resemble the specified acoustic basis. ASTM C140/C140M-26a provides the unit-testing framework and identifies density and absorption among the relevant characteristics.[25]

Unit substitution deserves special control. A contractor may propose a unit of the same nominal size and compressive classification but different density, percentage solid, cell geometry or surface texture; structural equivalence does not establish acoustic equivalence; the substitution review should compare the entire assembly evidence and should identify whether a

25 MB-0131. ASTM International, ASTM C140.

new test, revised prediction or first-of-type field mock-up is required. A written “no acoustic impact” assertion without data is not an engineering evaluation.

Worked example 15.9. Density-class substitution and surface mass

A wall uses units with net concrete volume 0.00670 m^3 per 0.0800 m^2 modular face area. For a lightweight concrete density of 1,600 kg/m^3, unit-derived surface mass is

$$m'_L = \frac{1,600(0.00670)}{0.0800} = 134 \text{ kg/m}^2.$$

For a normal-weight density of 2,100 kg/m^3,

$$m'_N = \frac{2,100(0.00670)}{0.0800} = 176 \text{ kg/m}^2.$$

The difference is 42 kg/m^2 before mortar or grout. Ideal mass-law screening predicts a difference

$$\Delta R = 20 \log_{10}\left(\frac{176}{134}\right) = 2.37 \text{ dB}.$$

The result does not prove the normal-weight wall is 2.37 dB better at every frequency; geometry, porosity, damping and restraint can alter the curve; it shows that a density-class substitution is not acoustically neutral.

15.8 Mortar bedding, head joints and the continuity of the air barrier

Mortar joins units into a wall, transfers force and closes the network of bed and head joints; its acoustical significance follows from all three functions; a sound wall can be weakened by incomplete joints even when the units are heavy. Conversely, a continuous mortar network can increase structural coupling between units and into adjoining construction; the correct question is not whether mortar is present, but whether the specified mortar, bedding pattern, joint fill, tooling and movement provisions exist in the required locations.

ASTM C270-26 provides two alternative specification routes, proportion and property, for unit masonry mortar.[26] It also states an evidentiary limitation that is frequently ignored: field-sampled mortar compressive strength does not represent the laboratory qualification mortar or the mortar in the wall and must not be used as the standard's compliance criterion. Forensic reports that compare a field cube strength directly with the property-table value commit a category error. Compliance is evaluated through the specified materials and procedures, not by pretending that a site sample reproduces laboratory flow and curing.

Bed-joint construction differs among unit types and structural systems; hollow CMU is commonly face-shell bedded, while solid units may require full bedding; special conditions, bond beams, pilasters and grouted cells can alter the detail; the acoustic drawing should not invent a bedding pattern independently of the structural specification. Instead, the designer should identify where air closure is required and confirm that the structural bedding and acoustic closure together form a continuous boundary.

Head joints are particularly vulnerable because they are vertical, repeated and visually obscured after finishing; mortar may be buttered incompletely, displaced during unit placement or omitted around awkward cuts and embeds; a narrow unfilled region can connect room air to a cell network. If cells align through courses, the path can extend over substantial height;

26 MB-0140. ASTM International, ASTM C270-26.

parging one face may close the room-side entrance, but a later penetration through the coating can reconnect the network.

Tooling affects exposed-joint durability and closure. Concave or V-shaped tooling compacts the mortar surface, whereas raked or struck profiles can create different weathering and leakage behaviour. Interior secure-room walls may later receive paint or lining, but the joint condition remains part of the wall. BIA workmanship guidance emphasises complete joint filling and protection of unfinished masonry during construction.[27] These practices are relevant to acoustic continuity even when their original purpose also concerns water resistance.

Mortar shrinkage and unit movement can produce microcracks at interfaces; a crack that is negligible structurally can be significant acoustically if it forms a continuous air path; conversely, a visible hairline surface crack may terminate in the coating and carry little energy. Diagnosis should use close visual mapping, controlled temporary sealing and frequency-resolved measurement rather than a conclusion based on appearance alone.

27 MB-0368. Brick Industry Association, Technical Note 7B, Water Penetration Resistance - Construction and Workmanship.

Table 15-3. Mortar, grout, parging and plaster perform different wall functions, exhibit different failure modes and demand different inspection evidence.

Material	Wall function	Typical failure evidence
Mortar	Bedding, joint closure, force transfer	Incomplete head joints, shrinkage cracks
Grout	Composite action around reinforcement	Unfilled cells, lift interruption, segregation
Parging	Surface closure and modest mass	Debonding, cracking, incomplete returns
Plaster	Finish, closure, local damping	Keys broken, delamination, incompatible repair

Worked example 15.10. Mortar-joint area fraction

Consider modular units 400 mm long by 200 mm high, including 10 mm joints; approximate visible mortar area per module can be estimated from one horizontal joint strip and one vertical strip, avoiding double count at the intersection:

$A_j = (0.400)(0.010)+(0.200)(0.010)-(0.010)(0.010) = 0.00590\ m^2$.

Module area is

$A_m = 0.400 \times 0.200 = 0.0800\ m^2$.

Thus visible joint fraction is

$\alpha_j = (0.00590)/(0.0800) = 0.0738$,

or 7.38 per cent. The estimate is geometric, not a leakage fraction; proper mortar can be as airtight as the unit surface, while a small discontinuous portion of the joint area can dominate transmission; the calculation shows why repeated joints deserve systematic inspection rather than being treated as negligible lines.

Worked example 15.11. Incomplete head-joint leakage

A 24 m^2 wall has field transmission loss of 52 dB at a selected band. Suppose three vertical joint defects each measure 200 mm high by 2 mm wide, giving total open area

$S_o = 3(0.200)(0.002) = 0.00120\ m^2$.

Wall transmission coefficient is

$\tau_w = 10^{(-52/10)} = 6.31 \times 10^{-6}$.

Treat the defects conservatively as open with $\tau_o = 1$. The composite coefficient is

$\tau_c = ((24-0.0012)\ \tau_w + 0.0012)/(24) = 5.63 \times 10^{-5}$,

and composite transmission loss is

$R_c = -10 \log_{10}(5.63 \times 10^{-5}) = 42.5$ dB.

The illustrative defects occupy 0.005 per cent of wall area yet reduce the calculated band result by about 9.5 dB. Real cracks have impedance and tortuous paths; the example nevertheless demonstrates the leverage of small continuous openings.

15.9 Grout materials, placement, consolidation and concealed discontinuity

Grout is designed to flow into masonry spaces, surround reinforcement and develop the required composite structural action. It differs from mortar in aggregate grading, consistency and placement. ASTM C476-23 recognises conventional and self-consolidating masonry grout and establishes material requirements.[28] Selection must be coordinated with cell dimensions,

28 MB-0152. ASTM International, ASTM C476-23.

reinforcement congestion, lift height, absorption and construction procedure. A mixture that meets strength requirements but cannot flow through the actual cell geometry is not an adequate construction solution.

Placement should be described as a sequence. Before grouting, cells are checked for debris and mortar protrusions. Cleanouts are provided where required. Reinforcement and embeds are inspected. Grout is placed in controlled lifts, consolidated or reconsolidated as applicable, and observed for interruptions or leakage. The record identifies batch, time, temperature, location and personnel. CMHA guidance on grouting and grout quality assurance is useful for this operational layer, while the controlling project specification and TMS 602 requirements remain primary.[29][30][31]

A high slump is not synonymous with successful filling; fluidity must be achieved with a suitable mixture and controlled water content; excess water can alter segregation, shrinkage and strength; self-consolidating grout has different placement behaviour from conventional grout and should not be treated merely as conventional grout without vibration. The wall detail, mock-up and field observations should reflect the selected system.

Reinforcement creates both purpose and obstruction. Vertical bars may be centred or displaced; splices, ties and horizontal reinforcement restrict passages; bond-beam units and knock-out webs change geometry; grout can flow preferentially on one side of a bar, leaving a shadow region. The engineer should expect spatial variability rather than assuming that hydrostatic head will cure every obstruction.

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29 MB-0424. Concrete Masonry & Hardscapes Association, TEK 18-08B, Grout Quality Assurance.
30 MB-0419. Concrete Masonry & Hardscapes Association, TEK 03-02A, Grouting Concrete Masonry Walls.
31 MB-0420. Concrete Masonry & Hardscapes Association, TEK 09-04A, Grout for Concrete Masonry.

Testing sampled grout provides evidence about the material placed during a time interval. ASTM C1019-26 governs sampling and testing, but it does not establish the location or continuity of grout after it leaves the placement hose.[32] A complete quality record combines test results with placement logs, observed lifts, cleanout inspections and, where risk justifies it, targeted verification of concealed cells.

Quantity reconciliation can expose gross anomalies. The theoretical cell volume, expected loss allowance and delivered batch quantity can be compared; large shortfalls or excesses require explanation; the method remains indirect because unit cells vary, grout can enter unintended spaces, and retained material may not be measured precisely. It is a screening control, not a volumetric certificate.

Voids should be classified by mechanism. A small entrapped air pocket differs from a large bridge beneath a mortar fin; a local unfilled corner differs from a continuous missed cell; a void adjacent to reinforcement may have structural implications beyond acoustics; acoustic remediation should never inject material into a loadbearing wall without structural, moisture and compatibility review.

Worked example 15.12. Grout-density and fill-fraction estimate

A wall zone has theoretical grout volume 0.620 m^3; representative cured grout density is 2,080 kg/m^3; if placement records and material balance support an installed grout mass estimate of 1,160 kg, apparent fill fraction is

$$\varphi_g = (1{,}160)/(0.620 \times 2{,}080) = 0.900.$$

32 MB-0108. ASTM International, ASTM C1019-26.

The corresponding apparent unfilled fraction is 10.0 per cent; uncertainty is substantial because delivered wet mass, retained grout, absorption and density corrections matter; the calculation is best used to decide whether targeted verification is warranted; it does not locate the missing volume.

Worked example 15.13. Sampling probability for missed grouted cells

Suppose a wall contains 120 cells intended to be grouted; twelve cells are defective, a prevalence of p = 0.10; if ten cells are selected independently for inspection, the approximate probability of detecting at least one defect is

$P\_d = 1-(1-p)^{10} = 1-0.9^{10} = 0.651.$

A ten-cell sample has only about 65 per cent detection probability under the independent approximation. For twenty samples,

$P\_d = 1-0.9^{20} = 0.878.$

The exact hypergeometric calculation should be used for sampling without replacement, and defects may be clustered rather than random; the example shows why a small convenience sample can create false confidence; inspection design must reflect defect consequence and likely spatial pattern.

15.10 Reinforcement, bond beams and structural-acoustic interaction

Reinforcement and grout are introduced to satisfy structural demands, but they also alter the path by which vibration moves through the wall and into adjoining structure; vertical reinforced cells form stiff lines. Bond beams form horizontal bands. Lintels, pilasters and boundary elements create local concentrations; at low frequency, these features can change global modes; at higher frequency, they create periodic discontinuities and junction paths.

Steel mass is usually a small fraction of wall surface mass, but its stiffness and continuity are not negligible; a continuous bar embedded in grout couples separated wall regions and transfers force into anchors or foundations. The acoustical consequence is configuration-specific. Removing or interrupting reinforcement for isolation would be structurally unacceptable; the design response lies instead in room layout, isolated linings, service support, adjoining-structure treatment or acceptance of bounded residual transmission.

Bond beams are often located at floor, roof, opening or intermediate levels; a bond beam can increase direct-wall mass locally while also coupling into a slab or lintel; a frequency-resolved scan may show a radiation band associated with that line. The finding should not be described simply as “the block wall leaks at the bond beam”; it may be direct radiation, a junction path, cracking beneath the beam, or an adjacent service condition. Vibration and intensity measurements can separate the possibilities.

Structural drawings are therefore acoustic source documents; they identify bar spacing, bond beams, control joints, pilasters and support; the acoustical consultant should review them before proposing a field model; a wall described only in the architectural finish plan is under-specified for vibration analysis. Conversely, structural detail alone does not show sealant, parging, services or linings. The evidence map must coordinate both disciplines.

The perimeter-restraint research discussed earlier applies with particular force to reinforced masonry. A rigid boundary can increase total loss factor by transferring energy into the surrounding structure, improving direct sound reduction above coincidence but potentially increasing flanking elsewhere.[33] The room-level result depends on where that energy goes. Optimising a specimen curve without modelling the receiving paths can displace rather than eliminate risk.

Worked example 15.14. Vertical reinforcement line-mass contribution

Number 5 bars with nominal mass 1.56 kg/m are placed at 800 mm centres in a 3.2 m high wall. Per square metre of wall, vertical bar length is approximately

$\ell_s = \frac{1}{0.800} = 1.25$ m/m^2.

Steel surface-mass contribution is

$m'_s = 1.56 \times 1.25 = 1.95$ kg/m^2.

The mass addition is small relative to a 250 kg/m^2 wall, less than one per cent; the bars can nevertheless affect stiffness, cracking and junction force transmission; mass fraction alone is therefore an inadequate measure of their dynamic importance.

15.11 Parging, Portland cement plaster and surface closure

Parging is a continuous cementitious coating applied to masonry, often thinner and less architecturally elaborate than a full plaster system. Portland cement-based plaster is governed by more explicit layer, substrate and

33 MB-1003. Jukka Keränen and Valtteri Hongisto, “Effect of Resilient Joints on the Airborne Sound Insulation of Single-Leaf Heavyweight Constructions”.

application requirements, including ASTM C926-26.[34] Both can add mass and close distributed pores or imperfect surface joints. Neither should be described as an acoustic cure without specifying thickness, coverage, adhesion, cracking and interfaces.

The principal acoustic benefit can arise from air closure rather than added mass; a 13 mm cementitious layer may add tens of kilograms per square metre, but that mass yields only a modest ideal mass-law increase on an already heavy wall. Closing many small connected pores can yield a larger high-frequency improvement; the distinction matters when interpreting before-and-after data; if gains occur mainly in bands sensitive to leakage, surface closure is the likely mechanism; if the entire curve shifts gradually, mass and damping may also contribute.

The coating must be continuous at returns, frames, corners and service entries; a large field of excellent parging can be bypassed at the wall head, floor edge or electrical box; the construction drawing should show where the coating begins and ends, how it terminates at movement joints and whether later finishes conceal it. Coating behind fixed equipment may be omitted unless a hold point requires inspection.

Substrate preparation controls bond. Dust, release agents, paint, excessive suction, smooth dense units and moisture conditions can cause debonding; a hollow-sounding area may indicate separation, although sounding is qualitative and geometry-sensitive; cracks can follow substrate movement, control joints or shrinkage; a rigid coating across a required movement joint

34 MB-0198. ASTM International, ASTM C926-26.

can crack or transfer stress. The coating design must therefore respect structural and moisture behaviour.

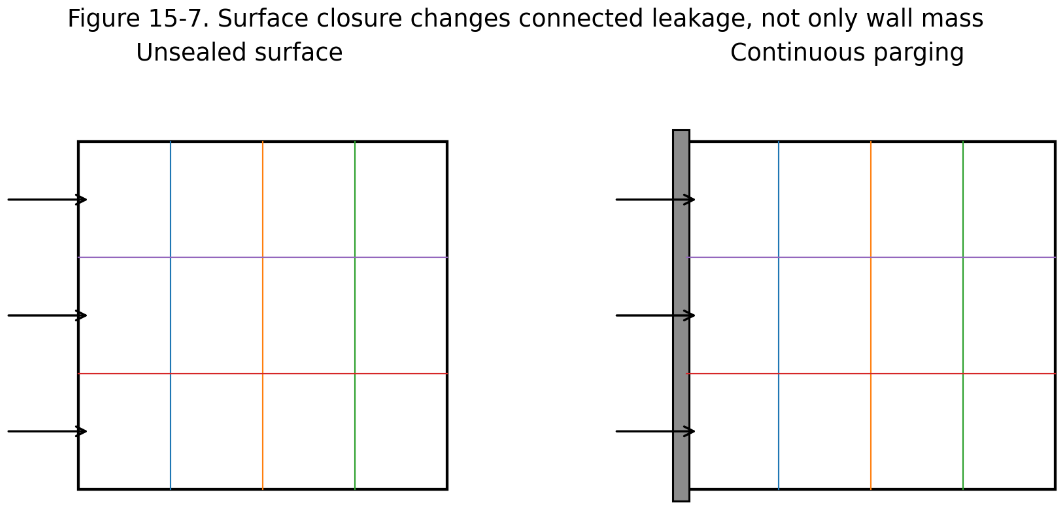

Figure 15-5. Unsealed and continuously parged masonry leakage networks. Author's original schematic. A coating improves only the surface it covers and retains.

Surface texture presents another trade. Open-textured CMU can provide useful room absorption, reducing reverberant build-up; parging or painting closes the pores and reduces that absorption while improving boundary continuity; if internal absorption remains necessary, it should be supplied by controlled room finishes that do not compromise the separation. One material should not be expected to optimise opposing functions without analysis.

Parging can also support forensic diagnosis. A wall that improves substantially after a temporary airtight membrane is applied to a small test zone likely has a distributed surface path; a permanent compatible coating can then be considered; the test must control edges and compare the same source, receiver and background states. Applying coating to the whole room without diagnosis can conceal cracks, trap moisture and complicate later inspection while leaving the actual door or duct path untouched.

Worked example 15.15. Added surface mass from parging

A 12 mm parging layer has dry density 1,850 kg/m³. Added surface mass is

$\Delta m' = \rho t = 1{,}850 \times 0.012 = 22.2$ kg/m².

For an existing wall of 170 kg/m², the ideal mass-law change is

$\Delta R = 20 \log_{10}((192.2)/(170)) = 1.07$ dB.

The calculation indicates that mass addition alone predicts only about 1 dB. A larger measured improvement would suggest that sealing, damping or another changed condition contributed. The conclusion requires frequency-resolved before-and-after data.

Worked example 15.16. Distributed porosity and surface sealing

Suppose a 20 m² wall has effective distributed leakage area 0.0020 m² before coating and 0.00020 m² after coating; the opaque field has R = 55 dB, giving $\tau_w = 3.16 \times 10^{-6}$. Treat leakage conservatively as open. Before coating,

$\tau_{c1} = (19.998(3.16 \times 10^{-6})+0.0020)/(20) = 1.03 \times 10^{-4}$,

so R_{c1} = 39.9 dB. After coating,

$\tau_{c2} = (19.9998(3.16 \times 10^{-6})+0.00020)/(20) = 1.32 \times 10^{-5}$,

so R_{c2} = 48.8 dB. The 90 per cent leakage-area reduction yields nearly 9 dB in this simplified band example, far greater than the mass-only prediction; real porous paths are not open holes; the calculation clarifies the potential mechanism.

15.12 Concrete brick, fired-clay brick and multi-wythe walls

Concrete brick and fired-clay brick must not be merged into a single “brick” evidence class. ASTM C55-25 concerns solid dry-cast concrete building brick manufactured from hydraulic cement, water and aggregates.[35] ASTM C62-23 concerns fired-clay or shale building brick where external appearance is not a requirement, while ASTM C216-26a covers facing brick with additional type and grade classifications.[36,37] Material composition, forming, firing, density, porosity and elastic properties differ. A wall test on one class cannot be assigned to another by matching dimensions.

A single-wythe solid brick wall may approximate a massive plate at low and middle frequencies, but the mortar network, finite size and restraint remain; multi-wythe construction introduces cavities, ties, headers, collar joints and interfaces; if the wythes are structurally bonded, vibration coupling may be strong. If they are separated by a cavity and connected by ties, the system resembles a massive double wall with discrete bridges, but drainage, moisture and structural requirements constrain the cavity.

The cavity-wall concept can be misunderstood. Increasing separation can lower the mass-air-mass resonance, but ties and mortar debris transmit force between leaves. Shelf angles, lintels, floor edges, flashing and fire safing create additional paths. In exterior walls, ventilation and drainage openings are intentional. Research on masonry façades shows that ventilation apertures can reduce sound reduction and that hollow-brick or

35 MB-0155. ASTM International, ASTM C55-25.
36 MB-0163. ASTM International, ASTM C62-23.
37 MB-0139. ASTM International, ASTM C216-26a.

gypsum inner leaves produce different frequency behaviour.[38] Acoustic modification cannot simply seal required drainage or ventilation.

Figure 15-5. Brick cavity wall with discrete and accidental bridges

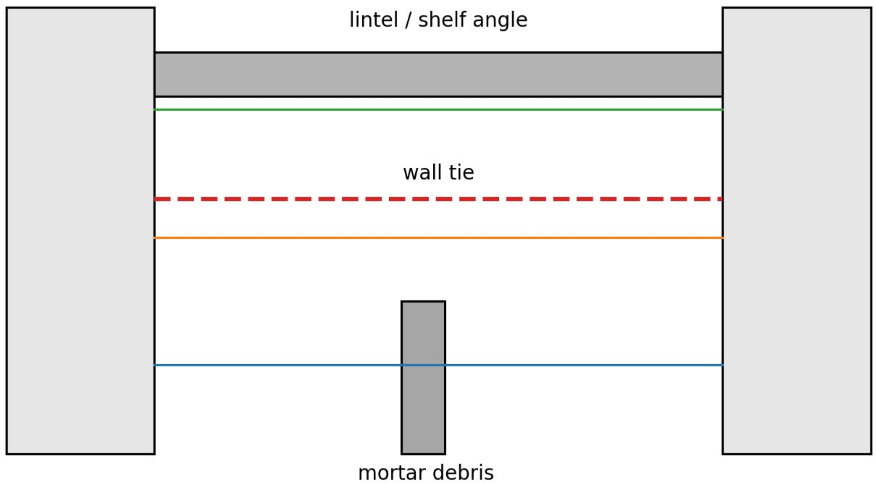

Figure 15-6. Brick cavity wall with ties, mortar debris, lintel and floor-edge paths. Author's original schematic. Nominal cavity separation is not equivalent to mechanical independence.

Wall ties deserve explicit documentation. Their material, stiffness, spacing, orientation and attachment affect both structural stability and vibration transmission. The Brick Industry Association provides detailed tie guidance for brick masonry, but the acoustical effect of a specific tie system may still require modelling or testing.[39] Corrosion, looseness or poor embedment can create nonlinear rattling as well as structural concern. A tie investigation must be coordinated with the structural engineer.

Cavity fill is not a universally benign upgrade; porous absorption can reduce cavity resonance and sound build-up, but rigid or expanding materials can bridge leaves; moisture and drainage behaviour may be altered; a retrofit

38 MB-0378. C. Díaz and A. Pedrero, “On the Sound Insulation of Masonry Wall Façades”.
39 MB-0366. Brick Industry Association, Technical Note 41, Hollow Brick Masonry.

proposal should identify the fill's mechanical stiffness, installation pressure, hygroscopic properties, fire behaviour and reversibility. The cavity is a building-envelope system, not unused space available solely for acoustic treatment.

Table 15-4. Concrete brick, fired-clay brick, hollow brick and structural clay tile distinctions. Similar external shape does not establish equivalent material or acoustic behaviour.

System	Material / geometry	Acoustic caution
Concrete brick	Dry-cast hydraulic cement unit	Do not substitute fired-clay data
Solid clay brick	Fired clay or shale	Joints and restraint remain decisive
Hollow brick	Fired unit with cores	Cell and tie behaviour differs
Structural clay tile	Large hollow fired-clay units	Historic condition and cell orientation unknown

Worked example 15.17. Mass-air-mass screening for a masonry cavity wall

Consider two leaves with surface masses $m'_1 = 180$ kg/m^2 and $m'_2 = 110$ kg/m^2, separated by clear air cavity $d = 0.100$ m. An ideal resonance estimate is

Equation 15.3

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{\rho_0 c^2}{d}\left(\frac{1}{m'_1}+\frac{1}{m'_2}\right)},$$

with air density $\rho_0 = 1.20$ kg/m^3 and sound speed $c = 343$ m/s. Substitution gives

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{1.20(343)^2}{0.100}\left(\frac{1}{180}+\frac{1}{110}\right)} = 23.5 \text{ Hz}.$$

The dimensional term under the square root has units s^{-2}; the low ideal value does not mean the actual wall has no audible-band deficiencies; ties, finite panels, local hollow units, cavities within units, openings and structural flanking invalidate the independent-leaf idealisation. The calculation is a screening boundary, not a rating.

15.13 Structural clay tile and historic hollow masonry

Structural clay tile demands a different evidentiary posture from modern concrete masonry; the units were manufactured in numerous cell arrangements, shell thicknesses and grades, often under standards that changed across decades; they were laid as loadbearing walls, nonloadbearing partitions, fireproofing enclosures and backing for plaster. A finished historic wall may now contain original tile, later brick infill, cementitious patches, timber grounds, abandoned flues and service chases; the present configuration cannot safely be inferred from one exposed unit or from a general description in an architectural history.

ASTM C34-23 provides current product requirements for structural clay loadbearing wall tile at the time of purchase.[40] It does not certify historic tile extracted after many years of loading, moisture exposure, drilling and alteration. The distinction is material. Fired-clay webs can be brittle, local fractures can connect cells, and old lime or gypsum plasters can carry a substantial part of the air-sealing function. Removing a finish to “inspect the tile” may destroy the very layer that limits leakage. Investigation therefore begins with archival drawings, surface mapping, infrared or other non-invasive indications where appropriate, and carefully selected openings approved by the structural and conservation team.

The cell network changes both vibration and airflow. Large aligned cells can behave as local acoustic cavities, while webs and shells support bending and extensional waves. Broken webs may join adjacent cells into a larger volume. Mortar droppings, rubble and later fill create irregular damping and mass. A simplified homogeneous plate model can assist with a first screening calculation, but it should not be presented as a measured property of the wall. Research on hollow-brick walls demonstrates that

40 MB-0142. ASTM International, ASTM C34-23.

periodic geometry and anisotropic wave behaviour can materially affect the transmission curve.[41][42]

Figure 15-7. Structural clay tile and concealed cell continuity

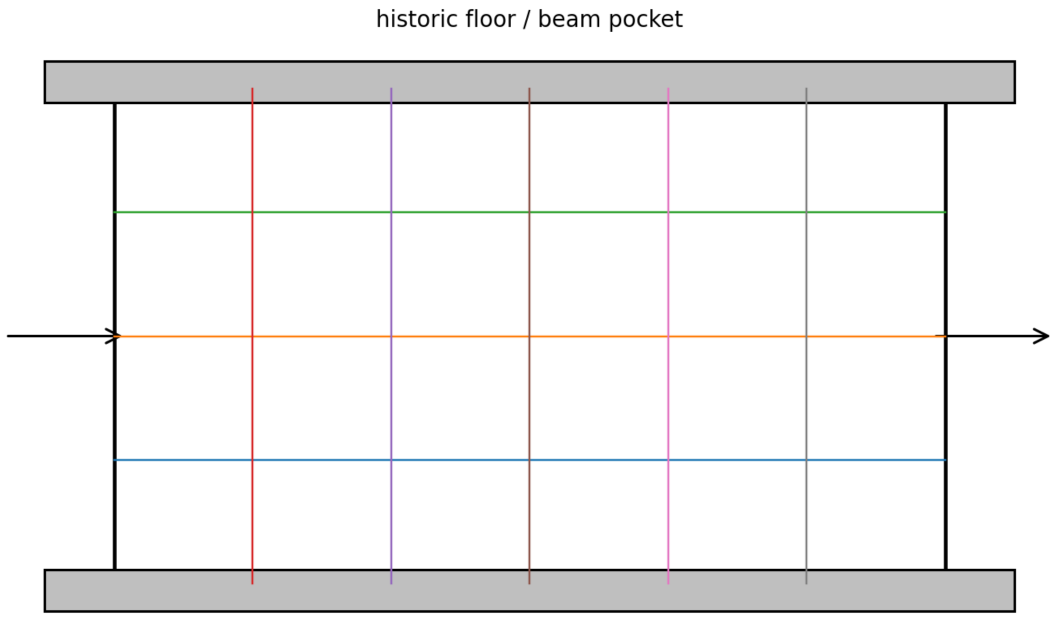

Figure 15-7. Historic structural clay tile with irregular cells, local fractures and uncertain infill. Author's original schematic. Existing-condition uncertainty should be made explicit before drilling, loading or assigning an acoustic model.

Plaster attachment deserves particular care. Wood or metal lath, direct gypsum plaster, cement plaster and later gypsum-board overlays create different mechanical systems; a plaster layer may add mass and close joints, yet keys projecting into cells also couple the finish to the tile. Detached plaster can rattle, crack or form a shallow cavity; a proposed independent lining should avoid fastening through weak tile webs without tested anchors and structural review; it should also preserve inspection access to suspect moisture and cracking conditions.

41 MB-0956. J. A. Díaz-Cereceda et al., "Sound Transmission Loss Analysis Through a Multilayer Lightweight Concrete Hollow Brick Wall by FEM and Experimental Validation".
42 MB-1008. M. Villot et al., "A Homogenised Vibratory Model for Predicting the Acoustic Properties of Hollow Brick Walls".

Worked example 15.18. Screening the surface mass of a hollow clay-tile wall

A 100 mm thick historic tile unit has gross face dimensions 300 mm by 200 mm, measured dry mass 8.4 kg and modular face area 0.063 m^2 including joints. The unit-derived surface mass is

$m'_t = (8.4)/(0.063) = 133\ kg/m^2$.

Suppose 18 mm plaster on both faces has dry density 1,350 kg/m^3. Its combined surface mass is

$m'_p = 2(0.018)(1{,}350) = 48.6\ kg/m^2$.

The screened total is therefore 182 kg/m^2 before mortar, moisture and local infill are included; the calculation is dimensionally a mass divided by area; it does not justify an STC assignment; the tile geometry, plaster attachment, cracks, wall dimensions, supports and adjoining paths remain controlling uncertainties.

15.14 Moisture, porosity, air leakage and cracking

Masonry moisture is an acoustic, structural and conservation variable; water changes mass and may alter elastic modulus and internal damping; more importantly, wetting and drying drive shrinkage, expansion, salt transport, freeze-thaw damage and differential movement between units, mortar, grout, plaster and adjoining concrete. A wall measured during construction may therefore differ from the same wall after the building reaches equilibrium; the test report should record temperature, relative humidity, recent wetting, visible dampness and any conditioning history that could affect interpretation.

Porosity should not be reduced to one bulk absorption number. Concrete and fired-clay products contain pores of different size and connectivity. Surface texture can permit distributed airflow even when no visible crack exists. Paint, parging or plaster can reduce connected porosity, but the coating may also crack or debond. CMHA guidance notes that open-textured concrete masonry can transmit more sound and that plastering or painting can improve transmission performance while reducing absorption.[43] This is a useful qualitative relation, not a universal numerical correction.

Cracks must be classified by origin and continuity; drying shrinkage, thermal movement, foundation settlement, restrained expansion, reinforcement corrosion, lintel movement and incompatible repairs leave different patterns; a surface craze in a coating is not equivalent to a through-crack crossing the mortar and unit. Conversely, a narrow through-crack can be acoustically important despite negligible structural width; the investigator should map crack width, length, orientation, depth indication, moisture state and change over time. Temporary sealing, performed without damaging evidence, can test whether a crack contributes to a measured band.

Brickwork is especially sensitive to differential movement because fired-clay units can expand irreversibly after manufacture while concrete frames and mortars undergo other thermal and moisture strains. BIA Technical Note 18 addresses volume change and the need for movement accommodation.[44] A secure-room detail that rigidly bridges an intended movement joint may suppress visible motion briefly, then crack elsewhere or transmit vibration.

43 MB-0423. Concrete Masonry & Hardscapes Association, TEK 13-02A, Noise Control With Concrete Masonry.
44 MB-0362. Brick Industry Association, Technical Note 18, Volume Changes - Analysis and Effects of Movement.

The correct solution maintains structural movement capacity while preserving an airtight, durable and inspectable acoustic closure.

Worked example 15.19. Moisture-related change in screened mass law

A masonry wall has dry surface mass 220 kg/m^2; after wetting, gravimetric measurements support an additional retained water mass of 9 kg/m^2; at a frequency where ideal mass law is a reasonable screening approximation, the change is

$\Delta R = 20 \log_{10}((229)/(220)) = 0.35$ dB.

The small result shows why moisture-induced changes in cracking, stiffness and leakage may matter more than the added water mass. The example does not claim that a real wall changes by 0.35 dB at every band.

Worked example 15.20. Through-crack screening

A 16 m^2 wall has opaque-field transmission loss of 58 dB at 2 kHz. A through-crack is 1.5 m long and has mean open width 0.20 mm, giving geometric area

$S_c = 1.5(0.00020) = 3.0 \times 10^{-4}\ m^2$.

Using the conservative open-aperture model, $\tau_w = 10^{(-5.8)} = 1.58 \times 10^{-6}$, and

$\tau_{tot} = ((16-S_c)\,\tau_w+S_c)/(16) = 2.03 \times 10^{-5}$.

The corresponding value is

$R_{tot} = -10 \log_{10}(2.03 \times 10^{-5}) = 46.9$ dB.

The calculation overstates transmission where the crack is tortuous or partially filled, but it demonstrates why tiny continuous openings can dominate a high-performing massive field.

15.15 Frames, penetrations, embedded services and openings

An acoustically strong masonry field is frequently defeated at its interfaces; door frames, ducts, electrical boxes, conduits, pipe sleeves, access panels and structural embeds interrupt both mass and air closure; the correct design unit is the opening assembly, not the masonry alone. For each opening, the drawings should identify the rough opening, reinforcement and lintel, frame anchorage, grout or backing, perimeter seal, fire-stopping, movement accommodation and the responsibility for later adjustment.

Hollow metal frames are often grout-filled for structural or fire reasons, but grout placement around anchors and jamb profiles can leave voids; a filled frame can transmit more vibration into the wall than an unfilled frame, even while improving local mass. Acoustic performance depends upon the tested door-and-frame assembly and the field seal. Chapter 20 treats doors in detail; here the masonry obligation is to provide a plumb, dimensionally controlled, structurally adequate and sealable opening whose perimeter does not bypass the door system.

Electrical boxes require a deliberate layout. Back-to-back or closely opposed boxes remove mass, connect cells and complicate sealing; surface-mounted raceway may preserve the masonry field but introduces fasteners and operational exposure; recessed boxes should be located in separately grouted or otherwise closed cells where the approved assembly requires it, with putty pads or other treatments only where their fire, electrical and acoustic compatibility is established. A product marketed as acoustic does not excuse an unsealed conduit or an open knock-out.

Sleeves and conduits can act as waveguides; a rigid pipe penetrating both sides of a wall couples airborne pressure and structural vibration; annular fire-stopping may close the air path but remain mechanically stiff; conversely, a soft acoustic sealant may not satisfy fire or smoke requirements. The detail must identify a tested fire-stop system where required and separately demonstrate that the configured system preserves the acoustic objective. These requirements should be coordinated rather than assigned to different trades without an interface owner.

Worked example 15.21. Composite effect of an access panel

A 30 m^2 masonry wall has R_w = 60 dB at a selected band. A 0.40 m^2 access panel achieves only 32 dB. The combined transmission coefficient is

$\tau_c = (29.6(10^{-6})+0.40(10^{-3.2}))/(30) = 9.39 \times 10^{-6}$,

so

R_c = 50.3 dB.

The access panel occupies 1.3 per cent of the area yet reduces the band result by nearly 10 dB. The appropriate response is not to increase masonry thickness, but to redesign or eliminate the weak opening.

15.16 Laboratory evidence, field evidence and bounded inference

Laboratory transmission-loss data remain indispensable because they isolate a defined specimen from many building paths. ASTM E90-23 provides the laboratory framework, and ASTM E413-22 supplies the STC classification.[45][46] The complete test report must be reviewed. Unit type, density, wall dimensions, mortar, grout, coatings, support, curing, attached linings and opening treatment are part of the result. A catalogue table that omits those conditions is a selection aid rather than a complete evidentiary record.

Field measurement under ASTM E336-25a or ISO 16283-1:2025 addresses the configured rooms, including direct and flanking transmission as defined by the method.[47][48] It does not identify the masonry path by itself. If the field curve falls below the laboratory basis, the difference can arise from the wall, joints, doors, ducts, ceilings, floors or measurement conditions. Path diagnosis may require intensity scanning, vibration measurements, temporary sealing, source relocation or selective shutdown of building systems.

ISO 717-1:2026 and ASTM E413-22 reduce curves to single-number ratings for comparison and regulatory use.[49][50] Secure-room design should retain the frequency data. Hollow units, leaks, cavity effects and structural flanking can create narrow or broad deficiencies that matter to speech but contribute modestly to the integer. Background-limited bands should be reported as bounds rather than silently assigned large measured reductions.

A report should state the narrowest proposition supported by the data; “the configured wall achieved ASTC 54 between the tested rooms” differs from

45 MB-0335. ASTM International, ASTM E90-23.
46 MB-0284. ASTM International, ASTM E413-22.
47 MB-0272. ASTM International, ASTM E336-25a.
48 MB-0874. International Organization for Standardization, ISO 16283-1:2025.
49 MB-0902. International Organization for Standardization, ISO 717-1:2026.
50 MB-0284. ASTM International, ASTM E413-22.

“the CMU wall is STC 54”; the former describes a field result; the latter may falsely attribute a composite result to one component. Occupied speech privacy and formal acceptance require additional evidence beyond either statement.

Worked example 15.22. Laboratory-to-field residual

A laboratory specimen similar to the design has band transmission loss 58 dB at 500 Hz. The installed rooms yield apparent transmission loss 49 dB in the same band. The energy-ratio difference is

$$(\tau_{field})/(\tau_{lab}) = 10^{((58-49)/10)} = 7.94.$$

The field transmits about eight times the acoustic energy represented by the laboratory specimen at that band; the residual does not identify a cause; it defines the magnitude that the combined workmanship and flanking investigation must explain.

15.17 Construction surveillance and inspection hold points

Masonry quality cannot be reconstructed reliably after both faces are concealed; the project should therefore establish inspection hold points before work begins; at minimum, the team should verify unit identity and condition, mortar materials and bedding, reinforcement and embeds, cleanouts, grout placement, wall heads, control joints, frame perimeters, sleeves, coatings and independent linings. The record should include location-linked photographs, drawing references, date, responsible trade and disposition of deviations.

Table 15-5. Construction-surveillance hold points for masonry work.

Hold point	Condition to verify	Release evidence
Unit delivery	product, density class, lot and damage	approved submittal, sample measurements, photographs

Hold point	Condition to verify	Release evidence
Before grouting	clean cells, reinforcement, embeds and cleanouts	signed inspection record and location photographs
During grout lifts	batch, lift height, consolidation and interruptions	placement log, tests and observed sequence
Before concealment	joints, penetrations, wall head and coatings	annotated elevation and closed deficiency list
Before acoustic test	doors, services, ceilings and operational state	configuration register and readiness review

The hold-point system should prevent later trades from undoing accepted work; a wall photographed as complete can be compromised the next day by cable coring, equipment anchors or a replacement frame; configuration control therefore continues through fit-out and occupancy. Each penetration receives an identifier and a record of approval, treatment and inspection.

Statistical sampling must reflect defect clustering. Mortar omissions may follow one mason, one lift or one inaccessible wall zone; grout voids may cluster around reinforcement congestion; random samples that ignore work sequence can miss the pattern; the inspection plan should combine risk-based targeted observation with a documented random element where statistical inference is intended.

Worked example 15.23. Probability of missing a clustered defect zone

A wall contains six grout lifts, and all defects are believed to be confined to one lift. If an inspector chooses two lifts at random without replacement, the probability of including the defective lift is

$P = (2)/(6) = 0.333.$

A nominally respectable two-lift sample has only one-third probability of detecting the clustered condition. Reviewing placement logs and targeting the interrupted lift can be far more effective than increasing random sample count without a causal model.

15.18 Forensic inspection and controlled opening

Forensic examination should escalate from least destructive to most destructive methods; the initial record includes drawings, submittals, inspection reports, photographs, change orders and maintenance history; a visual survey maps joints, cracks, dampness, coatings, frame interfaces and later penetrations. Acoustic and vibration measurements then identify frequency and spatial patterns; borescope access or non-destructive indications may refine the hypothesis before any opening is authorised.

Sounding can detect some detached coatings or voided areas, but it is operator-dependent and affected by thickness, texture and support; ultrasonic pulse velocity can indicate changes in material continuity, yet interpretation in heterogeneous grouted masonry is difficult. The method should be calibrated against known conditions and should not be represented as a direct acoustic-performance measurement; a controlled opening remains the most direct way to verify a local concealed condition, but it destroys part of the evidence and can alter the transmission path.

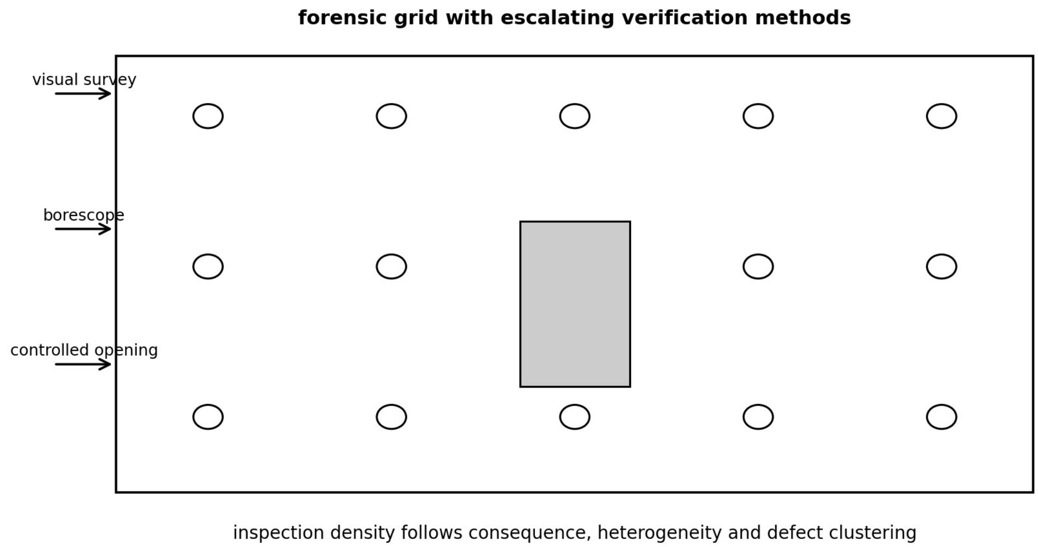

Figure 15-8. Forensic inspection grid with escalating verification methods. Author's original schematic. Inspection density should follow consequence, heterogeneity and likely defect clustering.

Every opening should have a written objective, predicted observations under competing hypotheses, safety review, evidence-control procedure and restoration detail; the examiner photographs the untouched surface, records dimensions and tool locations, retains removed material where relevant and documents the restored assembly. If litigation or disciplinary action is possible, chain-of-custody and witness requirements should be established before the wall is disturbed.

Worked example 15.24. Borescope grid spacing

A 9.6 m long wall is divided into 0.8 m structural modules. One observation per module at two heights would require

$N = (9.6)/(0.8) \times 2 = 24$

locations. If inspection is reduced to every second module, only 12 locations remain and a single-module defect can be missed completely; grid spacing should therefore be tied to the expected spatial scale of the defect, not to an arbitrary convenient number of holes.

15.19 Remediation principles

Remediation should change the demonstrated mechanism. Surface leakage may justify compatible parging, plaster, crack repair or a continuous independent lining; a localized void may justify structural review and targeted grout repair; a wall-head path may require a movement-capable closure; a service opening may be relocated or reconstructed. Slab flanking may require treatment outside the wall. Adding mass to an already massive field is rarely a rational first response when the evidence indicates openings or structure-borne paths.

Repair materials must be compatible with the masonry; hard, dense cement-rich repairs can damage softer historic brick or lime mortar by concentrating stress and moisture; expansive foam can bridge a cavity, obstruct drainage or lack fire resistance. Injection materials can migrate into unintended cells; the project should define adhesion, modulus, shrinkage, vapour behaviour, fire classification, reversibility and inspection access rather than selecting by acoustic marketing language.

Independent linings can be effective when the masonry itself cannot be altered or when the dominant need is decoupling; their success depends upon cavity depth, leaf mass, absorber, support stiffness and elimination of bridges; directly fastening a heavy lining through the cavity into the wall defeats much of the intended isolation. Chapter 16 develops linings and junctions in detail.

Before-and-after testing should use comparable conditions and preserve raw data; a repair that improves one band but worsens another may have shifted a resonance or created a bridge; the acceptance decision should consider the complete room, operational speech state and uncertainty. Formal acceptance remains the authority's decision.

15.20 Integrated design case: grouted CMU secure conference room

A hypothetical conference room is constructed within a concrete frame; the initial concept specifies 200 mm fully grouted normal-weight CMU and a high laboratory STC; the room also contains one acoustic door, two supply ducts, one return path, recessed electrical boxes and a suspended ceiling. A system review shows that the wall field is unlikely to govern above the low-frequency structural region; the door and return path are weaker, while slab continuity creates a possible flanking route.

The design team retains the grouted wall for structural, fire and durability reasons but changes the acoustic strategy; electrical services are surface-mounted on the protected side where practicable; required recessed boxes are staggered and placed in separately closed cells. Door rough-opening tolerances, frame grouting and perimeter seals are coordinated with the door manufacturer; the wall extends to the structural slab, and the head detail accommodates deflection with a tested fire and acoustic closure. The return-air route receives a lined, baffled path designed for airflow and insertion loss rather than an open transfer grille.

A first-of-type wall zone is built before repetitive work; unit lot, density, mortar, reinforcement and grout placement are documented; parging is applied continuously on the corridor face before finishes conceal the wall;

photographs record each penetration and frame. The acoustic test then measures the complete rooms. A deficiency around 1 kHz is localised to the door perimeter, not the wall. Adjustment of latch compression and automatic-bottom contact improves the residual curve.

The final report distinguishes the evidence. Product and construction records describe the CMU wall; the field test describes the configured rooms; an occupied speech assessment addresses representative use; the competent authority reviews the total record for the intended mission. No statement claims that “fully grouted CMU” is inherently approved for classified discussion.

15.21 Hollow-cell resonances, face-shell modes and frequency-resolved interpretation

A hollow concrete masonry wall should not be modelled as a homogeneous plate unless the limits of that simplification are stated. The two face shells, transverse webs, mortar network, air cells, reinforcement and intermittent grout create a periodic structural-acoustic system. At low frequency, the wall may respond through global bending of the complete panel between supports. At higher frequencies, the face shells can develop local bending fields between webs, while the enclosed cells support acoustic pressure distributions whose wavelength is comparable with the cell dimensions. The measured transmission curve is therefore the superposition of several mechanisms rather than a single mass-controlled slope. [51]

The local face-shell frequency depends upon shell thickness, clear distance between webs, elastic modulus, density, restraint and damping; a thin shell spanning a wide cell behaves differently from a thick shell supported by

51 MB-0188. ASTM International, ASTM C919-24.

closely spaced webs, even when gross wall thickness and nominal unit type are the same. Manufacturing tolerances, aggregate grading and compaction alter the local stiffness; mortar bedding can increase restraint at bed joints, whereas incomplete bedding or shrinkage cracks can reduce continuity; the effect is spatially repetitive, so a receiver scan can reveal bands of elevated radiation associated with unit courses or web spacing.

The air cells add another layer. A cell that is closed by mortar and surface coatings can support standing pressure modes; a cell connected through imperfect head joints or penetrations becomes part of a larger air network; the network may act as a chain of cavities and necks rather than as isolated rectangular chambers. A simple quarter-wave or Helmholtz estimate can identify an order of magnitude, but the installed geometry rarely satisfies the assumptions of a perfectly rigid, lossless cavity; tortuosity, porous unit material, mortar fins and leakage add resistance and shift the response. The calculation is therefore a diagnostic screen, not a prediction of the final room rating.

Grout changes both shell and cavity behaviour; a fully filled cell removes most of the enclosed air volume and increases local stiffness and mass; a partially filled cell can create a shorter cavity above the grout lift, with a rough and irregular lower boundary. Grout adjacent to one face shell but separated from the other by a void creates an asymmetric section; reinforcement adds a stiff inclusion that may transfer force into bond beams and foundations. These states cannot be represented reliably by the label “grouted block” unless the locations and continuity of filling are known.

Frequency-resolved interpretation should proceed in layers. First, compare the direct-wall curve with the expected broad mass-controlled trend;

secondly, identify narrow or repeated troughs that may be consistent with local shell or cavity phenomena; thirdly, compare source and receiving scans across unit courses, bond beams, pilasters and grouted zones. Fourthly, perturb a suspected mechanism where that can be done safely, for example by temporarily sealing a joint, adding local damping to a face shell, or changing source position; a spectral feature that moves or changes under a controlled intervention is stronger evidence than a feature observed only once.

The finite dimensions of the wall and the laboratory opening also matter; a specimen built tightly into a massive test aperture may have different edge restraint from a field wall under a deflecting deck. A wall with continuous vertical edges at concrete columns may transfer energy into those columns, while a wall with movement joints may behave more nearly as a bounded panel; two walls built from the same units can therefore exhibit different modal densities and radiation efficiencies because their boundary conditions differ. The laboratory result remains valuable, but it must be attached to its specimen geometry and support state.

Integrated worked example 15.25. Screening a local face-shell resonance

Consider one face shell idealised as a simply supported rectangular strip spanning 130 mm between webs; let shell thickness be 32 mm, material density 1,850 kg/m3, elastic modulus 14 GPa and Poisson ratio 0.20. The flexural rigidity per metre width is

D = E h^3 / [12(1 - nu^2)].

Substituting the stated values gives D approximately 39,800 N m; for a first screening estimate, treat the strip as a one-dimensional simply supported plate segment; the angular frequency of its first bending mode is approximated by

omega_1 = pi^2 / a^2 times sqrt(D / m'),

where a is the clear span and m' = rho h is shell surface mass; here, m' = 59.2 kg/m2 and a = 0.130 m, giving a screened frequency near 2.4 kHz; the dimensional term under the square root is (N m)/(kg/m2) = m4/s2, whose square root is m2/s; division by a2 yields 1/s as required.

The estimate is deliberately bounded. The face shell is not an isolated strip, web restraint is not perfectly simple, mortar joints interrupt the material, damping is uncertain and the second shell is coupled through webs and air; nevertheless, the calculation identifies an upper-mid-frequency region in which local shell behaviour may contribute. If a measured trough occurs near that region and receiver scans show radiation centred between webs, the mechanism becomes plausible; the calculation does not establish field sound isolation or occupied speech security.

15.22 Partial grouting as a periodic medium and the limits of area averaging

Partially grouted masonry is frequently described by the percentage of cells filled; that percentage is necessary but insufficient; the spatial arrangement of filled cells determines whether the wall behaves as a fine periodic medium, a set of stiff vertical ribs, a sequence of isolated pilasters or a highly irregular composite. Two walls with the same twenty-five per cent grout fraction can have materially different vibration fields when one is grouted at regular 1.2 m centres and the other contains clustered grout around openings and corners.

Area-weighted transmission coefficients provide a useful first screen when filled and unfilled regions act as independent parallel paths; that assumption weakens when wavelengths are long enough for the wall to respond globally, or when reinforcement and bond beams couple the regions. At low frequency the whole wall may bend as one panel with spatially varying stiffness; at intermediate frequencies the grouted lines can scatter bending waves and create pass-band and stop-band behaviour; at higher frequency the ungrouted cells may dominate local radiation. The engineer should therefore retain the grout layout, not merely the arithmetic fraction.

Regular grout spacing can create a structural periodicity; if the spacing is d, Bragg-type scattering becomes possible when structural wavelength approaches approximately twice d; the actual masonry is too lossy and heterogeneous for a perfect periodic-lattice model, yet the concept is useful. A repeated stiffness line can redistribute energy and create directional response; the frequency of interest depends upon plate-wave dispersion, so it cannot be estimated from airborne wavelength alone. A finite-element or wave-based model may be justified for a high-consequence wall where repeated grouted ribs, bond beams and concrete boundaries form a clear lattice.

Irregular partial grouting introduces uncertainty rather than a clean periodic response; placement drawings may indicate intended cells, but field deviations can arise from blocked cells, moved reinforcement, access constraints and local repairs; radiography is rarely practical for an entire occupied wall, and ultrasonic methods can be difficult to interpret across heterogeneous units. The preferred evidence set combines reinforcement and grout drawings, placement logs, photographs before closure, quantity reconciliation, targeted borescope or pulse-velocity checks, and acoustic scans. No single method is sufficient.

The interaction with openings is especially important; grouted cells around doors and windows stiffen jambs and support lintels, but they also create force paths into frames and adjacent structure; a door opening bordered by grouted jamb cells may transmit more structure-borne energy than the same opening in ungrouted block, even though local airborne leakage is reduced. The frame perimeter, anchor pattern and sealant joint therefore belong in the same model as the masonry.

Integrated worked example 15.26. Comparing regular and clustered partial grouting

A 12 m long wall contains ten grouted cells, each represented by a 0.20 m wide vertical strip; case A distributes the strips uniformly at 1.2 m centres; case B places six strips within the first 3 m around a door and four strips within the final 2 m near a corner. Both cases have the same nominal grouted area fraction, 2.0/12 = 0.167.

Suppose a screening model assigns effective bending stiffness per unit width D_u to ungrouted wall and $4D_u$ to grouted strips. The area-averaged stiffness is identical in both cases:

$D_{avg} = 0.833\ D_u + 0.167(4D_u) = 1.50\ D_u$.

That equality does not imply equal dynamic response; in Case A, the stiffness lines are distributed and can divide the wall into similar bays; in

Case B, the first 3 m behaves as a much stiffer opening zone, while the central ungrouted region remains flexible. A global model will show different mode shapes, different force transfer into the door frame and different receiving-side radiation; the worked example demonstrates why average grout fraction is a material inventory, not a complete acoustic model.

15.23 Air permeability, distributed leakage and pressure-difference testing

Masonry leakage is often discussed only in terms of visible cracks or holes; porous units, incompletely filled joints, interfaces behind finishes and connected cell networks can create distributed airflow that is difficult to see; the acoustic significance depends upon the impedance of the leakage path, not merely upon whether air can be detected. A long tortuous pore can pass steady air under a pressure difference while attenuating high-frequency sound; a narrow direct slot may pass less volumetric air yet transmit speech energy efficiently. Air-permeability testing and acoustic testing answer related but different questions.

A pressure test can be valuable as a diagnostic map; the room or a bounded wall zone is placed under a controlled differential pressure, and airflow is measured while smoke, tracer gas, thermal imaging or local velocity probes identify paths. The pressure must remain low enough to avoid damaging seals or changing joint geometry; results should be normalised by area and pressure, with environmental conditions recorded; the test is especially useful before surface coatings or linings conceal the masonry.

The measured flow can be modelled by a power law Q = C DeltaP^n, where Q is airflow, C is a leakage coefficient, DeltaP is pressure difference and n characterises the path regime. The equation is empirical. It does not convert directly to transmission loss because acoustic flow oscillates, inertia and compliance matter, and path dimensions govern frequency response; still, repeated tests before and after parging can quantify whether distributed air closure improved.

Acoustic leakage mapping should use a complementary source; broadband or swept excitation in the source room is measured at the receiving face with a scanning microphone, intensity probe or pressure-gradient method; hot spots near joints, frames and service entries are compared with the pressure-test map. Agreement between airflow and acoustic hot spots supports a common opening path. Disagreement is informative. It may indicate a structure-borne path, a cavity resonance, or a porous route with different steady and oscillatory behaviour.

Surface coatings must not be treated as universal air barriers; a parge coat can bridge small pores but crack at movement joints; paint can close surface porosity while leaving head-joint voids connected behind electrical boxes; a gypsum lining may hide leakage without closing it, and the cavity may redistribute sound to another opening. The specification should therefore identify the air-control plane and require continuity at returns, frames, wall heads, floors and penetrations.

Integrated worked example 15.27. Pressure-test evidence without acoustic overclaim

A 30 m2 wall zone is tested at 25 Pa; initial airflow attributable to the wall is 72 m3/h; after continuous parging and perimeter repair, airflow falls to 18 m3/h; normalised leakage changes from 2.40 to 0.60 m3/(h m2) at the test pressure, a seventy-five per cent reduction.

A concurrent one-third-octave test shows gains of 8 to 12 dB above 1 kHz, 3 to 5 dB from 250 to 800 Hz, and no reliable change below 125 Hz because flanking and background dominate; the combined evidence supports the conclusion that distributed surface and joint leakage was materially reduced, especially in the upper bands. It does not prove that the wall now has a particular laboratory STC, nor does it establish whole-room speech security; the result belongs to the tested field configuration and the measured frequency range.

15.24 Grout flow, obstruction, verification and repair restraint

Grout placement is a fluid-transport problem constrained by masonry geometry. Cell width, web projections, reinforcement congestion, lift height, unit absorption, mortar fins, cleanout condition and mixture rheology determine whether grout reaches the intended space. A material certificate establishes composition and sampled strength. It does not establish the path followed inside the wall. [52]

The flow field changes as the lift rises; hydrostatic pressure increases with depth, while water loss into absorptive units can reduce workability locally; conventional grout may require mechanical consolidation and reconsolidation; self-consolidating grout relies on verified flow properties and compatible geometry. Reinforcement laps and ties can divide the cell. Mortar droppings create shelves. A narrow passage can allow grout to bridge above a void. The completed wall can therefore contain defects even when delivered volume and compressive tests appear satisfactory.

52 MB-0414. Carl Hopkins, Sound Insulation.

Construction surveillance should focus on moments when evidence is still obtainable. Cleanouts are inspected before closure. Reinforcement, embeds and cell obstructions are photographed; lift heights and placement sequences are recorded; grout delivery tickets are mapped to wall zones. Consolidation is observed, not assumed. Leakage at unit joints is documented because it can reveal unintended flow paths; where the consequence justifies it, a first-of-type mock-up is opened after curing to compare actual filling with the procedure.

Nondestructive verification is possible but method-dependent. Ultrasonic pulse velocity can indicate changes in continuity, yet path length, coupling, moisture and unit geometry complicate interpretation; impact-echo or resonance methods may detect large voids in suitable geometries, but reinforcement and multiple interfaces create ambiguity; ground-penetrating radar can locate reinforcement and some contrasts, although wavelength and dielectric variability limit void resolution. Borescope openings provide direct evidence at selected points but sample a very small volume; a defensible programme combines methods and states detection limits.

Repair by injection requires restraint. Pumping grout, resin or foam into an uncertain cavity can impose pressure on fragile units, block drainage, trap moisture, alter fire behaviour or create a stiff bridge; structural review is mandatory for loadbearing walls; material compatibility and reversibility matter in historic work. The repair objective must be explicit. Closing an acoustic air path may not require filling every void, while restoring structural composite action may require a code-governed repair; the two objectives should not be conflated.

15.25 Brick cavity walls, ties, debris, lintels and floor-edge coupling

A multi-wythe brick wall can provide substantial direct airborne isolation through mass and separation, but the cavity is only beneficial when its geometry and connections are controlled. Metal ties transfer wind and gravity-related forces between wythes. Mortar droppings can bridge the cavity. Shelf angles, lintels, slab edges and flashings connect the façade to structure. Openings interrupt continuity. The acoustic model must therefore represent both leaves, the cavity and the mechanical connections. [53]

Tie stiffness and spacing affect structural coupling; a sparse flexible tie system may preserve more leaf independence than a dense stiff system, but structural and durability requirements govern the permissible design; the acoustical engineer should not specify tie reduction without the façade engineer. Instead, the secure room can be placed behind an independent inner lining, the cavity can be kept free of debris, and floor-edge paths can be treated at the interior boundary.

Mortar droppings are acoustically important when they form solid bridges; a few isolated contacts may have little effect at low frequency but can create local high-frequency paths; a continuous ledge at a flashing or shelf angle can couple a broad strip. Inspection during construction is therefore more reliable than attempting to infer every bridge after closure; cavity cameras can inspect accessible zones, yet field of view and obstruction limit coverage.

Lintels and shelf angles create mixed paths; the outer wythe may bear on steel connected to the floor slab; the inner wythe may connect around

53 MB-0118. ASTM International, ASTM C1193-25.

window openings; a secure room adjacent to the façade can receive sound through the window, frame, spandrel, slab edge and inner masonry return. Treating only the brick field can miss the controlling path. Exterior listener access and façade radiation should also be considered where the protected room abuts a publicly accessible exterior.

Moisture management cannot be sacrificed for acoustic closure; weeps, flashings and drainage cavities have building-envelope functions; blocking them to improve sound isolation can cause deterioration that later creates larger cracks and repair interventions; the preferred strategy is to preserve drainage in the exterior assembly and establish the acoustic boundary at a separate, inspectable inner layer.

15.26 Structural clay tile, brittle webs and conservation-compatible stabilisation

Structural clay tile appears in historic buildings as loadbearing walls, partitions, fireproofing around steel and floor systems. The units may have thin brittle webs, multiple cells and irregular mortar bedding. Later alterations can include plaster, furring, chases, embedded pipes and patch materials of different stiffness. Product standards for new tile do not establish the condition or geometry of an installed historic wall. [54]

Drilling presents a special risk. A conventional expansion anchor can fracture a web or spall the face; a core hole can open several cells and create a concealed acoustic network; services may have been chased into the tile and patched with dense mortar. The patch can be acoustically stronger than the surrounding tile but structurally discontinuous; existing-condition

54 MB-0188. ASTM International, ASTM C919-24.

investigation should begin with archival drawings, non-invasive survey and small targeted openings agreed with the conservation and structural teams.

Stabilisation must distinguish structural necessity from acoustic preference; a failing tile wall may require anchors, reinforced plaster, shotcrete or a new supporting frame; those interventions alter mass, stiffness and coupling; an acoustically independent lining can improve isolation while minimising alteration to the historic fabric, but it must not conceal active cracking, moisture or unsupported tile. The cavity should remain inspectable where feasible, and supports should be located in verified substrate rather than assumed solid zones.

Fire performance also matters. Historic tile assemblies often formed part of a fire-resistance system around structural steel; removing plaster, cutting openings or adding combustible cavity materials can alter that function; acoustic rehabilitation should be coordinated with a qualified fire-protection professional and the authority having jurisdiction. A secure room is not improved by creating an unverified life-safety condition.

15.27 Integrated forensic case study. A grouted CMU wall with unexplained speech recovery

A secure conference room is separated from a service corridor by a nominal 200 mm fully grouted CMU wall; drawings show vertical reinforcement at 800 mm centres, two bond beams and a continuous parge coat on the corridor side. The wall has no intentional door or window; field testing nevertheless shows a pronounced loss of isolation from 500 Hz to 2 kHz, and controlled listening confirms intermittent recognition of names and numbers near one corridor column.

The first inspection finds no visible crack in the wall field; the electrical drawings, however, show two conduits entering a recessed control cabinet near the column; the cabinet back is fixed to a framed opening cut into the masonry. The opening perimeter has been patched with mortar, but borescope inspection reveals an unfilled head-joint region connected to an adjacent hollow cell; the parge coat stops behind the cabinet. A steel angle supporting the cabinet bridges to the concrete column.

The evidence plan separates three hypotheses. Hypothesis A is direct airborne leakage through the cabinet and connected cell; hypothesis B is structure-borne transmission through the steel angle and column; hypothesis C is a broad wall deficiency caused by incomplete grout; a loudspeaker source is operated in controlled bands. Pressure scanning identifies a strong local maximum around the cabinet at 1 kHz and 2 kHz. Accelerometer measurements show a smaller but repeatable column response below 500 Hz. Temporary airtight closure of the cabinet opening improves the upper-band level difference by 11 to 16 dB but changes the low bands by less than 2 dB. Temporary resilient isolation of the steel angle reduces the low-band response by 4 to 6 dB.

The results support two distinct paths. The cabinet and cell network dominate speech-relevant upper bands, while the rigid angle contributes a lower-frequency structural path; no evidence supports a conclusion that the entire wall is ungrouted; targeted pulse-velocity comparisons between intended grouted cells and reference zones show no gross anomaly, although the method cannot exclude small local voids.

Remediation closes the cabinet opening with a tested, fire-compatible assembly, extends the air-control layer behind the cabinet and replaces the rigid angle detail with a structurally adequate isolated support; the conduits receive listed penetration systems consistent with movement and fire requirements. Photographs, product data, torque records, sealant batch information and as-built dimensions are retained; post-remediation testing is repeated under the same source and receiving geometry; the upper-band deficit disappears, the low-band structural feature is reduced, and controlled listening yields no recognised protected tokens under the authorised test state.

The report does not state that the CMU wall has acquired a laboratory STC, nor that the room is accredited solely because listening produced no recognised words; it states that two measured field paths were identified and remediated, and that the configured room satisfied the project's documented field and operational acceptance criteria subject to the competent authority's decision.

15.28 Evidence-rich specification and lifecycle record for masonry boundaries

A secure-room masonry specification should be written as a chain of evidence; product clauses identify unit type, density class, dimensions, mortar, grout, reinforcement and coatings; execution clauses identify bedding, joint filling, lift procedures, consolidation, cleanouts, tolerances, movement joints and protection. Acoustic clauses identify the required laboratory or field evidence, frequency range, configuration and decision rule; quality clauses identify hold points, photographs, logs, mock-ups and nonconformance procedures.

Submittals should include complete acoustic test reports rather than isolated certificates; the report must identify specimen area, boundary conditions, unit properties, mortar, grout state, coatings, attached linings and openings. Substitutions require a mechanism-based comparison. A unit with the same nominal size but different density, shell geometry or absorption is not automatically equivalent; a new grout mixture is not equivalent unless flow and placement are compatible with the cell and reinforcement arrangement.

The as-built record should preserve the hidden construction; a wall-zone map identifies grouted cells, bond beams, reinforcement, embeds, openings, conduits and repair areas; photographs are keyed to that map; grout lifts and batch records are retained. Penetrations introduced after occupancy are added to a controlled register. Maintenance work that removes cabinets, cuts chases or changes firestopping triggers inspection and, where the risk warrants, targeted acoustic retesting.

Lifecycle assurance is proportionate to consequence and change; stable masonry does not require destructive reinspection on a calendar alone; it does require review after structural movement, water intrusion, impact, service modification, unexplained acoustic change or nearby construction. A baseline field curve and receiving-space map permit later comparison; the objective is not perpetual testing. It is the preservation of a reconstructible relation between the physical boundary, the evidence and the authorised use.

15.29 Predictive modelling of masonry without false precision

Analytical and numerical models can organise masonry evidence, but they can also create false precision when the input geometry is idealised; a useful model begins with the question; if the question is whether a door dominates the wall, an area-weighted transmission calculation may be sufficient. If the question is whether grouted ribs create a low-frequency path, a plate or finite-element model with spatially varying stiffness may be required; if the question is whether a connected cell network carries speech, an acoustic network or computational-fluid-acoustic model may be more relevant.

Homogenised models replace units, mortar and voids with effective properties. They are efficient for wavelengths large relative to the unit geometry. Their validity decreases when local face-shell modes, cell resonances or repeated joints are important. Detailed unit-cell models can represent those mechanisms but require material properties, damping and boundary conditions that are often uncertain. The model should therefore be validated against a measured wall or at least against a simpler limiting case. [55]

Model calibration must not absorb every discrepancy into one fitted loss factor; a high fitted damping value may be compensating for leakage, support loss or measurement bias; sensitivity analysis should vary density, modulus, joint stiffness, cavity connectivity and boundary restraint separately. The report should identify which conclusions remain stable across plausible input ranges.

Mesh resolution follows the shortest structural or acoustic wavelength of interest; a model intended to explain a 2 kHz face-shell feature needs much finer resolution than one intended to screen a 63 Hz global wall mode; mortar joints and thin cracks may be represented by interface elements

55 MB-0196. ASTM International, ASTM C920-18.

rather than full geometry. The representation should be explained so that another analyst can reproduce it.

A secure-room decision rarely requires a claim that the model is exact; the useful output may be a path ranking, a frequency region, or a prediction that one design change is robustly better than another; field verification remains necessary because workmanship and flanking cannot be fully represented.

15.30 Masonry interfaces with doors, glazing and adjacent construction

Masonry does not terminate acoustically at an opening line; door frames, glazing frames, lintels, sills, columns and slabs form transition zones in which mass, stiffness and sealing change rapidly; these zones should be detailed as complete assemblies.

A hollow metal door frame in CMU may be grout-filled, anchored to reinforced cells and sealed at the perimeter; grout around the frame can improve local mass while creating a stiff structural path; an incomplete perimeter seal can bypass both wall and door. The rough opening dimensions, jamb-cell state, anchor type, grout and air seal belong in the door evidence package.

Glazing in masonry requires similar coordination. A heavy masonry wall with a small window can be controlled by glass, frame and perimeter; lintels and shelf angles can carry vibration around the frame; exterior cavity walls may connect to curtain wall or secondary glazing systems. The composite calculation should use tested or measured component data and preserve frequency curves.

At columns, the masonry may be keyed, tied or isolated; at slabs, the wall may bear, be separated by a movement joint or continue through a floor opening. The transition determines flanking. Architectural drawings often show the finish, while structural drawings show the support; the acoustic review must reconcile both.

15.31 Construction tolerances, dimensional survey and statistical quality control

Masonry quality varies spatially. Unit dimensions, mortar thickness, wall plumbness, opening size and joint width affect frames, linings and seals. A tolerance statement in a specification is only useful when the inspection method and sampling plan are defined.

Dimensional survey should focus on acoustic interfaces; opening diagonals and jamb plumbness affect doors; wall-head gap affects fire and air closure. Lining cavity depth affects resonance. Joint width affects sealant strain. Survey points are keyed to drawings and retained before finishes conceal them.

Statistical quality control should distinguish random variation from systematic defect; ten random checks may estimate average joint thickness but miss a repeated unfilled head-joint condition behind one crew; stratified sampling by elevation, work period, crew and detail type can provide better evidence. High-consequence locations, such as frames and penetrations, receive complete inspection rather than sampling.

Acceptance should not be based on an arithmetic average that conceals critical outliers; a wall with average head-joint fill of ninety-eight per cent can still have one continuous open route; the inspection plan should combine average tolerances with maximum permissible discontinuities.

Integrated worked example 15.28. Probability of detecting a systematic defect by stratified sampling

A project has four wall elevations, each built by a different crew; one elevation contains a systematic head-joint defect in twenty per cent of units; the others are sound; ten samples drawn randomly from the entire project have only about a one-quarter chance of landing on the defective elevation and defect combination for each draw. A stratified plan that inspects ten joints on every elevation gives detection probability 1 - 0.8^10 = 0.893 on the defective elevation.

The stratified plan uses more observations but aligns with the suspected mechanism. The calculation assumes independent sampling within the elevation. Real defects may be clustered, so targeted inspection near observed anomalies may be warranted.

15.32 Masonry lifecycle, water events and post-alteration retesting

Masonry is durable but not immutable. Settlement, thermal movement, water intrusion, corrosion, impact and service work can change the boundary. A baseline record allows later distinction between original construction and new damage.

Water events deserve prompt inspection. Saturation changes mass and damping temporarily, but drying can leave efflorescence, corrosion and cracks; a leak behind an independent lining may remain hidden; moisture sensors, access panels and periodic visual inspection support early detection; acoustic testing during an active wet condition should be interpreted cautiously.

Alterations are a larger routine risk. New conduits, data cables, cameras, displays and access-control devices create openings; a permit process should identify the protected boundary and require approved details; after work, the penetration register, photographs and as-built drawings are updated; targeted acoustic testing is triggered when the change is large, uncertain or near a previously weak path.

The retest should reproduce relevant baseline conditions; a difference caused by changed furniture or HVAC state should not be mislabelled as masonry degradation; the report compares band curves, spatial maps and environmental records; formal use decisions remain with the competent authority.

15.33 Unit manufacture, curing and production variability

Dry-cast concrete masonry units are produced under controlled plant conditions, but they remain manufactured mineral composites rather than perfectly uniform blocks; aggregate moisture, compaction energy, mix proportions, curing temperature, mould wear and handling can change density, absorption, dimensional accuracy and surface texture. Product compliance limits variability. It does not eliminate it.

For acoustic prediction, the relevant plant data include density class, measured oven-dry density, net volume, shell and web dimensions, moisture state and compressive strength where it bears upon modulus; a project that uses several plants or product lots should retain lot identity.

Substituting a visually identical unit from another plant can change surface mass and local shell response.

Curing affects early moisture and stiffness. Units delivered wet add mass and may later shrink; a laboratory wall built from conditioned units can differ from field construction assembled during wet weather; the effect is usually smaller than a major leakage path, but it can matter when comparing curves or investigating cracks. The test report and construction record should identify conditioning.

Dimensional tolerances influence joints. Slight changes in unit height accumulate through courses and alter wall-head gap; variations in face-shell thickness affect anchors and local mass; the survey should focus on interfaces and repeated conditions rather than treating tolerances as a paper exercise.

Integrated worked example 15.29. Lot-density contribution to wall-mass uncertainty

Three unit lots have measured dry densities 1,720, 1,810 and 1,890 kg/m3; equal quantities are used in one wall; mean density is 1,807 kg/m3 and sample standard deviation is 85 kg/m3, approximately 4.7 per cent. For a unit-derived wall mass of 160 kg/m2, density variability alone contributes about 7.5 kg/m2 standard spread before geometry, mortar and moisture are considered.

The calculation supports lot tracking and uncertainty allocation. It does not imply that the wall response varies uniformly with density because shell geometry and damping also change.

15.34 Mortar-unit interface mechanics and bed-joint stiffness

The mortar-unit interface transfers compression, shear and bending between units; its stiffness depends upon mortar type, joint thickness, unit absorption, workmanship, curing and load; a wall with stiff interfaces behaves more continuously; a wall with weak or cracked interfaces permits local slip and face-shell motion. Both conditions influence sound transmission.

Absorptive units draw water from mortar. Excessive suction can impair bond. Pre-wetting or mortar adjustment may be necessary under the masonry specification; tooling compacts exposed joints but does not repair poor internal bond; a visually complete joint can contain voids at the interface.

For structural design, joint properties are addressed through code-based masonry behaviour; for acoustic modelling, interface stiffness and damping may be represented by springs or contact elements; these inputs are difficult to measure directly; model calibration should therefore use wall-scale data and sensitivity ranges.

Cyclic structural movement can degrade interfaces over time; cracks may open at corners, lintels and wall heads; repointing replaces exposed mortar but may not restore deep bed-joint continuity; an independent lining may provide a more reliable acoustic boundary than repeated surface repair.

15.35 Masonry wall heads under concrete and steel structure

A masonry wall under a concrete slab can be bearing, nonbearing or partially restrained; under steel framing, deflection and fireproofing complicate the head; the detail must distinguish vertical load transfer, lateral restraint, movement accommodation, fire protection and air closure.

A bearing wall may be tightly grouted to the structure, creating strong continuity; a nonbearing wall may require a deflection gap; rigidly filling that gap can attract load and crack the wall; soft packing without a continuous seal can leak. A metal slip track can create a flanking path.

The acoustical engineer should review structural deflection calculations and the tested fire joint where applicable. The as-built gap is measured before closure. Flutes and irregularities are mapped. Later ceiling work must not disturb the head system.

Field scans often show wall-head radiation because the head combines air leakage, reduced mass, sealant and structural coupling. Diagnosis should separate these mechanisms. Temporary air closure tests the leak component. Vibration measurements test the structural component.

15.36 Bond beams, lintels and local stiffness transitions

Bond beams and lintels create zones of increased mass and stiffness; they can improve local airborne reduction while redirecting vibration to supports; cracks commonly form beneath lintels or at changes in restraint; door and window frames attach in the same zone.

A bond beam continuous through several rooms can act as a horizontal flanking element; its reinforcement connects pilasters and columns; an inner lining that is isolated over the wall field may be bridged at the beam by equipment supports. The design should identify the beam line.

Lintel deflection affects frame geometry and seal compression. A high-performing door cannot compensate for a moving opening. Structural serviceability and acoustic maintenance are therefore linked.

Integrated worked example 15.30. Lintel deflection and perimeter seal strain

A 2.4 m lintel deflects 3.0 mm at midspan; a door frame head remains straight over 1.0 m central width, creating an average differential gap of approximately 2.5 mm in that zone; if the acoustic perimeter seal was designed for 5 mm compression, half of its compression can be lost locally. The result is a geometric screen. Frame stiffness, anchor action and seal profile determine the actual contact.

15.37 Masonry repair materials and compatibility

Repair options include repointing, crack injection, grout injection, patching, parging, plaster, unit replacement and independent lining. Each changes the wall differently. A rigid repair can restore structural continuity but increase flanking; a flexible seal can close air leakage while accommodating movement; a dense patch can create a stiff island; a foam fill can alter fire and moisture behaviour.

The repair should address cause. Repointing an active structural crack is temporary; injecting a wet wall can trap moisture; filling hollow cells can overload foundations or block services. Unit replacement can disturb reinforcement. Structural, fire and conservation reviews are necessary.

Mock-ups are useful where appearance, compatibility and acoustic performance matter. The repair is tested locally and then at room scale. Removed material and photographs are retained when forensic issues exist.

15.38 Masonry field report structure

A complete report separates description, observation, measurement, inference and decision; description records units, joints, grout, reinforcement, coatings and openings; observation records visible and concealed condition; measurement records methods, calibration, geometry and uncertainty. Inference identifies supported mechanisms and alternatives. Decision states remediation or acceptance within authority.

Figures include wall-zone maps, photographs, band curves and path diagrams; tables link defects to evidence and corrective action; the report does not call a wall “secure” solely because of mass or STC; it states the tested configuration and residual limitations.

Table 15-R1. Masonry mechanism, discriminating evidence, bounded conclusion and primary corrective route.

Mechanism	Discriminating evidence	Bounded conclusion	Primary corrective route
Connected cell network	Pressure or tracer response aligned with acoustic hot spots	A continuous air route is supported in the tested zone	Close the controlled air plane and retest
Partial-grout periodicity	Grout map, mobility scan and model sensitivity	Spatial stiffness pattern may govern selected bands	Target lining or junction treatment rather than blanket mass
Head-joint discontinuity	Borescope, reversible seal and upper-band change	Local airborne leakage is supported	Rebuild joint or provide continuous surface closure
Bond-beam or pilaster path	Vibration coherence and receiving radiation map	Structure-borne path is supported	Treat receiver or junction without impairing structure
Historic clay-tile uncertainty	Archival record, non-invasive survey and targeted opening	Installed construction remains partly uncertain	Use reversible inner boundary and controlled verification

15.39 Conclusions

Masonry acoustic performance is controlled by configuration, continuity and evidence; unit standards identify products; mortar and grout standards identify materials and quality-control procedures; laboratory tests identify defined specimens; field tests identify configured rooms; none can substitute for the others. Hollow cells, selective grouting, joints, coatings, reinforcement, moisture, cracks, frames and services make the finished wall spatially heterogeneous.

The practical design lesson is not simply to choose the heaviest unit; the team must preserve air closure, movement capacity, structural safety, fire protection, moisture behaviour and inspectability while controlling direct and flanking sound paths; construction surveillance and targeted verification are essential because many decisive conditions become concealed. Remediation should follow demonstrated mechanisms and should be tested under comparable conditions.

Chapter 15 Glossary

Bond beam. A horizontally reinforced and grouted masonry course or member that distributes structural forces and creates a local band of increased stiffness and mass.

Cell. A vertical void within a hollow masonry unit, which may remain open, contain reinforcement, receive grout or communicate with adjacent openings.

Face-shell bedding. Mortar placement primarily beneath the face shells of hollow masonry units rather than across the full bed area.

Grout lift. The vertical height of grout placed during one controlled stage of masonry grouting.

Head joint. The vertical mortar joint between adjacent masonry units in a course.

Parging. A continuous cementitious coating applied to masonry, commonly to close surface porosity, improve weather resistance or provide a substrate.

Percentage solid. Net solid area divided by gross bed area, expressed as a percentage for a masonry unit.

Shadow void. An unfilled region created where reinforcement, mortar fins or geometry obstruct grout flow.

Structural clay tile. A fired-clay hollow masonry unit historically used in loadbearing and partition construction, with cell geometry that differs from brick and concrete masonry.

Through-crack. A crack that creates continuity through the wall thickness or connects otherwise separated voids and surfaces.

Air-permeability coefficient. Coefficient in an empirical relation between pressure difference and airflow through a bounded wall or joint zone.

Connected-cell network. A set of masonry cells and discontinuities that forms a continuous air route rather than isolated cavities.

Face-shell mode. Local bending response of a concrete masonry face shell between webs or other restraints.

Grout shadow. A void or poorly filled region formed where reinforcement, mortar fins or geometry obstruct grout flow.

Homogenised masonry model. A model that replaces units, mortar, voids and reinforcement with effective continuous properties within a stated wavelength range.

Periodic grout rib. A repeated grouted cell or pilaster that creates a spatial stiffness pattern within a partially grouted wall.

Chapter 16. Masonry Joints, Linings, Openings, Cracking, and Flanking

16.1 The discontinuity governs before the mass does

A masonry partition is rarely acoustically limited by the uniform central field alone; its weakest paths are concentrated at planned movement joints, wall heads, slab edges, columns, lintels, frames, penetrations, cracks and interfaces with independent finishes; these discontinuities are not ancillary details. They are local transfer systems in which air leakage, sealant stiffness, structural contact, geometric area, workmanship and adjoining construction act together; the central masonry field can possess very high direct transmission loss while a narrow perimeter joint permits intelligible speech energy to enter a corridor, plenum or neighbouring room.[56][57]

The design task is complicated because several objectives compete at the same location; a movement joint must remain capable of the calculated displacement; a fire-resistance joint may require tested safing, backing and sealant; a smoke boundary must limit air passage; an acoustic boundary must suppress airborne leakage without forming a rigid mechanical bridge. A heritage joint may have restrictions on removal, colour, tooling and substrate treatment; a secure-room specification that states merely “seal all joints acoustically” leaves these obligations unreconciled and gives the installer no basis for deciding which material, depth, backing or inspection method controls.

The evidence record must therefore identify the joint as a configuration. At minimum it should state joint type, nominal and measured width, expected

56 MB-1181. The Masonry Society, TMS 402-22 Building Code Requirements for Masonry Structures and TMS 602-22 Specification for Masonry Structures.
57 MB-0363. Brick Industry Association, Technical Note 18, Volume Changes: Analysis and Effects of Movement.

movement, substrates, surface preparation, primer, backing material, sealant classification, bead geometry, installation temperature, cure condition, fire or smoke listing, access for replacement and the acoustic test state. ASTM C1193-25 supplies broad guidance on joint design and installation; ASTM C919-24 addresses sealants used to reduce airborne flanking through joints, voids and penetrations; ASTM C920-18(2024) classifies elastomeric sealants by type, grade, movement class and use.[58][59][60] None of these documents alone proves the room result.

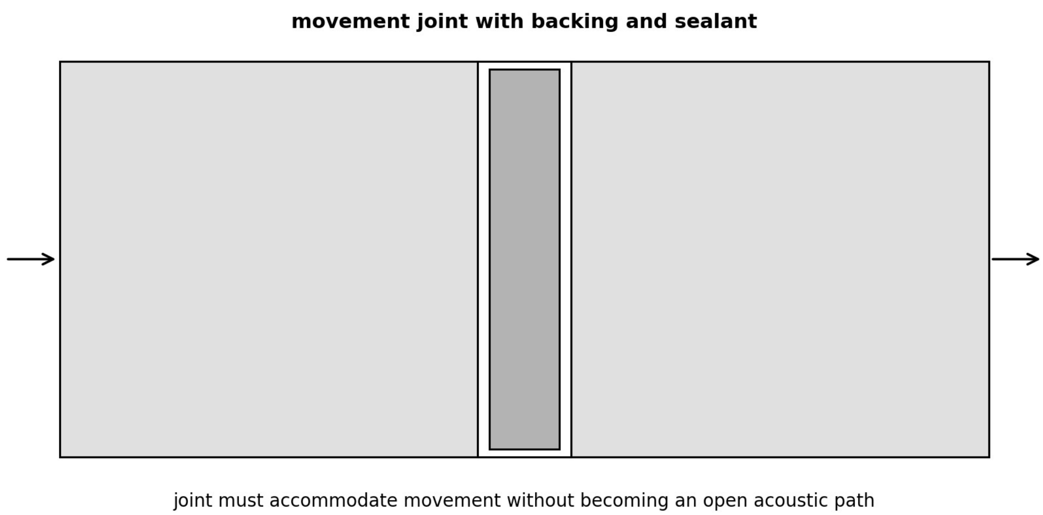

Figure 16-1. Movement-compatible masonry joint with backer rod, controlled bond line and discontinuous finish returns. Author's original schematic. The acoustic closure must remain airtight throughout the specified movement without becoming a rigid bridge.

Worked example 16.1. Required movement capacity of an interior masonry joint

A 12 m long clay-brick wall is restrained between concrete columns; the design team adopts a reversible thermal and moisture movement estimate

58 MB-0365. Brick Industry Association, Technical Note 18B, Accommodating Building Deflections.
59 MB-0421. Concrete Masonry & Hardscapes Association, TEK 10-02D, Control Joints for Concrete Masonry Walls.
60 MB-0363. Brick Industry Association, Technical Note 18, Volume Changes: Analysis and Effects of Movement.

of 0.50 mm/m and a construction tolerance allowance of 2 mm. The required joint movement is

$\Delta = (12)(0.50)+2 = 8.0$ mm.

If the nominal sealant width is 20 mm, the one-direction extension ratio is

$\varepsilon = (8)/(20) = 0.40$,

or 40 per cent. A sealant classified only for 25 per cent extension is not adequate under this simplified design case; the dimensional check is a length divided by a length; the calculation does not establish service life because substrate adhesion, temperature, ageing, installation depth and compression cycles remain. It does show why a generic caulk note cannot replace a movement calculation.

16.2 Movement sources and the acoustic consequences of restraint

Concrete masonry shrinks after manufacture and responds to temperature, moisture and structural deformation. Fired-clay brick can undergo long-term moisture expansion in addition to thermal movement. Concrete frames shorten, creep and deflect; steel shelf angles rotate; slabs curl; foundations settle; roofs move under temperature and wind. The relative movement at a joint is therefore the difference among several time-dependent responses, not one material coefficient multiplied by one length.[61][62][63]

Rigidly filling a movement joint may appear acoustically attractive because the material is dense and continuous; the apparent gain can be temporary;

61 MB-0364. Brick Industry Association, Technical Note 18A, Accommodating Expansion of Brickwork.
62 MB-0118. ASTM International, ASTM C1193-25.
63 MB-0196. ASTM International, ASTM C920-18.

restraint transfers stress into adjacent mortar, units, frames or finishes, producing cracks that are harder to inspect and repair. A rigid bridge also transmits vibration across a discontinuity that may have been intended to reduce structural coupling; in secure-room construction, the correct objective is durable closure with controlled compliance, not maximum local stiffness.

Movement can change the acoustic state without creating a visible open crack; a compressed gasket may lose contact at one edge; a sealant bead can debond internally while remaining visually smooth at the surface; a plaster return can bridge across a joint and crack behind an applied trim. A metal cover can rattle or transmit force between leaves. Commissioning should therefore include movement-state reasoning. Where practical, joints are inspected near representative thermal and moisture conditions, and subsequent lifecycle inspections record width, adhesion, surface condition and adjacent cracking.

Worked example 16.2. Differential vertical shortening at a masonry-to-frame interface

A concrete frame experiences 5.0 mm of cumulative shortening over the storey height after the masonry has been constructed; the masonry wall experiences 1.5 mm of net shortening over the same period. Differential displacement is

$\Delta_d = 5.0 - 1.5 = 3.5$ mm.

A wall-head detail with only 2 mm of free vertical accommodation will bind before the design movement is exhausted; the remaining 1.5 mm must be taken by deformation, crushing, slip or cracking. The calculation is deliberately elementary. Its significance lies in identifying a kinematic incompatibility that an acoustic sealant note cannot cure.

16.3 Control joints, expansion joints and isolation joints

A control joint in concrete masonry is intended to manage shrinkage cracking by creating a deliberate plane of reduced tensile continuity. An expansion joint in brickwork accommodates expansion and differential movement. An isolation joint separates elements that should move independently. Although these terms are sometimes used casually, their structural functions differ, and so do their reinforcement, keying, anchorage and sealant details.[64][65][66]

Acoustically, each joint creates a narrow strip whose transmission depends upon backing, sealant, covers, geometry and depth; a well-designed joint can be much weaker than the wall field yet acceptable at room level because its area is small and the receiving conditions are controlled. A failed joint can dominate because its effective transmission coefficient approaches that of an opening. The analysis should be frequency-resolved. A soft, deep and tortuous joint may limit high-frequency leakage while still transmitting low-frequency pressure through moving covers or flanking structure.

The joint should not be concealed before inspection; the reviewer needs to see substrate cleanliness, backer-rod placement, bead depth, adhesion faces and the absence of three-sided adhesion; cover plates, if required, should be attached to one side only or otherwise detailed to preserve movement and minimise bridging. Fire-rated joint systems must remain

64 MB-0134. ASTM International, ASTM C1635-22.
65 MB-0414. Carl Hopkins, Sound Insulation.
66 MB-0761. Frank Fahy and Paolo Gardonio, Sound and Structural Vibration, 2nd ed.

within their listing; acoustic treatment is coordinated around the tested system rather than substituted for it.

Worked example 16.3. Area-weighted influence of a sealed movement joint

A 30 m^2 wall has measured field transmission loss of 55 dB in a selected band; a vertical joint 3 m high and 20 mm wide occupies 0.060 m^2; assume the sealed joint has effective transmission loss 30 dB. The wall and joint transmission coefficients are

$\tau_w = 10^{(-55/10)} = 3.16 \times 10^{-6}$, $\tau_j = 10^{(-30/10)} = 1.00 \times 10^{-3}$.

The composite coefficient is

$\tau_c = ((29.94)\, \tau_w + (0.060)\, \tau_j)/(30) = 5.15 \times 10^{-6}$,

and

$R_c = -10 \log_{10}(\tau_c) = 52.9$ dB.

The small joint reduces the band result by about 2.1 dB; if the bead debonds and behaves more nearly as an opening, the reduction is far greater; the example assumes diffuse incidence and independent parallel paths, and it does not include structural coupling.

16.4 Sealant geometry, backing and adhesion

A sealant joint functions through controlled deformation of a bonded elastomeric element; the bead must adhere to the two intended faces, possess a suitable width-to-depth relationship, remain compatible with the substrates and backing, and cure under acceptable environmental conditions; backer rod controls depth, supplies a non-adhering rear surface and supports tooling. Primer may be necessary for porous or difficult substrates; dust, laitance, efflorescence, curing compounds, moisture, oil and old sealant can defeat adhesion even where the product is nominally suitable.[67][68][69]

Three-sided adhesion is a common failure because it constrains the bead and concentrates strain; a shallow smear can tear or debond; an excessively deep bead can become too stiff and consume material without improving movement capability. Tooling is not cosmetic. It consolidates the bead, promotes contact and produces the intended profile; a surface skin that bridges over an unfilled recess may look finished while leaving an air path behind it.

For acoustic service, the sealant must also remain continuous behind trim and at intersections; corners, frame returns and crossing joints deserve enlarged details; a firestop contractor, masonry contractor and acoustical-sealant installer may each assume that another trade closes the same location. The penetration register should assign one accountable installer and one inspection hold point.

Worked example 16.4. Sealant cross-sectional area and extension strain

A joint is 15 mm wide and uses a 7.5 mm deep hourglass bead. Approximate sealant cross-sectional area, ignoring concavity, is

$A_s = 15 \times 7.5 = 112.5\ \text{mm}^2$.

If the joint opens by 3 mm, nominal width strain is

$\varepsilon = (3)/(15) = 0.20$.

67 MB-0293. ASTM International, ASTM E488.
68 MB-0158. ASTM International, ASTM C597-22.
69 MB-0824. International Organization for Standardization, ISO 10848-1:2017.

The movement is 20 per cent of original width. The area calculation assists with material quantity, while the strain calculation screens movement class. Neither replaces a compatible-substrate adhesion test or the manufacturer's joint-design limits.

16.5 Wall heads, bases and slab-edge interfaces

The wall head is one of the most consequential interfaces in a secure room; it must accommodate floor or roof deflection, maintain fire and smoke continuity where required, close the acoustic boundary and avoid a rigid bridge between independent leaves. A wall that stops at a suspended ceiling leaves a plenum path unless the entire plenum is itself the controlled boundary; a wall that reaches the deck can still fail through fluted deck voids, corrugation, beam pockets, edge gaps and unsealed structural irregularities.

Deflection-head systems must be understood mechanically. Slotted tracks, slip clips, compressible mineral-fibre safing, fire-resistive sealants and acoustic sealants have distinct roles; a screw placed through a slotted track into the wrong member can lock the movement; a gypsum lining hard against the slab can bridge an otherwise independent system. A sealant bead too thin to follow movement can split; the inspection photograph should show the condition before ceiling closure.

At the base, floor flatness and construction debris govern closure; masonry may be built on a levelling bed, curb or slab; independent linings can be isolated with resilient strips, but the strip must support the intended load without excessive creep. Floor finishes, skirtings and raised-floor pedestals can bridge; cleaning and water events can degrade exposed sealant. The lifecycle plan should include accessible perimeter inspection rather than burying all evidence behind fixed cabinetry.

Worked example 16.5. Deck-flute bypass area

A wall intersects a metal deck with six open flutes, each approximated as 75 mm wide by 38 mm high. The total geometric opening is

$S_o = 6(0.075)(0.038) = 0.0171\ m^2$.

For a 24 m^2 wall whose opaque field is 58 dB, treating the flutes conservatively as open gives

$\tau_c = ((24-0.0171)10^{(-5.8)}+0.0171)/(24) = 7.14 \times 10^{-4}$,

so

$R_c = 31.5$ dB.

The result demonstrates why apparently small deck voids must be closed with a documented, movement-compatible and fire-compliant system. It is a conservative parallel-path calculation, not a prediction of a particular fluted-deck detail.

16.6 Openings, lintels and concentrated force paths

Door and service openings reorganise the masonry wall; lintels, bond beams, jamb reinforcement and frames create stiff local paths; corners around openings concentrate stress and commonly initiate diagonal cracking; a frame anchor transfers door-operating force into the wall. A duct sleeve interrupts mass and can connect cells. The opening must therefore be detailed as a structural-acoustic subsystem.

Lintel deflection and bearing influence crack formation; a lintel that rotates or deflects relative to masonry can open joints at the corners; a shelf angle supporting brick veneer introduces anchors and a horizontal discontinuity; a precast lintel may possess high mass but transmit structure-borne energy into a concrete frame. The acoustical drawing should identify these paths rather than showing only a generic rectangular opening.

Frames should not be assumed airtight because they are grout-filled; grout can leave cavities around anchors and profiles; a perimeter bead applied only to the visible face may not close a deep irregular gap; the preferred detail defines the primary air seal, backing and inspection surface. Door leaves, seals and thresholds are treated in Chapter 20, but their performance cannot exceed the dimensional and structural quality of the rough opening.

Worked example 16.6. Lintel-deflection crack opening

A 2.1 m lintel deflects 2.5 mm at midspan while adjacent masonry corners remain restrained. A simplified triangular separation over half-span gives an average local slope

$\theta \approx (2.5)/(1{,}050) = 0.00238$ rad.

Across a 200 mm masonry depth, compatible differential opening can be on the order of

$w \approx (0.00238)(200) = 0.48$ mm.

The calculation is geometric and does not model crack mechanics. It shows that visually modest structural deflection can create an acoustically significant path at a rigid frame or brittle finish.

16.7 Independent linings as controlled secondary boundaries

An independent lining can improve a massive wall when direct transmission, porosity, cracking or heritage restrictions justify an internal secondary leaf. The lining is not merely extra gypsum board; it is a mass-spring-mass system whose cavity depth, leaf mass, framing stiffness, absorber, perimeter isolation, service strategy and junctions determine performance; fixing the lining back to the masonry with frequent rigid brackets can erase much of the intended decoupling.[70][71]

The cavity should be inspected for moisture, salts and biological conditions before closure; a lining that conceals active dampness can accelerate deterioration and compromise indoor environmental quality; vapour and thermal behaviour require building-physics review; in historic fabric, reversibility and minimal intervention may favour a free-standing frame with limited, documented stabilisation points rather than adhesive bonding or widespread drilling.

Services should be contained on the room side of the secondary boundary where possible; recessed boxes, display mounts and cabinets reintroduce penetrations; heavy equipment requires independent support or engineered backing that does not bridge the cavity; access panels should be tested or located outside the protected boundary. The lining perimeter remains visible until inspected.

70 MB-0832. International Organization for Standardization, ISO 10848-2:2017.
71 MB-0847. International Organization for Standardization, ISO 12354-1:2017.

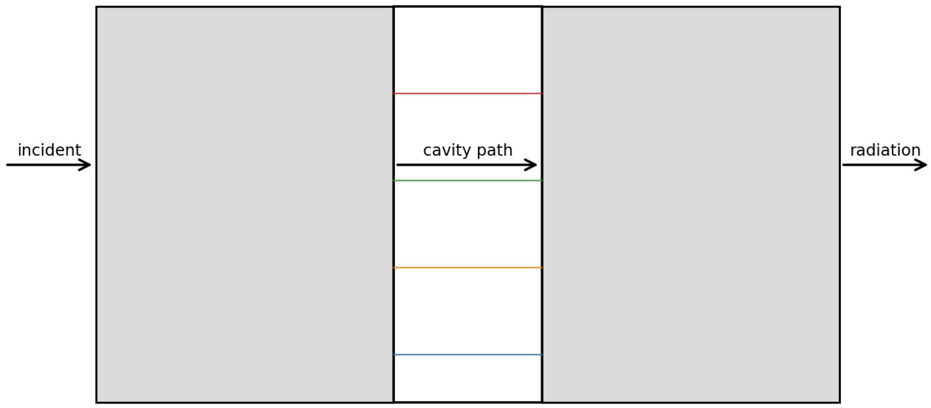

Figure 16-2. Independent lining against masonry with a clear cavity, absorber, isolated perimeter and services retained on the room side. Author's original schematic. Local stabilisation points must be designed as bounded mechanical bridges.

Worked example 16.7. Ideal resonance of a masonry-plus-lining system

A 13 kg/m² gypsum lining is separated from a masonry wall by a 100 mm air cavity. Treating the masonry as effectively rigid for a first screening, the resonance is approximated by

$$f_r = \frac{1}{2\pi}\sqrt{\frac{\rho_0 c^2}{d\,m'}}.$$

Using $\rho_0 = 1.20$ kg/m³, $c = 343$ m/s, $d = 0.100$ m and $m' = 13$ kg/m²,

$$f_r = \frac{1}{2\pi}\sqrt{\frac{1.20(343)^2}{0.100(13)}} = 52.4 \text{ Hz}.$$

The units reduce to inverse seconds. The estimate omits lining stiffness, finite dimensions, absorber, frame compliance and the non-rigid response of the masonry. It identifies a low-frequency region requiring frequency-resolved review.

16.8 Lining supports, anchors and bounded bridges

An independent frame must remain stable under self-weight, occupant impact, seismic demand and attached equipment; truly free-standing walls may be feasible at modest height, but taller systems often require lateral restraint; the design problem is not to pretend that no bridge exists. It is to minimise, locate, quantify and document the necessary bridges while maintaining structural safety.

Anchor selection depends upon substrate. Hollow CMU face shells, grouted cells, clay tile, brick and historic stone accept different anchors and failure modes. Product capacity in sound concrete cannot be transferred to weak tile or weathered mortar; anchor testing may be needed where the substrate is uncertain, but a pull test is itself an intervention; ASTM E488 provides test procedures for anchors in concrete and masonry elements, while project-specific structural design remains necessary.[72]

A restraint bracket can be isolated with an elastomeric pad or resilient washer, but the pad changes stiffness, creep, fire behaviour and load distribution; a soft material compressed to near-solid condition ceases to isolate; the support spacing should follow a dynamic as well as static model. A few stiff bridges can dominate high-isolation systems even though their total area is minute.

Worked example 16.8. Line stiffness introduced by stabilisation brackets

Six stabilisation brackets each have dynamic translational stiffness k_b = 2.0 × 10^6 N/m and serve a 12 m long lining. Total parallel stiffness is

72 MB-0272. ASTM International, ASTM E336-25a.

$K = 6k_b = 1.2 \times 10^7$ N/m.

Equivalent line stiffness is

$k_{ell} = \frac{K}{12} = 1.0 \times 10^6$ N/m².

If the effective moving lining mass over the supported length is 1,200 kg, the simplified support resonance is

$f_n = \frac{1}{2\pi} \sqrt{\frac{K}{m}} = 15.9$ Hz.

This lumped model cannot predict spatial wave transmission, but it makes the bridge stiffness explicit and allows alternatives to be compared.

16.9 Movement-compatible linings at columns and intersections

A lining often crosses columns, piers or intersecting walls; if the frame and boards are continuous across a structural movement joint, the finish can bridge the joint and crack; if the lining terminates, the termination joint must maintain both air closure and visual quality. Corners create three-dimensional paths where a wall, ceiling and floor meet. Standard two-dimensional sections are insufficient.

At a column, the design can wrap the lining around the column, stop at each side, or build a separate enclosure; each choice changes cavity continuity and flanking; a wrap may connect rooms around the column if the cavity is shared. A stop detail may create narrow sealant joints; a separate enclosure can add mass but requires service coordination. The room model should trace the cavity and framing continuously in plan and section.

Intersecting partitions should not automatically tie both leaves together; where a high-isolation wall meets an ordinary corridor partition, the lighter partition can form a flanking fin; the preferred sequence may interrupt the corridor partition at the secure wall, or continue the secure wall through and seal each adjoining construction independently. Fire and structural requirements control the permissible arrangement.

Worked example 16.9. Flanking fin screening

An ordinary gypsum partition intersects a masonry secure wall and extends 5 m into an adjacent office; a measured vibration transfer model estimates that the fin contributes an equivalent receiving-room sound power 8 dB below the direct masonry path. Combining two independent contributions, with direct path level normalised to 0 dB and fin at -8 dB,

$L_{tot} = 10 \log_{10}(10^{(0/10)}+10^{(-8/10)}) = 0.64$ dB.

The total level rises by 0.64 dB; if remediation improves the direct wall by 10 dB while the fin remains unchanged, the fin becomes dominant; the example shows why path ranking changes after upgrades.

16.10 Penetrations and cell-network communication

A penetration through masonry can connect the room to a cell, chase, riser or cavity rather than directly to the adjoining room; the resulting path may turn, branch and re-radiate at a distant opening; simple area-weighted aperture calculations then understate the importance of network topology. Inspection should determine whether the penetrated cell is grouted, isolated by mortar webs, connected to bond beams or open to a plenum.

Sleeves can be useful because they define the opening and permit compatible sealing, but rigid sleeves also bridge; a pipe may transmit structure-borne vibration through the sleeve; firestop systems can include mineral wool, intumescent material, sealant and collars. Acoustic modifications must remain within the listed system; the register should record sleeve material, annular gap, firestop system, acoustic treatment, support location and post-installation inspection.

Electrical and data conduits should be grouped deliberately rather than scattered across the wall; spare conduits require plugs at both ends; pull strings and bushings do not close sound; junction boxes should not be back-to-back. Surface pathways can reduce penetrations but may create security, impact and maintenance concerns. Every later cable installation should trigger boundary inspection.

Worked example 16.10. Annular opening around a conduit

A 32 mm outside-diameter conduit passes through a 50 mm diameter core hole. Annular geometric area is

$S_a = \frac{\pi}{4}(0.050^2 - 0.032^2) = 1.16 \times 10^{-3}\ m^2$.

This is 11.6 cm^2, far larger than the eye may perceive around the circumference; if left open in a high-performing wall, it can control high-frequency transmission; the actual sealed path depends upon depth, packing, sealant and firestop configuration.

16.11 Crack taxonomy and causal diagnosis

Cracks should be described by location, orientation, width, depth evidence, displacement, moisture, activity and relation to structural features; vertical cracks at control joints, diagonal cracks from opening corners, horizontal cracks beneath lintels, stair-step cracks through mortar and map cracking in coatings have different likely causes. Acoustic significance depends upon continuity and coupling, not visual severity.

The investigation separates three propositions. First, a crack exists. Second, the crack is an acoustic path; third, the crack is caused by a particular mechanism. These propositions require different evidence. Close photography and gauges establish geometry. Temporary reversible sealing and controlled acoustic tests address path contribution; structural analysis, movement monitoring and construction records address causation; a report should not jump from a visible crack to a conclusion that it explains the room failure.

Crack monitoring can use tell-tales, displacement gauges, optical measurement or periodic calibrated photography; the measurement interval should reflect expected movement. A static reading during one season cannot prove inactivity; moisture staining and salt deposition may reveal hidden water paths; ultrasonic pulse velocity, impact echo or other methods may assist in massive materials, but their interpretation is bounded and they are not direct acoustic-leak detectors.[73]

73 MB-0876. International Organization for Standardization, ISO 16283-1:2025.

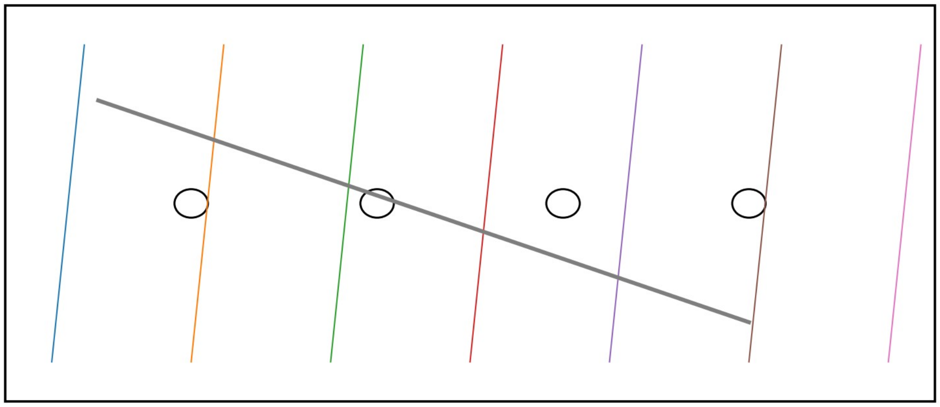

Figure 16-4. Crack-diagnostic sequence from mapping and classification through reversible sealing, spectral retest and causal analysis. Author's original diagram. A visible crack, an active acoustic path and a structural cause are separate propositions.

Worked example 16.11. Crack activity rate

A gauge records joint width increasing from 0.42 mm to 0.68 mm over 180 days. Mean rate is

$r = (0.68-0.42)/(180) = 1.44 \times 10^{-3}$ mm/day.

Annualised linearly, this is 0.53 mm/year, but seasonal cycles make linear extrapolation unsafe; the result supports the proposition that movement occurred during the observation interval; it does not establish the final range or cause.

16.12 Reversible sealing as a discriminating test

Temporary sealing is one of the most powerful field diagnostics when performed carefully; a removable putty, tape membrane, inflatable bladder or other reversible system is applied over a suspected path without altering unrelated construction; the source and receiving conditions are repeated. A frequency-specific improvement supports the hypothesis that the treated path contributes; no change suggests either that the path is insignificant, the treatment is ineffective, or another path dominates.

The method needs controls. The temporary material can add mass, damping or stiffness beyond simple air closure. It may bridge adjacent surfaces. Temperature and background can change between tests. Multiple paths may interact. The test plan records treatment area, material, photographs, timing, source stability and uncertainty; the result is not converted casually into a permanent design value.

Where evidence may be disputed, treatment should not erase the original state before documentation; samples of failed sealant, mortar or debris can be preserved; the competent authority should approve interventions in accredited or sensitive spaces; the acoustic team should coordinate with fire, structural and conservation personnel before applying materials to rated or historic surfaces.

Worked example 16.12. Before-and-after diagnostic significance

A receiving-band level is 38.4 dB before temporary sealing and 31.1 dB after sealing. Repeatability standard uncertainty for the difference is 0.9 dB. Observed improvement is

$$\Delta L = 38.4 - 31.1 = 7.3 \text{ dB}.$$

A simple standardised effect ratio is

$$z = \frac{7.3}{0.9} = 8.1.$$

The change greatly exceeds the repeatability uncertainty, supporting a real path contribution. It does not prove that the same gain will persist with a permanent sealant or under future movement.

16.13 Flanking as a network of junctions and radiating elements

Flanking transmission occurs when sound energy reaches the receiving room by routes other than the nominal separating element. In masonry construction, common routes include continuous slabs, façades, columns, beams, intersecting walls, roofs, ceilings, pipework and shared cavities; the path may begin as airborne excitation, travel as structural vibration, cross a junction and radiate from another surface. Treating flanking as one correction factor conceals the mechanisms needed for remediation.[74][75][76]

A network representation is useful. Nodes represent plates, walls, rooms or junctions; edges represent transfer functions; the dominant route depends upon frequency and configuration; a concrete slab may dominate low-frequency transmission, while an unsealed frame dominates high frequencies; improvement to one edge can expose another. The model should therefore retain several plausible paths rather than calibrating one aggregate number and calling the mechanism solved.

ISO 10848 provides a framework for laboratory and field measurement of flanking transmission, while ISO 12354-1 provides an estimation framework using element and junction data; these methods are powerful when the construction can be represented by their assumptions and when input data are appropriate. Historic mixed masonry, irregular joints and uncertain restraint may require measured transfer functions and bounded engineering judgement.

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74 MB-0284. ASTM International, ASTM E413-22.
75 MB-0904. International Organization for Standardization, ISO 717-1:2026.
76 MB-0188. ASTM International, ASTM C919-24.

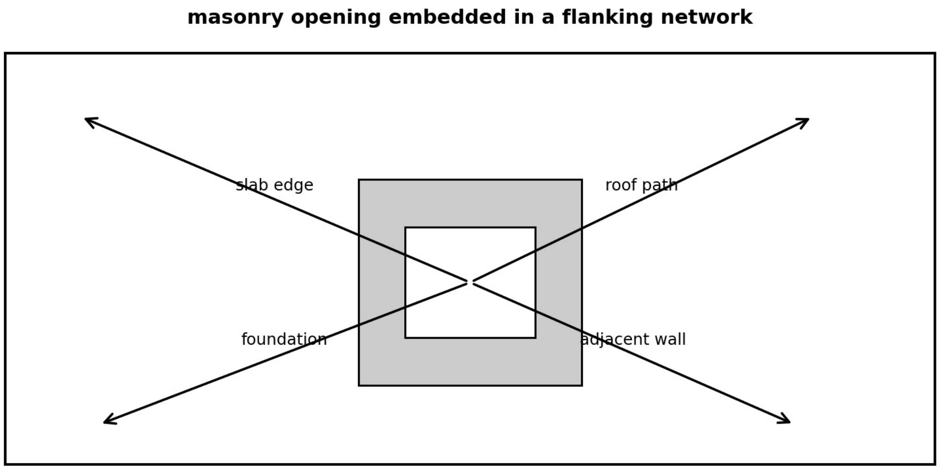

Figure 16-3. Direct and flanking network for a masonry separating wall. Author's original diagram. Slab, façade, intersecting partition, ceiling plenum and services can each become dominant after the direct wall is improved.

Worked example 16.13. Combining three path contributions

At 250 Hz, calculated receiving levels from direct wall, slab flank and façade flank are 29 dB, 33 dB and 27 dB. Total is

$L = 10 \log_{10}(10^{2.9}+10^{3.3}+10^{2.7}) = 35.2$ dB.

The 33 dB slab path is largest but does not act alone. Eliminating the 29 dB direct path entirely would reduce total only to

$10 \log_{10}(10^{3.3}+10^{2.7}) = 34.0$ dB.

A costly wall upgrade yields only 1.2 dB because the slab governs. This is the essence of weakest-path design.

16.14 Field mapping of junctions and radiating surfaces

Field diagnosis begins with a repeatable source and spatially resolved observations; microphone arrays, intensity probes, accelerometers, contact transducers and scanning methods can each answer different questions; a microphone near a surface measures the local sound field, not necessarily surface radiation. An accelerometer measures motion at a point and direction, not airborne power; intensity can help localise net energy flow but is sensitive to field conditions and probe limitations. The report should state the measurand and avoid converting every high reading into a leak.

Junction mapping should use coordinates tied to drawings; measurements at a slab edge, wall centre, column and opening corner are compared under the same source state; phase and coherence can help connect structural responses to the source. A broadband difference may suggest leakage; narrow resonances may suggest panels or cavities; low-frequency spatially coherent motion may suggest structural flanking; diagnostic confidence increases when controlled interventions produce predicted changes.

The source should represent the threat without damaging the building; loudspeaker positions, orientation, level and spectrum are documented; maximum vocal effort can be assessed separately from high-level test noise; a high-power test that drives nonlinear rattles may be useful diagnostically but should not be confused with normal operating performance.

Worked example 16.14. Vibration attenuation along a slab edge

Measured RMS velocity is 0.42 mm/s at 1 m from the wall junction and 0.075 mm/s at 6 m. Level change is

$$\Delta L_v = 20 \log_{10}\left(\frac{0.075}{0.42}\right) = -15.0 \text{ dB}.$$

Over 5 m additional distance, mean attenuation is 3.0 dB/m for this band and configuration. The result should not be extrapolated beyond the measured interval or to other frequencies without evidence.

16.15 Field sound-insulation evidence and path-limited conclusions

ASTM E336-25a and ISO 16283-1:2025 measure room-to-room airborne sound attenuation under field conditions.[77,78] Their results include the configured direct and flanking paths within the stated setup. They do not identify the contribution of one masonry element automatically. A single-number ASTC or weighted field rating is derived only after the band data are reviewed, corrected and reported under the applicable method.[79,80]

For secure-room work, the report retains source levels, receiving levels, background, reverberation or normalisation data, room volumes, source positions, microphone positions, door states, services, masking state and operating conditions; bands limited by background or dynamic range are reported as bounds. A high single number based partly on censored bands is not treated as exact.

The receiving locations must reflect accessible listener positions; a corridor corner, return-air grille, ceiling access hatch or adjoining cupboard may be more consequential than the room-average position; standardised room measurements and threat-oriented local measurements answer different questions and should be labelled accordingly.

Worked example 16.15. Background correction threshold

A receiving level with source operating is 24.0 dB, and background is 22.0 dB. The source-related level is

$$L_s = 10 \log_{10}(10^{2.4}-10^{2.2}) = 19.7 \text{ dB}.$$

77 MB-0794. International Code Council, 2024 International Building Code, subject to local adoption and amendment.
78 MB-0415. Carl Hopkins, Sound Insulation.
79 MB-0762. Frank Fahy and Paolo Gardonio, Sound and Structural Vibration, 2nd ed.
80 MB-0022. American Concrete Institute, ACI CODE-318-25.

The correction is 4.3 dB, indicating a background-sensitive result; small background error can materially change the corrected level; the band should be treated cautiously under the governing test method rather than reported with false precision.

16.16 Remediation hierarchy

Remediation begins with the demonstrated mechanism. Air leakage is addressed by restoring continuous, movement-compatible closure; structural flanking is addressed at the source, junction, receiving radiator or layout; a porous wall may benefit from parging or plaster; a weak direct path may justify an independent lining. A door-frame perimeter may require reconstruction rather than another surface bead. A shared plenum may require boundary extension and service treatment.

The intervention should be proportionate and reversible where uncertainty remains. Temporary tests precede destructive work. Fire, structural, moisture, accessibility and heritage constraints are reviewed; the repair record identifies removed materials, substrate condition, product batches, cure, photographs and retest conditions; a repair that improves one test day but cannot survive movement or maintenance is not a durable solution.

Independent linings are not universal remedies. They consume space, can conceal defects, introduce resonances and require new penetrations; grout injection can damage historic or loadbearing masonry and redirect moisture; rigid epoxy crack injection can bridge movement and transmit vibration; sealants can fail through poor geometry or incompatible substrate. The chapter’s governing rule is that remediation changes the verified path while preserving the other obligations of the assembly.

Worked example 16.16. Selecting among three remedial paths

A receiving level is composed of 34 dB direct wall, 31 dB slab flank and 28 dB door perimeter. Total is 36.2 dB. Three remedies are considered:

1. independent lining reduces direct wall by 12 dB;
2. slab treatment reduces slab flank by 8 dB;
3. door repair reduces door path by 10 dB.

Recomputed totals are approximately 32.9 dB, 35.0 dB and 35.5 dB respectively; the lining gives the largest single improvement, but the residual 32.9 dB is then governed by the slab; a combined lining and slab intervention yields about 28.9 dB. The exercise shows why sequential path calculations are more useful than selecting the repair associated with the visually largest defect.

16.17 Construction-surveillance hold points

Masonry joints and linings become inaccessible in stages; the surveillance plan should include hold points before grout, before parging, before frame closure, before firestop concealment, before lining board, before ceiling closure and before equipment mounting; each hold point has an acceptance checklist and photographic coordinates. A general instruction to “photograph construction” produces attractive but often untraceable images.

The record should show joint dimensions, backing, primer where required, tooling, sealant lot, date and installer; for independent linings, it should show cavity depth, clearances, absorber, brackets, isolators, frame spacing, service routes and perimeter isolation; for frames, it should show anchors, grout or backing and primary air seals. Nonconformances remain open until corrected and reinspected.

Sampling plans should account for clustered workmanship; ten adjacent joints installed by one crew during one hour are not independent evidence for the entire project; stratification by location, installer, date, detail and risk improves detection; critical boundaries may justify complete inspection rather than sampling.

Worked example 16.17. Stratified inspection allocation

A project has 240 ordinary penetrations, 40 high-risk penetrations and 12 movement joints; the plan inspects 20 per cent of ordinary penetrations, 100 per cent of high-risk penetrations and 100 per cent of movement joints. Required inspections are

$0.20(240)+40+12 = 100.$

Although only 34 per cent of all items are inspected, every high-consequence item is covered. The calculation does not prove workmanship quality; it documents a risk-based sampling rule.

16.18 Forensic case study. The silent wall and the speaking perimeter

A legal conference suite occupies a renovated concrete-frame building; the separating wall is fully grouted CMU with plaster on one face and an independent lining on the other; laboratory evidence for a similar wall suggests high direct isolation, yet names and numbers are occasionally recognisable in the adjacent service corridor after hours. Initial room-average testing shows a broad field deficit above 500 Hz.

Close mapping identifies elevated sound at the wall head and one frame jamb; drawings show a deflection head, but concealed inspection reveals gypsum board fixed through the slotted track into the structure at several locations; the frame perimeter has a surface sealant bead over an unfilled irregular cavity. Temporary membrane sealing of the frame improves the upper bands by 6 to 9 dB; removing two bridging screws, under controlled conditions, reduces vibration coherence at the head and improves mid-band attenuation.

The repair reconstructs the frame perimeter with backing and compatible sealant, corrects the head fasteners without compromising the fire system and adds an accessible inspection detail. Retest documents the configured improvement. The conclusion is not that CMU failed; the direct wall was not the limiting path; workmanship at two interfaces converted a strong wall into a weak room.

The case illustrates evidentiary discipline. Catalogue data supported only preliminary selection. Photographs and openings established as-built defects. Reversible interventions discriminated paths. Field testing established the room result. The client's use decision remained separate from the acoustical engineer's measurements.

16.19 Lifecycle control and change management

Masonry boundaries change after commissioning. New data cables, display anchors, card-reader wiring, plumbing alterations, ceiling work and door replacement can reopen paths. Joint sealants age and move. Cracks develop. Linings are breached for inspection. A secure room therefore requires a configuration baseline and a change process.

The baseline includes drawings, penetration register, door schedule, photographs, test data and unresolved limitations; proposed work is reviewed before access; contractors receive detail-specific instructions and are supervised according to risk; after work, closures are inspected and, where the change is material, tested. Emergency repairs are documented retrospectively without pretending they followed the normal process.

Periodic inspection frequency follows consequence, material behaviour and access history; movement joints and doors may require more frequent review than uniform wall fields; a new crack or changed seal is compared with prior photographs and measurements; trends matter more than isolated impressions. The lifecycle record supports maintenance and prevents the room from becoming an undocumented accumulation of small alterations.

Worked example 16.18. Risk-prioritised inspection interval

Assign consequence score C from 1 to 5, likelihood score P from 1 to 5 and detectability score D from 1 to 5, where high detectability difficulty receives a high value; a concealed wall-head joint has $C = 5$, $P = 3$, $D = 4$, giving risk priority

$$RPN = CPD = 60.$$

An exposed skirting seal has $C = 3$, $P = 3$, $D = 1$, giving 9; the numerical scale is an administrative aid, not a probability model; it supports more frequent or more intrusive inspection of the concealed head.

16.20 Sealant viscoelasticity, temperature and ageing

Joint sealants are viscoelastic. Their apparent stiffness, damping and recovery depend on temperature, loading rate, strain history and ageing; a bead that follows slow seasonal movement can behave much more stiffly under audio-frequency vibration; conversely, a highly damped seal can dissipate local motion while still transmitting pressure through an adjacent gap. Acoustic models should therefore avoid treating the manufacturer's movement class as a dynamic modulus.

Cold temperatures can raise modulus and closing stress at masonry interfaces; heat can soften some polymers and accelerate creep; ultraviolet exposure, moisture, cleaning chemicals, migration from adjacent materials and compression set alter service behaviour; interior secure-room joints are protected from weather but not from temperature gradients, dust, paint or maintenance damage. A joint behind a radiator, near an exterior wall or within a plant room may experience conditions unlike the occupied room average.

The lifecycle baseline should include sealant chemistry, batch, installation date and compatible replacement product; hardness or adhesion tests can assist investigations, but sampling destroys part of the joint; the decision should follow the consequence of failure and the availability of non-destructive indicators.

Worked example 16.19. Temperature-dependent stiffness screen

A sealant bead has measured dynamic stiffness 0.8 MN/m at 23°C and 1.3 MN/m at 5°C for a representative fixture; if the bead acts in parallel with a resilient backing of 0.4 MN/m, total stiffness changes from 1.2 to 1.7 MN/m. A connected mass of 120 kg has ideal natural frequencies

$$f_{23} = \frac{1}{2\pi} \sqrt{\frac{1.2 \times 10^6}{120}} = 15.9 \text{ Hz}$$

and

f_5 = 18.9 Hz.

The shift is about 19 per cent. The fixture result is not a universal material property, but it demonstrates why low-temperature commissioning can differ from warm laboratory conditions.

16.21 Firestop and acoustic closure at the same opening

Firestop systems and acoustic seals are related but not interchangeable. A listed firestop is tested with specified substrates, penetrants, annular gaps, packing depths and sealant thicknesses. An acoustic seal may be selected for flexibility and air closure without fire evidence. The correct detail either uses a system that satisfies both functions or preserves the listed firestop while adding a separate acoustic plane that does not invalidate it.[81][82]

Multiple trades create risk. The firestop installer may pack mineral wool deeply and apply an intumescent layer at one face; the acoustical contractor may later add a sealant that prevents inspection or chemically conflicts; a cable installer may remove material and replace it with ordinary foam. The penetration register should state the firestop system number, acoustic treatment, photographs and authorised reopening procedure.

Fire-rated movement joints are especially demanding because they must accommodate displacement while maintaining temperature and flame criteria; rigid mortar packing can destroy movement capacity; soft safing without a continuous smoke or acoustic seal can leak; the assembly should

81 MB-0037. American Concrete Institute, ACI SPEC-301-20.
82 MB-0022. American Concrete Institute, ACI CODE-318-25.

be reviewed by the fire-protection professional and acoustical engineer together.

Worked example 16.20. Annular firestop volume

A 100 mm sleeve contains a 40 mm cable bundle through a 250 mm wall. Annular area is

$S = (\pi)/(4)(0.100^2-0.040^2) = 0.00660\ m^2$.

If mineral-wool packing is 150 mm deep, packed volume is 0.000990 m^3, or 0.99 litres; the remaining 100 mm wall depth cannot be assumed acoustically closed without the complete listed and designed system.

16.22 Moisture, efflorescence and substrate preparation

Masonry surfaces can carry dust, laitance, salts and moisture that impair sealant adhesion; efflorescence is evidence of dissolved salts reaching the surface, not merely a cosmetic deposit; cleaning must remove contaminants without damaging the substrate or driving water deeper. Primer selection follows product testing and manufacturer guidance.

A damp joint can support adhesion initially and fail during drying; alkali or plasticiser migration can stain stone and soften some materials; paint applied over a flexible sealant may crack and mislead inspection; the specification should require adhesion testing on representative project substrates where risk is high.

Moisture also changes joint width through material movement. A repair performed at an extreme condition can be over-compressed or over-extended later. Installation records should include surface temperature and moisture condition.

Worked example 16.21. Joint-width seasonal range

A 20 mm joint is measured at 17.5 mm during a cool dry condition and predicted to reach 23.0 mm during warm wet service. Relative extension from installation width is

(23.0-17.5)/(17.5) = 31.4%.

Compression relative to the maximum width is 23.9 per cent when returning to 17.5 mm. The sealant must accommodate both directions and installation tolerance.

16.23 Cover plates, trims and concealed bridges

Joint covers protect seals and improve appearance, but they can bridge the very separation that the joint preserves; a metal plate fixed to both sides transmits force and restricts movement; a plate fixed to one side and allowed to slide over the other can preserve displacement, but fasteners, friction and debris affect behaviour. Raised cover profiles can also create impact or accessibility issues.

Decorative timber, skirtings and stone returns are equally capable of bridging; adhesive can form a continuous stiff bond; paint and plaster can span joints; the inspection sequence should verify the concealed functional joint before covers are installed and record the cover attachment.

Where covers rattle, the vibration may be audible or may modulate transmitted speech. Resilient bedding can suppress rattle, but it should not block drainage or movement.

Worked example 16.22. Cover-plate bridge stiffness

A stainless-steel cover plate is inadvertently screwed to both sides of a joint; its axial stiffness between screws is approximated by k = EA/L; with E = 190 GPa, effective area 30 mm² and span 80 mm,

$k = (190 \times 10^9(30 \times 10^{-6}))/(0.080) = 7.13 \times 10^7$ N/m.

This single bridge is much stiffer than many intended elastomeric joints. Slip and bending reduce the exact value, but the order of magnitude explains why one cover can dominate.

16.24 Stair, lift and shaft interfaces

Masonry secure rooms often adjoin stairs, lifts or service shafts because those spaces occupy building cores; cores are structurally stiff and vertically continuous; lift rails, machinery, doors and pressure changes create vibration and airborne paths; stair flights and landings can connect into the same walls and slabs.

A shaft wall may be massive yet contain openings, grilles and access doors; the listener access model must include the shaft and its maintenance spaces; a room wall tied rigidly to a core can transmit low-frequency energy to remote floors. Local surface sealing does not address this path.

Measurements should separate lift-operation noise from speech-correlated response. Time records and coherence are useful. Remediation may require source isolation, secondary linings or room relocation rather than alteration of the structural core.

Worked example 16.23. Remote-level attenuation

A controlled source produces wall velocity 0.20 mm/s at the room level and 0.025 mm/s two floors above on the same core. Velocity attenuation is

20 log_10(0.025/0.20) = -18.1 dB.

The remote response remains measurable. Whether it radiates intelligible sound depends on local surfaces and background.

16.25 Statistical treatment of clustered defects

Construction defects are often clustered by crew, shift, material lot or detail; an independent random-defect assumption can therefore overstate inspection confidence; a beta-binomial or other over-dispersed model may be more appropriate, but even a simple stratified plan is better than one pooled percentage.

The register should capture installer, date, location and detail so that findings can be grouped; one failed movement joint may justify expanded inspection of all joints installed under the same conditions; conversely, a local impact-damaged seal should not be used to condemn the entire building without evidence.

Worked example 16.24. Cluster-sensitive expansion rule

A project inspects 20 penetrations in each of five zones; zone 3 contains four failures while all others contain none; overall failure rate is 4 per cent, but the zone-specific rate is 20 per cent; treating all 100 as one population conceals the cluster. A defensible response inspects the remaining Zone 3 work and reviews its crew and material records before changing the global estimate.

16.26 Three-dimensional corner testing

Room corners combine wall, floor and ceiling paths; a two-dimensional joint section can appear correct while a small volume at the trihedral corner remains unsealed; fire safing, movement tracks, skirtings, ceiling hangers and services converge; these points deserve explicit three-dimensional details and targeted inspection.

Acoustic scanning near a corner is affected by local reflections; intensity or near-field level peaks require comparison with control corners and temporary treatment; a corner patch can change room absorption as well as leakage, so before-and-after interpretation remains cautious.

Worked example 16.25. Trihedral void volume

A corner void approximates a triangular prism with legs 20 mm and 25 mm and length 150 mm. Volume is

V = (12(0.020)(0.025)(0.150) = 3.75 × 10^)/(-5) m^3,

or 37.5 cm^3. Its volume is tiny, but if it connects room and plenum its acoustic importance follows opening geometry rather than volume.

16.27 Joint sealant mechanics over the service life

A sealant joint is a deformable mechanical element, an air-control detail and often part of a fire or weather-resistance system. Its acoustic adequacy cannot be judged from a neat surface bead; the relevant geometry includes joint width, sealant depth, backing material, adhesion surfaces, primer, substrate preparation and the space available for movement; the relevant material properties include modulus, elongation capacity, stress relaxation, compression set, tear resistance, ageing and compatibility with adjacent coatings. [83]

The familiar hourglass section is not cosmetic; a backer rod controls depth and discourages three-sided adhesion, allowing the sealant to deform

83 MB-0037. American Concrete Institute, ACI SPEC-301-20.

across the intended width; when sealant bonds to the back of the joint, movement is constrained and strain concentrates near the edges. A thick, deep bead may be stiffer than intended and can transfer more vibration; a very thin bead may tear or lose adhesion. The acoustic engineer should therefore coordinate the joint design with the sealant manufacturer's movement data and the structural movement calculation rather than writing "acoustical sealant" as an undefined product description.

Temperature changes the apparent stiffness of many sealants; a material that is compliant in a warm laboratory can become markedly stiffer at low temperature; ageing, ultraviolet exposure, plasticiser migration and repeated cycling can alter the response; interior secure-room joints are protected from weather but not from building movement, cleaning chemicals, humidity or heat from services. A perimeter joint behind a fixed cabinet may receive no routine inspection. Lifecycle design should identify which joints are concealed and how their condition can be inferred or accessed.

Movement capacity is not the same as durable cyclic performance; a product may accommodate a stated extension under a qualification test, yet long-term behaviour depends upon substrate, cure, bead geometry and cycling history; for an acoustic boundary, partial debonding can create a narrow slot whose area is small but whose transmission is large. The maintenance threshold should be based on adhesion and closure, not merely visible cracking.

A useful inspection sequence combines visual examination, gentle probing, local pressure or smoke testing and frequency-resolved acoustic scanning; destructive adhesion testing may be appropriate for representative mock-ups or sacrificial locations, but it should not be performed casually on a firestop or historic substrate. Results are mapped by joint segment. A conclusion that "the sealant passed" is too broad unless the sampled extent, method and acceptance criterion are stated.

Integrated worked example 16.26. Movement demand and sealant strain reserve

A 6.0 m masonry run is connected to a steel frame whose seasonal differential movement is estimated at plus or minus 6 mm; construction tolerance may reduce the nominal 20 mm joint to 16 mm at one location. If all movement is assigned to that narrowest section, one-direction strain is 6/16 = 37.5 per cent; the full movement range is 12/16 = 75 per cent.

If the selected sealant system has a qualified movement class of plus or minus 50 per cent under the applicable product and installation conditions, the arithmetic reserve appears adequate for one-direction movement but modest for the complete cycle when tolerance, substrate irregularity and ageing are considered. The dimensional ratio is unitless. The calculation does not prove durability because movement distribution, adhesion, temperature and cure remain uncertain; it does show why the narrowest as-built joint, rather than the nominal drawing dimension, controls the strain screen.

16.28 Head-of-wall systems, deck flutes and differential movement

The upper masonry interface is among the most consequential transitions in a secure room; it must accommodate vertical movement of the structure, lateral restraint of the partition, fire and smoke requirements, and closure of every flute, corrugation and irregularity. A rigid mortar fill can provide short-term mass but crack when the deck deflects; a soft mineral-fibre packing can accommodate movement but requires a continuous air seal; a metal deflection track can stabilise the wall while also creating a vibration path if fasteners or board layers bridge the intended slip plane.

Deck geometry should be surveyed, not assumed; rib depth, spacing, concrete fill, spray-applied fireproofing and service congestion can differ from the reflected ceiling plan; closure pieces must fit the actual profile; oversized gaps behind a firestop can remain acoustically open even when the visible face is sealed. Acoustic closure should be coordinated with the listed fire-resistance system where one applies. The acoustic designer cannot alter packing density, sealant depth or backing arrangement in a listed joint without review.

The deflection model should include both sustained and transient movement; long-term creep and shrinkage can lower a slab or beam; live load can produce shorter cycles; wind and thermal movement can act laterally; seismic drift may impose a different demand; the joint must remain closed throughout the authorised operating envelope. Where the extreme event exceeds ordinary acoustic-service limits, the post-event procedure should require inspection and retest before sensitive use resumes.

Fluted decks create parallel paths. Even if the wall head is sealed directly above the room, the flute can communicate beyond the wall and re-radiate through a ceiling or service opening; a flute closure at one line may not block longitudinal transmission. The system model should follow the deck profile to the nearest discontinuity or receiver; in some buildings, a concrete fill or cellular deck provides a more complex path that requires field investigation.

Integrated worked example 16.27. Longitudinal flute path

A metal deck flute has an effective open cross-section of 2,400 mm2 and continues 4.5 m beyond the partition before opening into a receiving plenum; a local head-of-wall seal closes the visible gap at the partition but does not interrupt the flute. Treating the flute as a simple air duct for screening, its hydraulic diameter and attenuation depend upon shape, lining and leakage; an unlined metal path of this length can preserve substantial mid-frequency energy.

A temporary absorbent plug placed 0.5 m into the receiving side reduces the measured 1 kHz level by 13 dB, while sealing the visible wall-head bead changes the level by only 1 dB; the intervention supports the flute-path hypothesis. The result does not quantify the final required closure or prove performance at other bands; a permanent remedy must satisfy structural and fire requirements and should be tested after installation.

16.29 Lining attachment topology and bridge sensitivity

An independent lining improves sound isolation only to the extent that it remains mechanically independent; stabilisation brackets, service supports, skirtings, cornices, cabinets and ceiling angles can create bridges; their effect depends upon stiffness, spacing, contact area and the mobility of the host wall. Counting brackets without modelling their dynamic role is insufficient.

A bracket that is flexible in one direction can be stiff in another; slotted holes may accommodate vertical movement while transmitting lateral vibration; a resilient pad can reduce high-frequency contact but become effectively rigid under excessive preload. Fastener torque, washer geometry and installation sequence matter; the as-built support state should therefore be documented with the same care as the visible lining layers.

Bridge sensitivity can be assessed by controlled modelling and field perturbation; a simplified spring model estimates whether bracket stiffness is negligible relative to the air-cavity and lining system; a finite-element model may be warranted where brackets are dense or the lining carries heavy equipment. In the field, temporary release or isolation of a representative bracket, where structurally safe, can show whether a local response changes; the intervention and restoration must be documented.

Corners and intersections are frequent short circuits; an independent lining on one wall may be screwed into a perpendicular partition; a continuous skirting can tie the lining to the floor; a suspended ceiling perimeter angle can connect the lining to a slab-edge path. The design detail should show the isolation sequence at every intersection rather than relying on a general note.

Integrated worked example 16.28. Stiffness of a bracket array

A lining panel is stabilised by twelve brackets; each bracket has measured lateral stiffness 0.35 MN/m under the installed preload; if the brackets act approximately in parallel, total bracket stiffness is 4.2 MN/m. The combined air-cavity and lining support stiffness over the same wall bay is estimated at 0.60 MN/m; the brackets are therefore seven times stiffer than the intended resilient path and cannot be treated as negligible.

Replacing them with slotted, elastomer-isolated brackets of measured stiffness 0.025 MN/m each reduces array stiffness to 0.30 MN/m; the bracket path is now one-half of the intended support stiffness rather than seven times larger. This remains a screening model. Distribution, frequency dependence and substrate mobility require further analysis, but the calculation demonstrates why “a few stabilising brackets” can govern a nominally independent lining.

16.30 Firestop and acoustic closure by penetration family

A penetration system must be classified before it is detailed. Metallic pipes, plastic pipes, cable bundles, cable trays, busways, ducts and mixed-use sleeves behave differently under fire, movement and acoustic excitation. A tested firestop system is tied to penetrant type, size, annular space, wall construction, packing and sealant. Acoustic requirements must be added without invalidating that configuration. [84]

Metallic pipes provide a structure-borne path as well as an annular air path; closing the annulus does not isolate the pipe; plastic pipes may soften or disappear during fire, requiring intumescent components; cable bundles change over time, and repeated additions can disturb packing. Ducts need both perimeter closure and internal cross-talk control. A single generic detail labelled “acoustic firestop” cannot address these mechanisms.

The design should identify the primary air seal and the listed fire-resistance system; in some systems the firestop sealant provides both functions; in others a separate acoustic seal is placed outside the listed system, with compatible movement and access. The drawing must avoid hidden cavities between the two layers; installers should know which layer may be disturbed during cable changes and which requires authorised repair.

84 MB-0022. American Concrete Institute, ACI CODE-318-25.

Inspection evidence differs by penetrant. For a pipe, record sleeve size, annular space, packing depth, sealant depth and support spacing; for a cable bundle, record fill ratio, cable types and future capacity; for a duct, record damper, breakaway connection, liner, silencer and perimeter system. Photographs should include a scale and unique penetration identifier; the penetration register is then updated whenever the assembly changes.

Integrated worked example 16.29. Cable-bundle change and annular reopening

A 100 mm sleeve initially contains a 55 mm equivalent-diameter cable bundle. The annular area is

A_1 = pi/4 (0.1002 - 0.0552) = 0.00547 m2.

After additional cabling, equivalent bundle diameter becomes 78 mm and annular area falls to 0.00307 m2; although the open area is smaller, the original packing and sealant were cut and not restored; a crescent-shaped direct slot of only 120 mm2 remains through the seal. The firestop label may still be visible, but both acoustic and fire evidence are incomplete.

The example shows that fill ratio alone does not establish closure. The updated condition requires inspection against the listed system, restoration by qualified personnel and, for a high-consequence boundary, targeted leakage testing.

16.31 Crack monitoring, environmental cycles and causal inference

A crack is an observation, not a cause; masonry can crack from shrinkage, thermal movement, differential settlement, corrosion, load concentration, restraint, moisture change or incompatible repair; the same visible width can represent a dormant surface crack or an active through-wall path. Acoustic significance depends upon continuity, depth, tortuosity and connection to cavities.

Monitoring should combine geometry and environment. Crack gauges or optical targets record width and displacement; temperature and relative humidity are logged; structural events, nearby construction and water intrusion are noted; acoustic tests are repeated only when the measurement state can be reproduced. A correlation between crack width and receiving level is useful, but causal inference requires a plausible mechanism and exclusion of concurrent changes such as door adjustment or HVAC operation.

Temporary sealing is a powerful discriminating test; a reversible, non-damaging seal is applied over a defined crack segment, and the receiving spectrum is compared under the same source; improvement localised to the expected bands supports an air path. Little change may indicate that the crack is superficial, that another path dominates, or that the temporary seal is incomplete; the result should be described narrowly.

Environmental cycles can change both crack aperture and sealant stiffness; a room tested only in summer may not represent winter; for exterior or perimeter walls, freeze-thaw and moisture can alter joints; an acceptance programme may therefore include a representative environmental state or a guarded design margin. The need should be proportionate to risk and climate.

16.32 Three-dimensional flanking at corners, columns and shafts

Two-dimensional wall sections conceal the complexity of corners; at a trihedral junction, wall, floor and ceiling meet; a column may interrupt the wall. A shaft may continue vertically. Each element has its own mobility and radiation efficiency; energy can cross the nominal boundary through several coupled routes, and local sealing of one plane may leave the others unchanged.

A proper survey maps the junction in three dimensions; source positions are chosen to excite different surfaces; receiving microphones and vibration sensors are placed along the wall, slab, column and ceiling; phase and coherence help distinguish common excitation from local noise. Intensity methods can identify radiating surfaces where field conditions permit. The result is represented as a path network rather than a single “flanking” label.

Columns deserve special attention. A masonry wall may be toothed, tied, butted or isolated at the column. Finishes can conceal the connection. A rigid chase wall on the receiving side can re-radiate column vibration. Fireproofing and encasement add layers. The remedial strategy depends upon the actual topology; cutting a sealant joint at the visible finish may do nothing if masonry units are keyed behind it.

Shafts combine airborne and structure-borne transmission. A service shaft can carry sound vertically through air, ducts, pipes, ladders and walls; a secure room adjacent to a shaft should not be assessed only against the immediately opposite room; accessible floors above and below may be receiving locations. The path map should follow the shaft to its terminations and openings.

Integrated worked example 16.30. Path ranking at a column intersection

Controlled measurements estimate three receiving contributions at 500 Hz when considered separately: direct wall path 31 dB, slab-edge path 28 dB and column path 25 dB, expressed as received levels under the same source. Linear addition gives

L_total = 10 log10(10^3.1 + 10^2.8 + 10^2.5) = 33.3 dB.

If the direct wall is improved by 15 dB, the new total is

10 log10(10^1.6 + 10^2.8 + 10^2.5) = 30.0 dB.

A substantial wall improvement yields only 3.3 dB system gain because the column and slab remain; if the column path is then reduced by 10 dB, total falls to about 28.7 dB; the calculation supports a path-ranked remediation sequence. It does not prove independence among paths; correlated excitation and measurement uncertainty must be considered.

16.33 Integrated remediation case. Moving joint, lined wall and concealed service bridge

A masonry conference-room wall meets a long-span steel beam at a deflection head; an independent gypsum lining stands 90 mm in front of the masonry; field testing reveals poor isolation from 160 to 630 Hz and a narrower upper-band leak near a display wall. Visual inspection shows intact perimeter sealant. Construction records are incomplete.

Borescope inspection at the wall head reveals mineral-fibre packing beneath a continuous sealant bead, but several deck flutes remain open longitudinally; the lining head track is screwed through the deflection assembly into the beam; behind the display, a steel backing plate connects the lining studs to the masonry and supports a large screen. Conduits pass through both leaves in one sleeve.

The investigation tests each mechanism. Temporary flute plugs improve 500 Hz and 1 kHz receiving levels by 7 to 10 dB near the ceiling; releasing one noncritical lining-head fastener changes low-frequency wall vibration, confirming a bridge; temporary removal of the display support is not feasible, but mobility measurements show high coherence between the backing plate and masonry. A sealed test cap over the conduit sleeve improves the upper-band leak by 12 dB.

The remediation separates functions. A listed, movement-capable flute system interrupts longitudinal air paths; the lining head is rebuilt with a verified deflection and isolation detail; the display receives a floor-supported independent frame whose lateral restraints use tested resilient elements; services are divided into staggered penetrations with restored fire and acoustic closure. The work is photographed before closure and entered in the penetration and equipment-support registers.

Post-work testing uses the same source positions, receiving grid and operating states; low-frequency performance improves but remains limited by slab and column flanking; the report states that residual limitation and avoids attributing it to the masonry alone. Upper-band speech leakage at the display disappears under the authorised listening protocol; the competent authority receives the field evidence, uncertainty statement, firestop records and as-built details as separate components of the acceptance dossier.

16.34 Service supports, flexible connections and hidden force paths

A service can cross a protected boundary through an acoustically sealed opening and still carry vibration through its supports; pipe clamps, trapeze hangers, duct frames, cable trays and equipment brackets connect the service to structure; the path may bypass the wall entirely. A penetration detail should therefore identify both the opening and the support topology on each side.

Flexible connectors have finite dynamic stiffness. A braided hose, canvas duct connector or elastomeric sleeve may be effective in one frequency range and nearly rigid in another; preload, pressure, length and alignment matter; a connector installed in tension can transmit more force than the design assumption. Supports placed too close to the connector can short-circuit its motion.

The survey follows the service to the nearest rigid support; a pipe sleeve in masonry may be sealed perfectly while a clamp on the receiving side is bolted to the same column as a source-side pump; a cable tray can bridge a sound lock. A sprinkler main can connect many rooms; the path model should not stop at the wall face.

Commissioning can include operational vibration measurements and controlled tapping of services. Coherence with room pressure helps distinguish radiating services from unrelated vibration. Any modification must preserve structural, fire and system-performance requirements.

16.35 Sealant compatibility with coatings, fireproofing and historic substrates

Adhesion depends upon the substrate actually present; paint, dust, curing compound, form oil, efflorescence, fireproofing and friable historic mortar can prevent durable bonding; primer may be required, but primer selection can affect staining, vapour behaviour or reversibility.

A field adhesion test on a representative mock-up is stronger evidence than a generic product statement; the mock-up should reproduce substrate preparation, joint geometry, backer rod, primer and cure; it can be cycled or exposed to temperature where the risk justifies it. Failure mode matters. Cohesive failure within the sealant differs from adhesive loss at the substrate or tearing of a weak coating.

Spray-applied fireproofing should not be treated as a structural or acoustic backing surface unless the listed system permits it; the seal may need to connect to concrete or steel behind the fireproofing; removing fireproofing for access requires authorised restoration. Historic stone and lime mortar may require softer compatible materials and reversible details.

16.36 Joint acoustics under pressure differential

A room pressure differential applies a static force to doors, membranes and flexible seals; it can open a marginal joint or improve contact depending upon direction; HVAC modes, smoke control and emergency operation can therefore change acoustic performance.

Pressure testing should record sign and magnitude; a seal that performs at neutral pressure may leak when the room is positive; a flexible cover plate can lift; a door may fail to latch. The authorised operating state should be included in acoustic commissioning.

A simplified slot-flow model can screen sensitivity, but actual joints have nonlinear contact; small pressure changes can move a seal from closed to open; repeated measurements at several pressure states are often more informative than one precise calculation.

Integrated worked example 16.31. Pressure force on a flexible joint cover

A cover plate spans a 2.4 m long joint and has effective exposed width 0.08 m. Area is 0.192 m2. A 50 Pa pressure differential applies 9.6 N total force; if the plate is held by clips with total normal preload 8 N, pressure can lift it and open the joint; increasing clip force may close the path but also stiffen the connection and impede movement. The detail requires a compliant seal rather than relying on cover-plate preload alone.

16.37 Acoustic commissioning of repaired joints

Repair acceptance should proceed from physical inspection to diagnostic testing and then to room-level verification; the physical stage confirms substrate preparation, backing, depth, continuity, movement allowance and compatibility; the diagnostic stage uses local pressure, smoke, acoustic scan or vibration tests. The room stage repeats the relevant field measurement.

The tests are not interchangeable. A room-level pass can conceal one weak joint if another path dominates or background limits the result; a local pass does not establish the whole room; the acceptance dossier should preserve both.

Uncertainty and state are recorded. Sealants may require cure before final testing. Temperature and pressure affect response. Temporary masking or construction noise can invalidate receiving data; a guarded decision rule should be agreed before measurement.

16.38 Lifecycle inspection matrix for joints and linings

Not every joint warrants the same interval; wall heads under long-span structures, door-frame perimeters, service penetrations and exterior interfaces carry higher change risk; dormant interior control joints may require only visual review unless an event occurs.

A risk matrix combines consequence, movement demand, accessibility, history and detectability; high-consequence concealed joints may justify embedded witness marks, access panels or periodic local testing; easily visible low-consequence joints can be managed by routine inspection.

The matrix should trigger review after seismic events, water intrusion, structural modification, ceiling work, service additions and unexplained acoustic change; results are entered into the room configuration record; this closes the loop between construction, maintenance and authorised use.

16.39 Dynamic stiffness of sealant and backing systems

Acoustical joint design often treats the sealant as an air seal and ignores its mechanical path; the combination of sealant, backer rod, cover plate and substrate has a frequency-dependent dynamic stiffness; a dense sealant bead over a narrow joint can transfer vibration between wall panels. A softer, properly proportioned bead may reduce that path while maintaining closure.

Dynamic stiffness depends upon shape factor. A wide shallow bead deforms differently from a narrow deep bead. Backer-rod compression changes restraint. Closed-cell and open-cell backers have different gas and material behaviour; the system should be evaluated in the installed geometry rather than by bulk sealant modulus alone.

Where the joint lies in a critical flanking path, a representative test assembly can be excited mechanically; force and velocity across the joint provide a transfer stiffness; temperature and preload should be controlled; the test need not become a product qualification; it supplies project-specific evidence.

16.40 Linings around doors, windows and equipment recesses

Independent linings often lose continuity at openings; a door frame may be fixed to the host masonry while the lining stops at the frame, creating a rigid return; a window reveal may be direct-bonded; equipment recesses can expose the host wall. These transitions require purpose-designed returns.

A lining return should preserve cavity depth, mass and isolation as far as practicable; where rigid support is unavoidable, its extent and stiffness are controlled. Seal layers remain continuous. The opening assembly and lining are tested together.

Heavy equipment should be supported independently. A wall-mounted display or cabinet can bridge the lining through backing. Floor-supported frames or isolated supports may be required. Service penetrations should be staggered and sealed.

16.41 Joint inspection under concealed finishes

Skirtings, trims, ceilings and casework conceal joints; the inspection plan should identify hold points before closure and future access where risk remains. Photographs include scale and location. A concealed joint with no record should be treated as uncertain, not assumed compliant.

Non-invasive later checks can include pressure testing, thermal imaging and acoustic scans. Their detection limits are recorded. If evidence is insufficient and consequence is high, a controlled opening may be justified.

16.42 Remediation sequencing and protection of evidence

When several paths are suspected, repairs should be staged; correct the most strongly supported and reversible path first, then retest; simultaneous repair of every joint can improve the room but destroy causal evidence and waste resources.

Before alteration, photograph and measure the condition. Removed sealant or backing may be retained if dispute exists. Temporary tests are distinguished from permanent work. The sequence supports both technical learning and legal defensibility.

16.43 Head-of-wall mock-ups and cyclic movement verification

A full-scale wall-head mock-up can expose defects that drawings conceal; the mock-up should reproduce the actual deck profile, fireproofing, deflection track, masonry or lining, packing, sealants and finishes; it is then subjected to representative movement before acoustic closure is judged.

Movement may be applied mechanically in a laboratory fixture or through a site mock-up with controlled displacement; the objective is not to create a new product qualification; it is to verify that the project detail remains closed, does not shed material and does not rigidly bridge under the anticipated movement range. Inspection includes both faces and accessible flute interiors.

Acoustic screening can use pressure, smoke and local sound transmission before and after cycling; a detail that performs only in the pristine state is not robust; the record should identify displacement amplitude, number of cycles, temperature and any repairs.

The mock-up also clarifies trade responsibilities. Masonry, firestop, framing, drywall and sealant installers can see the sequence. Photographs become the field reference. Deviations require review rather than improvised closure.

16.44 Acoustic joint design at seismic separations

Seismic separations can require movements far larger than ordinary control joints; their covers, fire barriers and waterproofing are specialised systems; a secure-room boundary should avoid crossing such a joint where possible; if unavoidable, the acoustic strategy may require independent rooms on one side or a tested multi-layer joint system.

A rigid acoustic infill is unacceptable because it defeats the separation; flexible fire barriers can transmit air or vibration; cover plates can lift under pressure; the design should evaluate normal service, seismic movement and post-event condition separately.

After a significant event, the joint is inspected before sensitive use resumes. Covers are removed where authorised, fire barriers are checked, and local acoustic tests are repeated. Formal acceptance may be suspended pending repair.

16.45 Masonry-to-curtain-wall and masonry-to-roof transitions

At façades and roofs, masonry meets lightweight systems with different movement and acoustic behaviour; a masonry return may stop at a curtain-wall mullion; a roof deck may pass over the wall; fire safing, insulation and membranes fill parts of the joint without creating a complete acoustic boundary.

The detail should trace the air-control plane in three dimensions. Exterior drainage and ventilation remain. An interior return wall or independent lining may create the secure boundary; the façade engineer, fire professional and acoustical engineer should review the same detail.

Field testing should include exterior or plenum receiving positions where accessible. Wind and rain background are documented. A high result limited by exterior background is reported as a lower bound.

16.46 Lining cavity inspection, debris and future access

An independent lining cavity can become a repository for mortar, screws, offcuts and service debris; a single rigid object can bridge the lining; debris can also obstruct drainage or conceal moisture; inspection before closure should include the base, supports and penetrations.

Where the cavity contains valves, junction boxes or heritage fabric, access panels may be necessary; the panel must preserve mass and seals; access should be controlled and logged; a cavity that cannot be inspected should receive stronger construction surveillance and conservative assumptions.

16.47 Forensic distinction between vulnerability, defect and confirmed disclosure

A failed seal or open joint establishes a vulnerability or defect; it does not by itself prove that protected speech was recovered; the forensic report should separate physical condition, measured transmission, listener access, recording capability and actual content exposure.

The distinction is legally and operationally important. Remediation may be urgent even when disclosure is unproven. Incident assessment may require access logs and other evidence outside acoustics. The engineer should not overstate the conclusion.

16.48 Joint and lining final acceptance dossier

The dossier contains movement calculations, product and listed-system data, mock-up results, as-built joint dimensions, photographs, penetration records, lining supports, local diagnostic tests, room-level measurements, uncertainty and maintenance triggers. It identifies residual flanking.

The acceptance statement is tied to the configured room and authorised state. It does not convert every joint into a product rating or imply formal accreditation without authority action.

16.49 Sealant bead geometry, substrate movement and recoverable strain

A sealant joint cannot be specified solely by product name. Its installed behaviour depends upon joint width, sealant depth, backing material, bond surfaces, temperature at installation, expected movement and the way adjacent substrates restrain the bead; a shallow hourglass section can distribute strain more favourably than a deep rectangular plug, while three-sided adhesion can convert expected extension into local tearing. ASTM

C1193 and ASTM C1472 provide the design framework for joint movement and sealant geometry, while ASTM C919 addresses acoustical applications; the acoustic requirement must be coordinated with, rather than substituted for, the movement calculation. [85]

For a wall head or control joint, the movement range should be expressed as a signed interval rather than a single percentage; thermal expansion, concrete creep, masonry shrinkage, live-load deflection and seismic drift can act in different directions. The joint must remain bonded and sufficiently airtight throughout the credible range; a product movement rating obtained under a prescribed laboratory method is not proof that an installed bead with different depth, primer, substrate or ageing will remain continuous.

Integrated worked example 16.32. Required sealant movement capacity

A 22 mm wide vertical joint is expected to close by 3 mm under thermal expansion and open by 5 mm under structural movement; the maximum extension is therefore 5/22 = 0.227, or 22.7 per cent, and the maximum compression is 3/22 = 0.136, or 13.6 per cent. If construction tolerance may reduce the installed width to 18 mm, the extension demand becomes 5/18 = 27.8 per cent; the design should be based on the minimum credible installed width, not the nominal drawing dimension. The calculation is dimensionless because displacement and width use the same unit; it does not establish acoustic performance. It establishes a mechanical demand that must be satisfied before the air seal can be expected to remain serviceable.

85 MB-0017. ACI/PTI CODE-320-25.

16.50 Backer rods, bond breakers and the acoustic consequence of installation depth

Backer rods control sealant depth and help prevent adhesion to the rear of the joint; open-cell and closed-cell products differ in compressibility, moisture behaviour and susceptibility to puncture; a backer rod that is too small can migrate or leave an uncontrolled deep cavity. One that is oversized can distort the joint edge or create excessive installation force; puncturing a closed-cell rod can release gas and form bubbles in the sealant; the inspection record should therefore state material, diameter, compression, installation depth and condition before the bead is applied. [86]

The backer does not itself constitute the principal acoustic seal unless the design explicitly makes it so; mineral fibre may provide fire and thermal functions but can remain air-permeable; a compressible foam may reduce local cavity resonance but still permit leakage around irregular edges. The completed joint should be assessed as a layered system whose air barrier, movement capacity and fire performance are separately identified.

16.51 Crack injection, rout-and-seal repairs and limits of acoustic inference

Crack repair methods address different mechanisms. Routing and sealing creates a surface closure while allowing limited movement; resin injection can restore continuity in a dormant crack but may be inappropriate where movement persists or moisture transport must be preserved; cementitious filling may be compatible with masonry but too rigid for a live interface. Acoustic improvement after repair can result from closing an air path, increasing local stiffness, reducing panel motion or altering damping; the

86 MB-0034. American Concrete Institute, ACI CODE-562-25.

report should not attribute the gain to one mechanism without a discriminating test.

A controlled temporary seal is often the least destructive first experiment. If a removable tape or putty treatment changes only high-frequency transmission, airborne leakage is supported. If low-frequency vibration and receiving-surface radiation remain, structural coupling may govern. Permanent repair is selected after the mechanism, structural cause, fire requirement and conservation constraint have been reviewed. [87]

16.52 Lining support loads, local failure and acoustic short circuits

Independent linings and clip-supported furring systems carry board self-weight, service loads, impact loads and construction handling; a local overload can rotate a clip, deform a channel or pull a fastener until the lining contacts the masonry; the resulting bridge may be intermittent and therefore difficult to detect during an unoccupied survey. Equipment supports, display mounts and cabinets should be included in the support analysis rather than attached later by trades seeking the nearest structural substrate.

The acoustic drawing should identify zones in which attachments may penetrate the lining and the approved means of carrying load; where a structural connection through the cavity is unavoidable, its stiffness, number and position should be controlled. A small number of designed stand-offs can be modelled and inspected; an unrecorded forest of screws, brackets and conduits cannot.

87 MB-0038. American Concrete Institute, ACI SPEC-563-25.

16.53 Field localisation of joint and lining paths

A useful localisation sequence begins with a stable source and a spatial receiving grid; broad level differences establish the weak frequency bands. Close microphone scans, sound intensity, vibration measurements and reversible sealing are then selected according to the suspected mechanism; the sequence should avoid excessive source level that excites unrelated rattles or overloads the measurement chain; environmental and operational states are held constant where practicable. [88]

A positive temporary-seal result supports a local airborne route but does not prove that the visible joint was the only path; pressure can redistribute through connected cavities; conversely, a negative result may reflect an incomplete temporary treatment or a measurement floor. Findings should be expressed as tested propositions: the intervention changed a defined band under a defined state, or it did not produce a resolvable change within uncertainty.

16.54 Specification language for joints and linings

A performance specification should name the boundary, required movement, air-seal plane, fire or smoke listing, substrate preparation, primer, backing, inspection point and acceptance evidence; the acoustical requirement should identify whether laboratory specimen data, field room-to-room data, local leakage testing or all three are required. Vague language such as "seal acoustically" transfers design responsibility without defining the measurand.

88 MB-0019. ACI/PCI CODE-319-25.

Prescriptive details remain necessary where workmanship controls the result. The drawing should show bead depth, termination at corners, transition to frames, closure at flutes, treatment behind linings and access for later inspection. Submittals should include compatibility evidence, installation instructions and the exact tested or listed configuration. Substitutions are reviewed against movement, adhesion, fire, durability and acoustic function, not merely catalogue classification. [89]

16.55 Integrated chapter disposition

Joints and linings are governed by movement, force transfer and continuity; a joint that is airtight on the day of testing can fail after temperature cycling or structural deflection; a lining that appears independent can be defeated by a single support, cabinet or service bridge. The finished room therefore requires an evidence chain from design movement through concealed-work inspection, commissioning and lifecycle review; the appropriate conclusion is bounded to the installed configuration and measured state, not to the nominal material name.

16.56 Temperature dependence and ageing of elastomeric joints

Sealant stiffness, recovery and adhesion can vary with temperature and age. A bead that remains flexible during installation may become significantly stiffer in a cold service condition, increasing force at the bond line and reducing its ability to follow rapid movement; heat, ultraviolet exposure, cleaning chemicals and sustained compression can change surface condition and bulk properties. The product data and project exposure

89 MB-1122. Precast/Prestressed Concrete Institute, PCI Design Handbook: Precast and Prestressed Concrete, 9th ed.

should therefore be reviewed together rather than assuming one room-temperature movement rating describes the entire life of the joint. [90]

Where a joint is critical to the protected boundary, lifecycle inspection should include elasticity, cracking, edge adhesion and dimensional state; a hardened bead may still look continuous yet transfer more vibration or pull away during movement; replacement intervals should follow observed condition and consequence, not an arbitrary calendar alone.

16.57 Repeated movement, fatigue and progressive debonding

Building joints experience cycles from temperature, occupancy, wind, vibration and structural movement; even where each cycle remains within nominal capacity, local imperfections can concentrate strain and initiate progressive debonding; corners, primer discontinuities, thin sections and substrate cracks are common starting points. A one-time static inspection does not establish fatigue resistance.

Mock-up cycling can be useful for unusual details; the cycle amplitude and number should represent the mechanism being studied, and the specimen should include actual substrates, backing and finishes; the result is project evidence for the tested detail. It does not convert the material into a universal acoustic seal.

Integrated worked example 16.33. Accumulated movement screening

A wall-head joint experiences a daily thermal movement range of 1.2 mm and an additional weekly live-load excursion of 2.5 mm; over one year, the

90 MB-1187. Tilt-Up Concrete Association, public design and construction resources, accessed 11 August 2026.

thermal cycle produces approximately 365 opening and closing excursions, while the live-load event produces about 52. A simple count gives 417 principal cycles, but the damaging effect is not proportional to count alone because amplitude, rate and temperature differ; the calculation demonstrates why an inspection plan should distinguish frequent small cycles from less frequent large cycles. It does not predict fatigue life without material-specific data and installed geometry.

16.58 Fire-resistive joint systems and acoustic continuity

A fire-resistive joint system is a tested assembly involving substrates, joint width, movement, packing, sealant and installation depth; acoustic changes must preserve the listing or receive the required engineering review. Replacing a listed joint material with an acoustical caulk, adding rigid mortar, or installing a cover plate through the movement zone can compromise fire or movement performance; conversely, a mineral-fibre packing alone may satisfy part of a fire detail while leaving an air-permeable acoustic path. [91]

The specification should identify the fire system and the acoustic air-seal plane separately; inspection photographs should show the packing and sealant before covers are installed; when a tested fire system is not available for the required geometry, the project should resolve the issue before construction rather than relying on field improvisation.

16.59 Field adhesion checks and witness samples

Sealant adhesion can be checked through project-approved methods, including small pull tests or witness samples, where compatible with the

91 MB-0159. ASTM International, ASTM C597-22.

system and authority; the purpose is to verify substrate preparation, primer and cure, not to damage every joint. Sampling locations should represent different substrates, orientations, environmental exposures and installers.

A failed witness sample should trigger investigation of the affected lot or work period; a passed sample does not prove every metre of joint; the evidence should be combined with visual inspection, bead geometry and installation records. Repairs to test locations must restore the complete system.

16.60 Statistical inspection of long joint runs

Long wall heads and façades can contain hundreds of metres of joint; a convenience sample near access points may miss clustered defects; the inspection design should consider likely defect mechanisms, installer sequence and concealed zones; stratified sampling across floors, crews, substrate types and dates can provide better coverage than one random percentage.

Integrated worked example 16.34. Detection probability for clustered joint defects

Suppose 8 per cent of a 200 m joint run is defective, but the defects are concentrated in four 4 m zones; inspecting ten isolated 0.5 m locations selected uniformly gives only 5 m total coverage and may miss every cluster. Under a simplified independent assumption with $p = 0.08$, probability of detecting at least one defect in ten locations is $1 - 0.92^{10} = 0.566$; clustering can make the actual probability lower if samples fall between zones. The calculation shows why inspection should follow construction lots and risk zones rather than rely on a nominal sample count.

16.61 Full-scale junction mock-ups

A junction mock-up can combine masonry, deck, fireproofing, lining, services, joint treatment and finishes; it allows trades to demonstrate sequence and gives the design team access before concealment; the mock-up should include difficult conditions such as deck flutes, corners, a penetration and a service support. Acoustic testing may use local pressure or room-pair methods according to scale.

The approved mock-up becomes a workmanship reference, but it must not conceal later variation. Field inspections should compare materials, geometry and sequence. Any substitution that changes movement, air closure or connection stiffness requires review.

16.62 Controlled disassembly and evidence preservation

When a joint or lining must be opened for diagnosis, the sequence should preserve evidence. Photographs are taken before disturbance. Trim, sealant, backing, fasteners and hidden supports are removed in stages and labelled. Samples retain orientation and location. The analyst distinguishes construction defect from damage caused during opening.

Controlled disassembly is particularly important in disputes; a destructive opening that removes the suspected bridge before it is documented can erase the mechanism; the repair record should show how the boundary was restored and what post-work tests were completed.

16.63 Remediation in occupied secure facilities

Work in an occupied facility introduces access, dust, noise, temporary openings and service interruptions; the room may need to leave sensitive use while the boundary is open; tools, materials and waste are controlled under the applicable security plan. Temporary barriers should not be represented as equivalent to the completed condition.

The remediation sequence should minimise the period of exposure and allow inspection before closure; final cleaning, equipment inventory and technical-security review may be required in addition to acoustic testing; the engineering record should remain separate from security procedures that are not public or not within the author's authority.

16.64 Digital joint register and configuration control

A digital register can link each critical joint to drawings, photographs, material lots, inspection dates, repairs and test results; location identifiers should remain stable through renovations; the register is useful only if changes are entered promptly and access is controlled.

The record can also identify maintenance triggers and recurring defect families; it should not become a substitute for physical inspection; a database entry that says "sealed" does not prove the present state of the bead.

16.65 Chapter closure. Movement-compatible acoustic continuity

A durable joint or lining system must remain continuous while the building moves and services operate; materials, geometry, attachment, fire protection, inspection and lifecycle control act together; the strongest result comes from a verified sequence: design the movement, construct the air seal, inspect before concealment, test the configured boundary and preserve the record. Nominal sealant type or lining thickness alone cannot support a secure-room conclusion.

Table 16-R1. Joint and lining failure modes, diagnostic controls and repair constraints.

Failure mode	**Diagnostic control**	**Repair constraint**	**Retest evidence**
Three-sided sealant adhesion	Probe geometry and local adhesion check	Preserve movement and listed fire system	Local scan plus room-level curve
Longitudinal deck-flute path	Temporary plug and ceiling-grid mapping	Coordinate fireproofing and structural deck	Band change at source and receiving grid
Lining support bridge	Mobility or controlled bracket perturbation	Maintain structural stability and seismic restraint	Before-and-after transfer function
Service-support bypass	Trace support topology and operational coherence	Preserve service loads and fire protection	Operational vibration plus airborne test
Active crack	Movement monitoring and reversible seal	Repair cause before cosmetic closure	Repeated environmental-state comparison

16.66 Technical schedules for joint, lining and forensic control

Table 16-1. Joint type, required movement and acoustic consequence

Joint condition	Primary structural function	Acoustic hazard	Minimum evidence
CMU control joint	Concentrates shrinkage movement at a planned plane	Open bead, rigid cover or finish bridge can dominate high bands	Joint location, reinforcement termination, measured width, backing, sealant class and photographs
Brick expansion joint	Accommodates irreversible moisture expansion and thermal change	Under-sized sealant debonds; hard infill transfers stress into adjacent joints	Brick run length, movement calculation, joint geometry, sealant product and seasonal inspection
Wall-head deflection joint	Allows slab or roof deflection without loading wall	Fasteners through slotted track and hard finish contact create structural bridges	Structural deflection criterion, listed fire system, fastener pattern and concealed-work inspection
Slab isolation joint	Separates floor or equipment pad from surrounding structure	Toppings, thresholds, conduits and reinforcement can short-circuit isolation	Structural joint detail, bridge inventory, resilient material and transfer-mobility test
Precast panel joint	Accommodates erection tolerance and panel movement	Interior bead may debond while exterior weather seal appears intact	Panel survey, two-stage seal detail, backing, substrate preparation and field leakage scan
Historic masonry joint	Permits compatible movement and vapour transport	Hard repointing damages stone; shallow pointing hides deep voids	Mortar analysis, depth survey, conservation approval, photographs and post-work field test

Table 16-2. Independent-lining design variables and failure mechanisms

Variable	Engineering role	Typical failure	Verification
Leaf surface mass	Controls inertial response and mass-air-mass resonance	Substituted board changes spectrum and support load	Approved material schedule, weighing or manufacturer data, as-built layer count
Clear cavity depth	Sets air-spring stiffness and room for services	Blocking, debris or bowed masonry reduces depth locally	Grid measurements before closure and borescope access
Frame independence	Reduces mechanical coupling to masonry	Frequent brackets or rigid perimeter contact short-circuit the lining	Bracket register, isolation detail and vibration comparison
Cavity absorber	Damps cavity modes and reduces resonance severity	Compressed, missing or wet absorber performs differently	Photographic coverage, density and thickness records, moisture inspection
Perimeter isolation	Completes the secondary boundary	Skirting, plaster, floor finish or ceiling grid bridges the gap	Concealed hold point and reversible local vibration test
Service zone	Keeps boxes and cables on room side	Unplanned recesses penetrate the secondary leaf	Coordinated reflected ceiling and equipment plans, penetration register
Moisture management	Prevents trapped dampness and deterioration	Lining conceals active leak or condensation	Hygrothermal review, cavity sensors and inspection access

Table 16-3. Crack observation, discriminating test and bounded conclusion

Observation	Competing explanations	Discriminating test	Permissible conclusion
Vertical crack at control-joint line	Expected shrinkage plane, failed sealant, structural restraint	Joint-width monitoring and temporary membrane sealing	Crack is active or inactive over measured interval and contributes or does not measurably contribute under test state
Diagonal crack from opening corner	Lintel deflection, settlement, local stress, finish-only crack	Structural survey, depth indication, movement gauge and acoustic retest	Geometry and acoustic contribution are established; cause remains bounded by structural evidence
Horizontal crack below slab	Wall-head binding, slab deflection, drying shrinkage	Inspect slotted track, fasteners, fire joint and slab movement	Observed bridge or separation supports a mechanism; room performance remains a separate field result
Map cracking in parging	Drying, incompatible coating, substrate movement	Close mapping, adhesion test and local reversible sealing	Surface coating is degraded; through-wall leakage is not assumed without response
Damp crack with salts	Water pathway, condensation, plumbing leak	Moisture tracing and environmental logging	Moisture source is identified or remains unresolved; acoustic treatment is deferred until compatible repair
No visible crack but local sound peak	Hidden joint, porous cell network, frame cavity or service path	Intensity scan, borescope and staged sealing	A concealed path is supported only when predicted changes occur

Table 16-4. Remediation selection matrix

Dominant mechanism	Preferred intervention class	Principal constraint	Acceptance evidence
Air leakage at movement joint	Reconstruct backing and compatible sealant while preserving movement	Fire listing, substrate compatibility and service temperature	Joint geometry record plus frequency-resolved before-and-after field data
Rigid bridge at lining bracket	Redesign or isolate bracket under structural review	Stability, seismic and equipment loads	Structural approval, bracket inventory and transfer-function reduction
Porous masonry field	Continuous parging, plaster or tested lining	Moisture transport and historic fabric	Coverage inspection and room field measurement
Slab or core flanking	Source isolation, junction treatment, receiving lining or room relocation	Structural load path and building services	Mobility or structural-intensity evidence plus room retest
Frame perimeter cavity	Remove cosmetic bead and reconstruct full-depth primary seal	Door alignment, fire and frame anchorage	Photographs, sealant record, local scan and door/room test
Unknown concealed condition	Controlled opening or targeted nondestructive examination	Evidence preservation and building safety	Documented opening, sample provenance and updated as-built model

16.67 Conclusions

Masonry joints, linings, openings and cracks must be designed as transfer systems rather than decorative details; durable acoustic closure depends upon movement, geometry, adhesion, backing, fire and smoke coordination, structural compatibility and access for inspection. A rigid patch can create a future crack; a beautiful sealant bead can conceal an empty joint; a lining can improve direct transmission while introducing bridges and moisture risks.

Flanking analysis changes the design question from “How good is the wall?” to “Which paths deliver protected speech energy to accessible locations under the configured state?” That question requires frequency-resolved measurement, structural reasoning and controlled interventions; remediation is justified only when it changes the demonstrated mechanism and survives the expected lifecycle.

Chapter 16 Glossary

Acoustic closure. A continuous material and geometric condition intended to limit airborne leakage at a joint, void or penetration.

Backer rod. Compressible, generally non-adhering material placed behind a sealant to control bead depth and support tooling.

Control joint. A deliberate plane in concrete masonry intended to manage shrinkage cracking and relative movement.

Expansion joint. A separation designed to accommodate expansion or differential movement, commonly in brickwork and long façades.

Flanking fin. An intersecting element that carries vibration or airborne energy around the nominal separating construction.

Independent lining. A secondary leaf supported substantially independently of the existing wall to reduce mechanical coupling.

Joint movement class. A sealant classification describing tested extension and compression capability under the applicable standard.

Primary air seal. The designated continuous plane responsible for air closure, distinguished from cosmetic surface sealant.

Reversible sealing test. A temporary, documented closure used to test whether a suspected discontinuity contributes to transmission.

Shadow void. An unfilled region behind an obstruction such as reinforcement, mortar projection or frame profile.

Three-sided adhesion. Unwanted sealant bonding to the back of a joint as well as its two sides, which constrains deformation and concentrates strain.

Dynamic joint stiffness. Frequency-dependent relation between joint force and relative displacement in the installed sealant and backing geometry.

Flute path. Longitudinal acoustic route through a metal-deck flute or similar repeated structural cavity.

Joint-cover lift. Opening of a cover plate or trim under pressure, movement or insufficient preload.

Sealant shape factor. Geometric relation of bead width, depth and bonded surfaces that influences deformation and stiffness.

Service-support bypass. Structure-borne path created by supports that connect a service across or around the nominal boundary.

Trihedral junction. Three-dimensional intersection of two walls and a floor or ceiling, often containing several coupled flanking paths.

Chapter 17. Cast-in-Place, Precast, Tilt-Up, and Composite Concrete Systems

17.1 Concrete is simultaneously barrier, structure and transmission path

Concrete is often selected for secure rooms because its surface mass, continuity, fire resistance and robustness can support high airborne isolation; that advantage is real but incomplete. The same stiffness and structural continuity that make a concrete wall an effective direct barrier can carry vibration into slabs, columns, beams, façades and foundations; a concrete shell may therefore exhibit very high laboratory transmission loss through its central field while the completed room remains limited by construction joints, cracks, precast interfaces, door openings, sleeves, embedded plates or structure-borne flanking.[92][93]

The acoustic description must begin with structural configuration; cast-in-place, precast, tilt-up, post-tensioned and composite systems differ in reinforcement, joint frequency, erection sequence, restraint and service integration; a nominal “200 mm concrete wall” is not an adequate specification. The record should identify density, thickness, reinforcement, concrete strength, casting sequence, joints, supports, form-tie treatment, embeds, openings, surface finishes, adjacent members and the source of each datum; ACI CODE-318-25 supplies current structural requirements for concrete systems, while ACI SPEC-301-20 addresses construction execution; neither assigns secure-room acoustic performance.[94][95]

92 MB-0178. ASTM International, ASTM C805.
93 MB-0128. ASTM International, ASTM C1383-15.
94 MB-0143. ASTM International, ASTM C42.
95 MB-0272. ASTM International, ASTM E336-25a.

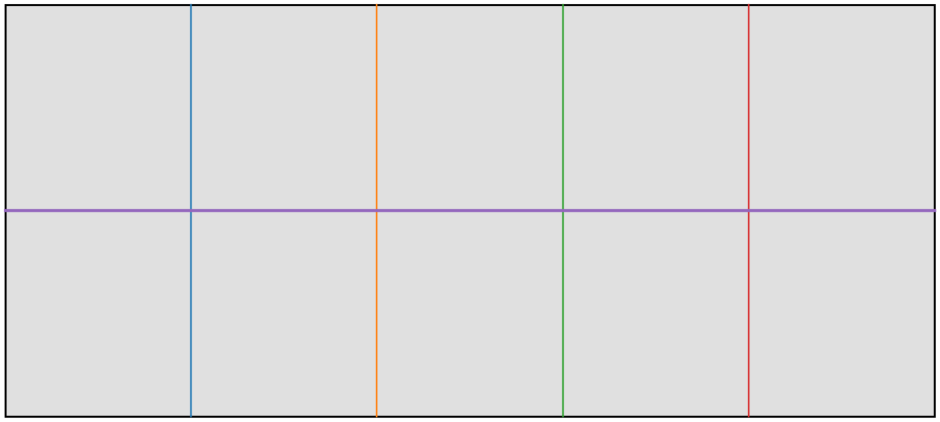

Figure 17-1. Cast-in-place concrete wall showing reinforcement, construction joint, form-tie locations, sleeve and slab junction. Author's original schematic. The uniform barrier is interrupted by deliberate and accidental paths that require separate evidence.

Worked example 17.1. Surface mass of a concrete wall

For normal-weight concrete density $\rho = 2{,}400\ \mathrm{kg/m^3}$ and wall thickness $t = 0.200\ \mathrm{m}$, surface mass is

$$m' = \rho\, t = (2{,}400)(0.200) = 480\ \mathrm{kg/m^2}.$$

The dimensional check gives kilograms per square metre; the result supports preliminary mass-law screening, structural load calculations and material reconciliation; it does not establish the wall transmission curve because stiffness, coincidence, wall dimensions, cracks, joints and flanking remain.

17.2 Structural-code compliance and acoustic proof are different records

ACI CODE-318-25 addresses safety, strength, serviceability, durability, fire resistance, construction and inspection for structural concrete;[96] ACI

96 MB-0876. International Organization for Standardization, ISO 16283-1:2025.

SPEC-301-20 translates many construction requirements into a project specification framework;[97] their evidence is indispensable, but the questions are structural and constructional; a compressive-strength test establishes a material property for sampled concrete. It does not prove wall thickness, absence of honeycombing, closure of sleeves or airborne isolation.

The acoustic proof chain therefore contains multiple layers; mix and batch records identify material; reinforcement and embed inspections identify concealed geometry; survey and thickness records identify dimensions; core or nondestructive tests may investigate local uncertainty; laboratory acoustic tests identify a defined specimen; field tests identify the configured room. Operational speech assessment and competent-authority disposition remain distinct; a single certificate cannot answer all these questions.

Specifications should avoid using structural terms as acoustic shorthand; “cast solid” does not mean void-free. “Monolithic” does not mean jointless. “Fully reinforced” says nothing about service penetrations; “minimum 35 MPa concrete” says little about low-frequency structural mobility; the architect, structural engineer and acoustical engineer should create a shared matrix of properties, mechanisms and evidence.

Worked example 17.2. Concrete volume and mass reconciliation

A wall is 9.0 m long, 3.6 m high and 0.225 m thick. Gross volume is

$V_g = (9.0)(3.6)(0.225) = 7.29\ m^3$.

Openings and blockouts total 0.84 m^3, giving net concrete volume 6.45 m^3. At 2,380 kg/m^3, expected mass is

97 MB-0034. American Concrete Institute, ACI CODE-562-25.

m = (6.45)(2,380) = 15,351 kg.

Delivered volume exceeding the geometric value by a modest waste allowance is normal; a large shortfall prompts review but does not locate a void. The calculation is an administrative screen, not an acoustic certification.

17.3 Cast-in-place continuity and the reality of construction sequencing

A cast-in-place wall is produced in lifts and placements constrained by formwork, concrete supply, access and structural sequencing. Construction joints are planned interruptions. Cold joints arise where continuity is not achieved as intended; lift lines, keyways, waterstops, roughened surfaces, dowels and bond conditions influence structural and acoustic behaviour; a wall cast in one architectural phase can be connected rigidly to a later slab or return wall, creating a powerful flanking path.

Form ties create repeated penetrations. Snap ties may leave conical recesses; she-bolts leave larger holes; reusable ties require sleeves; patching material, depth, bond and shrinkage matter; a cosmetic surface patch over an open sleeve is not equivalent to full-depth closure; tie patterns can produce a distributed leakage network or local stiffness periodicity. The hold-point record should identify tie type and closure method before finishes conceal the surface.

Consolidation around dense reinforcement and embeds is another acoustic issue; honeycombing and rock pockets reduce local mass and can connect pores; the severity depends upon depth and continuity; a superficial void may be repairable; a deep defect near reinforcement can require structural assessment. Acoustic remediation never proceeds independently of structural disposition.

Worked example 17.3. Repeated form-tie area fraction

A wall contains 180 tie sleeves of 20 mm diameter. Total geometric area is

$S_t = 180(\pi (0.020)^2)/(4) = 0.0565\ m^2$.

For a 36 m^2 wall, area fraction is 0.157 per cent; if sleeves were open, the acoustic effect would be severe despite the tiny fraction; proper full-depth closure reduces effective transmission, but the calculation shows why tie treatment must be specified and inspected systematically.

17.4 Density, aggregate and elastic response

Concrete density affects surface mass, but density alone does not define vibration; aggregate type, moisture, modulus, cracking and reinforcement influence wave speed and damping; lightweight concrete can reduce structural load and may exhibit different damping and coincidence behaviour, while normal-weight concrete generally offers greater surface mass for equal thickness. A secure-room design should use measured or specified properties appropriate to the actual mixture rather than a generic textbook value.

The ideal mass law predicts increasing transmission loss with mass and frequency for a limp, infinite barrier; concrete is neither limp nor infinite; at low frequency, room and panel modes matter; at higher frequency, bending waves and coincidence can alter the curve; boundary restraint transfers energy into adjoining structure. Finishes, linings and cavities further modify response.

Compressive strength and elastic modulus are correlated only imperfectly; two mixtures with equal specified strength can have different density and modulus; acoustic prediction should not infer modulus solely from strength without uncertainty; where low-frequency structural response is consequential, modal or mobility measurements can calibrate the model.

Worked example 17.4. Ideal mass-law comparison for two densities

Two 180 mm walls have densities 1,900 and 2,400 kg/m³. Surface masses are 342 and 432 kg/m². Ideal difference at the same frequency is

$\Delta R = 20 \log_{10}((432)/(342)) = 2.03$ dB.

The value is a screening result. It does not prove a 2 dB difference across the measured spectrum because stiffness, damping, geometry and construction differ.

17.5 Reinforcement, prestress and structural coupling

Reinforcement is essential to concrete structural performance, yet its acoustic influence is not captured by mass fraction alone; bars and welded reinforcement transfer tensile force, restrain cracking and create continuous paths into foundations and slabs; dense cages can impede consolidation; embedded plates and headed studs create local stiffness. Post-tensioning introduces sustained compression and tendons that cross large distances.[98][99]

A reinforced wall can radiate less from a given pressure in some bands because stiffness reduces motion, while transmitting more energy into adjoining members; prestress can alter crack state and modal frequency.

98 MB-0038. American Concrete Institute, ACI SPEC-563-25.
99 MB-0415. Carl Hopkins, Sound Insulation.

These effects are configuration-specific. It is unsafe to claim that more reinforcement is either acoustically better or worse in general.

The acoustic team should review structural drawings for bar continuity, boundary elements, dowels, collector elements, coupling beams and tendon profiles; proposed isolated linings and floating floors must not compromise inspection zones, tendon access or structural fire protection. Drilling in post-tensioned construction requires scanning and formal approval.

Worked example 17.5. Reinforcement surface-mass fraction

A wall has 16 mm vertical bars at 200 mm centres on two curtains. Bar mass is approximately 1.58 kg/m. Steel length per square metre is

$\ell = 2\left(\frac{1}{0.200}\right) = 10\ \text{m/m}^2$.

Steel surface mass is 15.8 kg/m²; for a 480 kg/m² concrete wall, steel is about 3.3 per cent of total surface mass; its dynamic significance can exceed this fraction because it changes stiffness, cracking and force transfer.

17.6 Cracks, joints and repair categories

Cracks in concrete arise from plastic shrinkage, drying shrinkage, thermal gradients, restrained volume change, settlement, overload, corrosion, alkali-silica reaction and other mechanisms; acoustic significance depends upon whether the crack is through-thickness, connected to voids or services, moving, wet or associated with delamination. Structural significance is a separate evaluation.

Repair material must match the mechanism; routing and sealing can restore surface air closure for suitable non-structural cracks. Flexible sealing accommodates movement. Epoxy injection can bond cracks structurally but creates a stiff path and is inappropriate for active movement without engineering justification; cementitious injection may fill voids but can shrink or redirect moisture; ACI CODE-562-25 and ACI SPEC-563-25 provide current frameworks for assessment and repair of existing concrete.[100][101]

The original crack should be documented before repair; width, length, orientation, depth evidence, movement history, moisture and relation to reinforcement or joints are recorded; temporary acoustic sealing can test path contribution; acoustic benefit does not authorise a structural repair method.

Worked example 17.6. Open-crack parallel-path screen

A 20 m^2 wall has field transmission loss 60 dB at a selected band. A continuous crack is 2.4 m long and 0.15 mm open, giving area

$S_c = (2.4)(0.00015) = 3.6 \times 10^{-4}$ m^2.

Treating it as open,

$\tau_c = ((20-S_c)10^{-6}+S_c)/(20) = 1.90 \times 10^{-5}$,

and R_c = 47.2 dB. The model is conservative because real cracks are tortuous, but it demonstrates leverage.

17.7 Precast panels and the primacy of joints

Precast construction moves much of the concrete production into a controlled plant, where dimensions, curing and quality systems can be rigorous; the building, however, is assembled from discrete elements; panel joints, bearing pads, welded or bolted connections, grout pockets, embeds,

100 MB-0762. Frank Fahy and Paolo Gardonio, Sound and Structural Vibration, 2nd ed.
101 MB-0023. American Concrete Institute, ACI CODE-318-25.

sealants and closure pours govern continuity. A high-performing panel can be bypassed by a narrow erection joint.[102][103]

The acoustic design should distinguish structural connection from air seal; a welded plate may transfer force while leaving an irregular cavity; an exterior weather seal may not close the interior acoustic plane; a backer rod and sealant on one face may leave the joint cavity communicating with floors or façades. Double seals can create a controlled cavity, but trapped water and pressure equalisation must be considered in exterior assemblies.

Panel bow, differential camber and erection tolerance alter joint width; sealants selected for nominal width can be overstrained at local extremes; shims and temporary braces can create bridges; closure pours may crack at interfaces. The as-built survey should record joint geometry before sealant and after building loading.

102 MB-0017. ACI/PTI CODE-320-25.
103 MB-0415. Carl Hopkins, Sound Insulation.

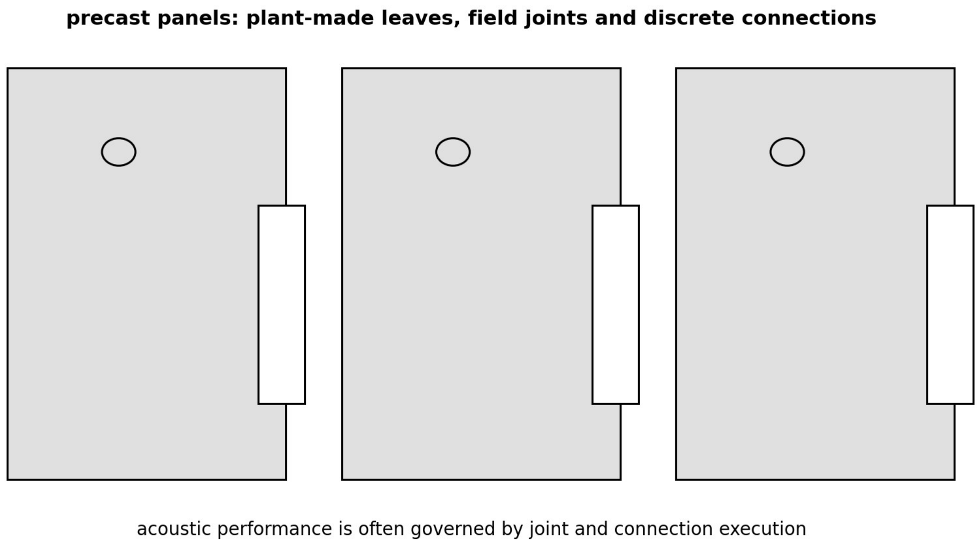

Figure 17-2. Precast panel joint showing structural connection, bearing, interior acoustic seal, exterior weather seal and cavity. Author's original schematic. Structural continuity and air closure are separate functions.

Worked example 17.7. Precast-joint area effect

Four panel joints, each 3.5 m high and 18 mm wide, have total area

$S_j = 4(3.5)(0.018) = 0.252\ m^2$.

For a 42 m^2 wall, joints occupy 0.6 per cent. If panel field is 62 dB and joints provide 35 dB in one band, composite result is

$R = -10 \log_{10}((41.748(10^{-6.2})+0.252(10^{-3.5}))/(42)) = 47.0$ dB.

The joints dominate. The result is illustrative and assumes independent diffuse-field paths.

17.8 Precast connection dynamics

Precast connections can be designed for gravity, shear, moment, diaphragm action, seismic ductility or erection stability; their mechanical impedance influences vibration transfer; welded plates and grouted sleeves create stiff paths; bearing pads can provide compliance, but they are selected principally for structural load, rotation and durability. An elastomeric bearing compressed under high load may be dynamically stiff.

Acoustic prediction should identify connection locations and tributary areas; a few discrete connections can excite panel modes. Repetition creates periodicity. The receiving structure may radiate more efficiently than the source panel; mobility or transfer measurements can assist where high isolation is required.

Connections must remain inspectable and protected. Concealing a weld or grout pocket before structural inspection is unacceptable. Acoustic absorbers or linings are installed around the accepted connection rather than obscuring evidence prematurely.

Worked example 17.8. Discrete connection transmissibility screen

A panel is supported by four pads, each dynamic stiffness 3.0×10^8 N/m, with effective panel mass 12,000 kg; parallel stiffness is 1.2×10^9 N/m. Simplified rigid-body natural frequency is

$$f_n = \frac{1}{2\pi} \sqrt{\frac{1.2 \times 10^9}{12,000}} = 50.3 \text{ Hz}.$$

The model omits panel flexibility and frequency-dependent pad properties. It identifies a region where support dynamics may influence transfer.

17.9 Tilt-up panels, casting beds and erection sequence

Tilt-up panels are cast horizontally, lifted and braced into position; lifting inserts, brace anchors, panel joints, roof connections and foundations create a distinctive evidence chain; casting-bed flatness and bond breakers affect surface; panel thickness, openings and reinforcement are established before lifting; erection tolerances determine joint width and alignment.[104]

Brace holes and lifting inserts require permanent treatment after structural acceptance; a shallow cosmetic patch over an insert recess can leave a local cavity; roof and diaphragm connections transfer lateral forces and vibration; panel-to-slab joints can crack under shrinkage or settlement. The acoustic plan should follow the erection sequence so that critical conditions are inspected when visible.

Tilt-up secure rooms often use an interior independent lining because exterior panels contain joints, thermal insulation, structural connections and services; the lining can create a controlled inner boundary, but it must be detailed around braces, roof structure and doors. It should not conceal water infiltration at panel joints.

104 MB-0017. ACI/PTI CODE-320-25.

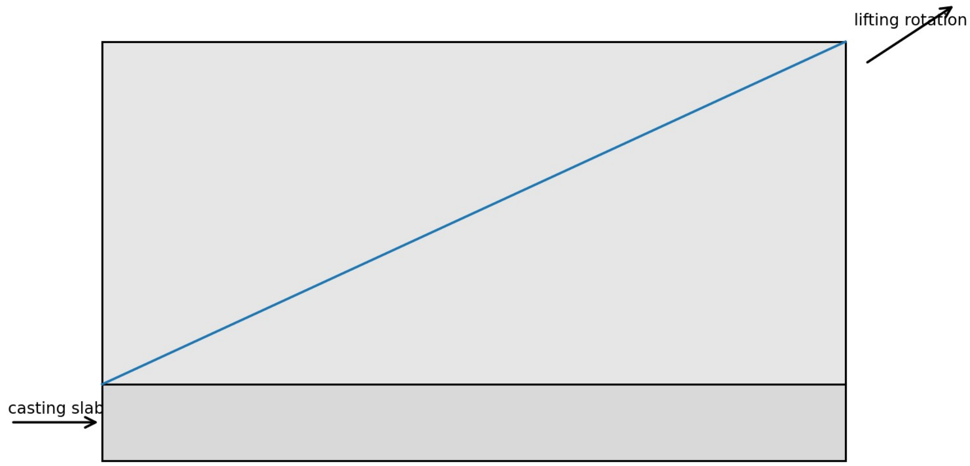

Figure 17-3. Tilt-up sequence from casting through lifting, bracing, joint sealing and interior secondary boundary. Author's original schematic. Acoustic evidence must follow the construction sequence.

Worked example 17.9. Brace-hole closure count

A room uses eight tilt-up panels, each with two temporary brace anchors. Sixteen holes require permanent closure. If inspection samples only four at random and two closures are defective among the sixteen, probability of detecting at least one defect without replacement is

P = 1-(C (14, 4))/(C (16, 4)) = 0.45.

A four-hole sample has less than even odds of finding a two-defect condition. Complete inspection is justified where consequences are high.

17.10 Composite concrete systems

Composite systems include concrete on metal deck, precast planks with toppings, steel beams acting with slabs, concrete-filled steel elements and sandwich panels; each component contributes mass, stiffness and junctions; metal deck flutes create air paths and local resonances. Shear connectors increase structural coupling. Toppings can close joints but crack at supports; insulation layers can act as springs if continuous and resilient.

A composite floor may exhibit high airborne isolation yet carry impact and machinery vibration efficiently; the room boundary often intersects deck ribs, beams and columns. Fireproofing can conceal openings. Acoustic seals must be compatible with fire systems and movement; a drawing that shows a flat slab where fluted deck exists is not adequate.

Composite sandwich panels require attention to wythe connectors; rigid connectors transmit vibration between concrete wythes; fibre-reinforced connectors can have different stiffness and thermal behaviour; insulation discontinuities, panel joints and anchors matter; product descriptions should not replace full test reports.

Worked example 17.10. Added topping mass

A 65 mm concrete topping with density 2,300 kg/m^3 adds

m' = 0.065(2,300) = 149.5 kg/m^2.

If the underlying plank system has 300 kg/m^2, ideal mass-law screen suggests

$\Delta R = 20 \log_{10}((449.5)/(300)) = 3.51$ dB.

Actual improvement depends on composite action, joints and coincidence. The topping may also increase structural flanking.

17.11 Openings, sleeves and embedded plates

Concrete openings are often established by blockouts, sleeves or later coring; planned openings allow reinforcement and structural forces to be coordinated; unplanned cores can cut bars or tendons, reduce fire cover and create irregular annular gaps; every opening should have an identifier, structural approval, service description, firestop system and acoustic closure.

Cast-in sleeves provide geometric control but are rigid bridges; plastic sleeves can have lower stiffness but different fire behaviour; steel sleeves can transmit pipe vibration; sleeves that remain open for future services must be capped at both ends with durable systems. Foam alone is rarely adequate for high isolation.

Embedded plates support equipment, partitions or façades; they can form direct force paths into the shell; heavy screens and loudspeakers should not be attached casually to the protected wall; equipment support is integrated with structural and acoustic design.

Worked example 17.11. Annular area around a pipe sleeve

A 60 mm pipe passes through a 100 mm sleeve. Annular area is

$S = (\pi)/(4)(0.100^2 - 0.060^2) = 0.00503\ m^2$.

This is 50.3 cm^2. The opening requires a documented fire, smoke and acoustic system. A thin surface bead does not fill the three-dimensional path.

17.12 Room-within-room construction inside a concrete shell

A concrete shell provides robust outer protection, but a high-consequence room may use an isolated inner room to control structure-borne and service paths; the inner room can include resiliently supported floor, independent walls and isolated ceiling; its performance depends upon continuous separation. One rigid pipe support, cable tray, door threshold or ceiling hanger can short-circuit the system.

The cavity between inner and outer rooms becomes a controlled inspection zone; it needs drainage, fire detection, access and environmental management; services should cross through designed transition assemblies; the inner floor must carry occupants and equipment without bottoming. The ceiling supports must remain safe under seismic and fire conditions.

A room-within-room system shifts the weakest path towards doors, ducts and services. The direct concrete shell may cease to matter acoustically. Commissioning must test the complete operational state, including ventilation, power and conferencing equipment.

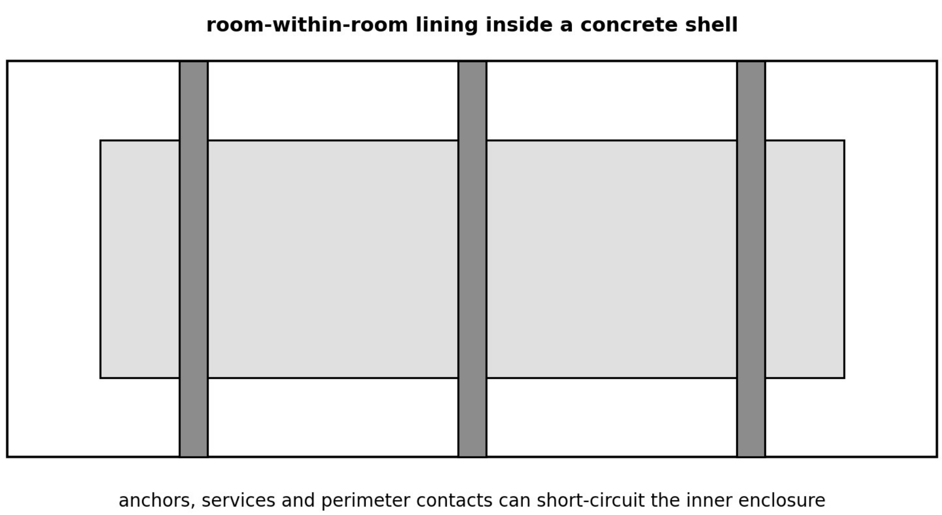

Figure 17-4. Room-within-room construction inside a concrete shell with isolated floor, independent walls, isolated ceiling and controlled service transitions. Author's original schematic.

Worked example 17.12. Floating inner-room resonance

An inner room and equipment have supported mass 38,000 kg. Resilient supports provide total vertical stiffness 2.5×10^7 N/m. Natural frequency is

$$f_n = \frac{1}{2\pi} \sqrt{\frac{2.5 \times 10^7}{38{,}000}} = 4.08 \text{ Hz}.$$

Forcing well above sqrt (2) f_n can enter the isolation region in an ideal damped model. Static deflection, damping, horizontal stiffness, rocking and support tolerances must also be checked.

17.13 Surface treatments and attached linings

Concrete surfaces may be left exposed, painted, plastered, furred or lined independently; paint can reduce distributed porosity but contributes little mass. Plaster adds mass and closure. Direct-bonded gypsum changes surface damping and stiffness but does not decouple; furred linings create cavities and resonances; independent linings can provide major improvement if bridges are controlled.

Surface preparation matters. Form release agents, curing compounds, laitance and moisture affect adhesion. Cracks hidden by finishes remain. A lining can conceal leaks and make future inspection difficult; the design should state whether the concrete or the inner lining is the primary boundary and how each is inspected.

Absorptive finishes inside the room reduce reverberant energy but do not increase wall transmission loss directly. Occupants may compensate with vocal effort. The occupied speech-security model must retain both effects.

Worked example 17.13. Cavity resonance with direct furring

A 10 kg/m^2 lining is furred 50 mm from concrete. Ideal rigid-backing resonance is

$$f_r = \frac{1}{2\pi} \sqrt{\frac{1.2(343)^2}{0.050(10)}} = 84.6 \text{ Hz}.$$

Rigid furring connections can raise coupling beyond the air-spring model. The calculation identifies a risk band but not field performance.

17.14 Nondestructive examination and controlled verification

Concrete investigation can use cover meters, ground-penetrating radar, ultrasonic pulse velocity, impact echo, rebound hammer, infrared methods and radiography under suitable controls; each method has a defined measurand and limitations; cover meters identify reinforcement location, not void-free concrete; rebound number screens surface hardness, not direct compressive strength without correlation. Ultrasonic pulse velocity responds to path, moisture and coupling; impact echo can estimate thickness and detect certain interfaces.[105][106][107]

Core sampling provides direct material and thickness evidence but is destructive and local; ASTM C42/C42M governs obtaining and testing cores;[108] coring in post-tensioned or heavily reinforced work requires scanning and structural approval; a core hole must be repaired with a compatible structural, fire and acoustic system.

The investigation plan begins with the question; if the concern is a suspected open sleeve, borescope access may be more discriminating than rebound testing; if the concern is thickness, impact echo or cores may help; if the concern is structural flanking, mobility measurement is more relevant. Tool availability should not determine the hypothesis.

Worked example 17.14. Pulse-velocity screen

A 300 mm wall produces ultrasonic transit time 72 microseconds along a direct path. Apparent pulse velocity is

$v = (0.300)/(72 \times 10^{-6}) = 4{,}167$ m/s.

105 MB-0294. ASTM International, ASTM E492-22.
106 MB-0343. ASTM International, ASTM E989-21.
107 MB-0200. ASTM International, ASTM E1007-21.
108 MB-0877. International Organization for Standardization, ISO 16283-2:2020.

The value is plausible for dense concrete, but moisture, reinforcement alignment and coupling affect it. It does not prove acoustic transmission loss or absence of local voids elsewhere.

17.15 Field acoustical measurement of concrete rooms

Field measurement under ASTM E336-25a or ISO 16283-1:2025 captures the complete configured room-to-room path;[109][110] massive concrete creates dynamic-range challenges because receiving levels can approach background; bands that cannot be resolved are reported as lower bounds; the report should not convert a censored spectrum into a falsely exact rating.

Low-frequency source and microphone placement require attention; concrete rooms support strong modes, and spatial averages can vary; structural flanking may be coherent over large surfaces; vibration measurements at slabs, walls and columns can support path discrimination, but they do not replace airborne measurement.

The test state records door closure, ventilation, penetrations, masking, equipment, temporary seals and adjacent-room activity; a room tested before services are commissioned is not the operational room; retesting after material changes preserves the evidence chain.

Worked example 17.15. Dynamic-range lower bound

Source-room level is 96 dB in a band; receiving level with source is 20 dB, while background is 19.5 dB; reliable subtraction is not possible under a typical method; the level difference is at least approximately 76 dB, not

109 MB-0905. International Organization for Standardization, ISO 717-2:2020.
110 MB-0062. ASHRAE, ASHRAE Handbook, HVAC Applications.

exactly 76.5 dB. The band is reported as a lower bound and excluded or treated according to the classification rule.

17.16 Forensic case study. Precast boardroom with a hidden joint path

A corporate boardroom occupies a precast concrete building; panel field measurements and design data suggest high direct isolation, but speech fragments are audible in an adjoining stair enclosure; the common wall comprises two precast panels joined at a vertical connection concealed behind plaster and millwork.

A scanning sound-level map identifies a narrow vertical maximum; thermal imaging shows no useful anomaly; removal of a controlled millwork panel reveals an interior sealant bead debonded from one panel, with the joint cavity connected to the stair-side finish; the structural welded plate is intact. A reversible membrane seal improves the upper speech bands by 11 dB while leaving low-frequency slab response unchanged.

The permanent repair removes incompatible sealant, prepares substrates, installs backing and a movement-capable seal, and restores finishes with inspection access. Field retest verifies improvement. The report distinguishes structural joint integrity, air closure and room performance; no conclusion is drawn from panel mass alone.

17.17 Construction surveillance and hold points

Concrete evidence is strongest when acquired during construction; hold points include reinforcement and embeds before placement, form ties and sleeves, joint preparation, consolidation observations, precast connections, grout pockets, closure pours, tilt-up insert closure, firestop and lining cavities. Photographs use coordinates and scales. Batch and placement records are linked to wall zones.

Nonconformance management must preserve both structural and acoustic consequences; honeycombing repaired under an approved structural procedure is documented for acoustic review; a relocated sleeve triggers penetration-register revision; a change in precast sealant is reviewed for movement, substrate, fire and service life. Closing finishes before acceptance creates an evidence deficit that later nondestructive testing may not fully cure.

The completed as-built model records what remains uncertain. Scholarly and professional integrity require explicit uncertainty rather than invented completeness.

Worked example 17.16. Inspection coverage of form ties

A wall contains 420 form-tie closures. Risk-based plan inspects all 36 closures within 1 m of protected-room openings and a stratified 15 per cent of the remaining 384. Total inspected is

$36+0.15(384) = 94.$

The plan covers 22.4 per cent overall but concentrates on high-consequence zones. It remains a sampling plan, not proof of every closure.

17.18 Concrete mixture, shrinkage and acoustic stability

Concrete mixture proportions influence density, elastic modulus, creep, drying shrinkage, thermal response and crack susceptibility; these effects matter acoustically because a wall commissioned soon after casting may continue to dry and shorten; restraint at slabs, columns and returns can convert free shrinkage into tensile stress. A surface that initially tests well can later develop cracks at construction joints, form-tie patches or penetrations.

The acoustical specification should not attempt to redesign the structural mixture; it should identify which concrete properties enter the prediction and require the structural and materials records needed to interpret later measurements; density, age, moisture, curing, placement temperature and crack survey are more useful than a generic compressive-strength label.

Worked example 17.17. Restrained shrinkage strain

A 12 m wall has free drying-shrinkage strain 450 microstrain. Free shortening is

$\Delta L = (450 \times 10^{-6})(12) = 5.4$ mm.

If restraint prevents most shortening, tensile stress and cracking risk develop according to creep, reinforcement and tensile capacity. The calculation does not predict crack width, but it quantifies the incompatible movement.

17.19 Thermal gradients and transient cracking

Thick concrete walls can experience temperature gradients between room and exterior or between freshly placed concrete and ambient conditions; differential strain bends panels and stresses joints; solar heating of tilt-up or precast panels can change joint widths during the day. Interior finishes can conceal the movement.

Field acoustic tests should record relevant temperature states; a seal that performs at dawn may open at an afternoon extreme; long-term monitoring can correlate crack or joint width with temperature; this is particularly important where a protected room adjoins an exterior precast wall.

Worked example 17.18. Thermal extension

A 10 m precast panel with thermal coefficient 10×10^{-6}/^(°) C experiences a 35°C temperature change. Free movement is

$\Delta L = (10 \times 10^{-6})(35)(10) = 3.5$ mm.

Panel joints and seals must accommodate this movement plus moisture, creep and tolerance.

17.20 Sandwich panels and wythe connectors

Insulated precast sandwich panels use two concrete wythes separated by insulation and joined by connectors; structurally composite panels use connectors that transfer shear between wythes; non-composite panels permit more independent action; the connector type changes thermal bridging, stiffness and vibration transfer. Insulation acts as a cavity material but is not necessarily a resilient acoustic spring because connectors and perimeter concrete remain.

Openings, panel edges and connection zones can short-circuit the wythes. Laboratory evidence should identify panel size, wythe thickness, connector type, insulation and supports. A thermal-performance designation does not establish airborne isolation.

Worked example 17.19. Sandwich-panel surface mass

Two concrete wythes are 75 mm and 100 mm thick at 2,350 kg/m^3. Total concrete surface mass is

$m' = 0.175(2{,}350) = 411$ kg/m^2.

The insulation adds little mass. Direct performance still depends on connector coupling and panel modes.

17.21 Embedded conduits and distributed weakness

Electrical conduits are sometimes cast into walls and slabs; a single small conduit may be benign, but repeated runs reduce local section, create cracking planes and connect boxes; metallic conduit transfers vibration; plastic conduit has lower stiffness but remains an air path when open. Future cable pulls can reopen closures.

The structural design controls permissible embed size and spacing; the acoustic plan favours dedicated transition zones and surface-side distribution within the protected room; as-built scanning and photographs are valuable because embedded routes disappear completely after casting.

Worked example 17.20. Distributed conduit displacement

Ten 25 mm conduits run vertically in a 200 mm wall over 3 m height. Total displaced volume is

$V = 10(\pi\,(0.025)^2)/(4)(3) = 0.0147\ m^3$.

Across a 3 m by 3 m wall zone, equivalent concrete surface-mass reduction is only about 3.9 kg/m^2, but local stress, boxes and open conduit ends can dominate.

17.22 Numerical modelling and model discrepancy

Finite-element and boundary-element models can examine concrete wall modes, slab flanking and junction forces; their value depends upon geometry, material properties, boundary conditions, mesh, damping and validation; an elegant model with assumed fixed edges and uniform concrete can misrepresent a cracked, jointed building.

Model discrepancy should be treated as an uncertainty term rather than hidden by calibration; measurements of mobility, modal frequency or transfer functions can update parameters, but overfitting one dataset can damage predictive value; the report states which outputs are robust to uncertain inputs and which remain scenario-dependent.

Worked example 17.21. Modal-frequency sensitivity to modulus

For a plate mode with frequency proportional to sqrt (E), a ±20 per cent modulus range produces frequency factors sqrt (0.8) = 0.894 and sqrt (1.2) = 1.095; a predicted 100 Hz mode could lie roughly between 89 and 110 Hz before other uncertainties. Reporting 100.0 Hz would be false precision.

17.23 Repair verification and compatibility

Concrete repair closes defects, restores durability or strength and can improve acoustic continuity. Repair shrinkage, bond, stiffness and moisture compatibility govern longevity; a very stiff patch can concentrate stress at its edges; a flexible seal can preserve movement but may not restore structural action; the selected method follows the diagnosed cause and ACI 562/563 framework.[111][112]

Verification includes substrate preparation, material batch, placement, cure, visual inspection and retest. Acoustic improvement is measured under comparable conditions. A surface repair that improves one band but leaves structural flanking unchanged is reported accordingly.

Worked example 17.22. Repair-area mass effect

A 0.8 m^2 honeycombed zone in a 30 m^2 wall is repaired, increasing local surface mass from 320 to 470 kg/m^2. Wall-average mass increases by

111 MB-0889. International Organization for Standardization, ISO 20816-1:2016.
112 MB-0861. International Organization for Standardization, ISO 16063-21:2003.

$\Delta m' = (0.8(150))/(30) = 4.0\ kg/m^2$.

The average mass effect is small; closing pores and restoring continuity may create the main acoustic gain.

17.24 Concrete microstructure, density, modulus, damping and uncertainty

Concrete is not a single material. Its acoustic and structural response depends upon aggregate type and grading, paste content, water-cementitious ratio, air content, curing, moisture, age, cracking and reinforcement; a nominal density can support a preliminary mass calculation, but it does not establish elastic modulus, damping, porosity or radiation efficiency; two concretes of equal density may have different wave speeds and loss factors because the aggregate-paste interfaces and crack populations differ. [113]

For direct airborne transmission through a thick wall, surface mass is important; for structure-borne transmission, stiffness and damping are equally important; the longitudinal wave speed depends broadly upon elastic modulus, density and Poisson ratio; bending-wave behaviour of a panel depends upon flexural rigidity, which scales with thickness cubed. A modest thickness change can therefore shift modal and coincidence-related behaviour more strongly than a comparable percentage change in density.

Moisture alters both mass and dynamic properties; young concrete continues to hydrate and dry; a wall tested shortly after construction may not represent its later state; temperature and humidity also change joints and attached linings; the commissioning record should identify concrete

113 MB-0762. Frank Fahy and Paolo Gardonio, Sound and Structural Vibration, 2nd ed.

age, environmental condition and whether finishes have reached equilibrium. Repeated tests should compare like states where possible.

Damping is particularly uncertain. Concrete exhibits material damping, microcrack friction, interface loss and energy transfer into adjoining structure; a small specimen loss factor cannot be applied uncritically to a full wall connected to slabs and columns. Boundary loss may dominate. Field decay measurements, mobility tests and model calibration can be more informative than a generic material value.

The uncertainty budget for a predictive model should therefore separate density, thickness, modulus, damping, boundary restraint and opening geometry. Correlations matter. Higher-strength concrete may have higher modulus and different cracking; a repair material may be denser and stiffer than the substrate; treating every input as independent can overstate or understate uncertainty.

Integrated worked example 17.23. Sensitivity of a wall mode to modulus and thickness

A simply supported concrete panel is screened with natural frequency proportional to h sqrt(E/rho), where h is thickness, E is elastic modulus and rho is density; let the baseline be h = 0.200 m, E = 30 GPa and rho = 2,400 kg/m3. If thickness increases by 5 per cent while E and rho remain fixed, the screened frequency increases by 5 per cent; if modulus increases by 10 per cent, frequency increases by sqrt(1.10) = 1.048, or 4.8 per cent.

If both changes occur, frequency ratio is 1.05 times 1.048 = 1.100, approximately a 10 per cent increase. The relation is dimensionally consistent because E/rho has units m2/s2, its square root has m/s, and multiplication by h divided by a squared span supplies 1/s in the complete plate equation; the example shows why thickness and modulus records matter to modal interpretation. It does not predict the field wall without geometry, boundary and damping data.

17.25 Construction joints, lift lines, waterstops and acoustic continuity

Construction joints are planned interruptions in placement; they can be structurally adequate while remaining acoustically consequential; surface preparation, aggregate interlock, reinforcement continuity, shear-friction design, waterstops and sealants determine how force and air pass across the interface; a joint is therefore neither automatically weak nor automatically monolithic.

Vertical wall lifts can create horizontal planes of different surface texture and compaction; if laitance is not removed or consolidation is poor, a porous band can remain; formwork leakage can create fins or honeycombing; a waterstop may divide the section and introduce a local compliance. Reinforcement crosses the joint, preserving structural force transfer. The resulting acoustic path can include direct air leakage, local radiation and structure-borne continuity.

The specification should identify joint locations before acoustic design is complete; a joint placed behind a large display, door frame or service zone can combine multiple vulnerabilities; where the secure boundary cannot avoid a joint, the detail should show surface preparation, keying, reinforcement, seal or injection provision and inspection. Photographs and placement records should be linked to the wall-zone map.

Cold joints differ from planned joints. An unplanned delay can produce uncertain bond and consolidation; the event log should record time, concrete temperature, cause and corrective action; a visual line after stripping is not enough to assess depth; nondestructive methods can screen, but targeted coring may be required where structural or security consequence is high.

Water-retaining details can conflict with acoustic repairs; injecting a crack with rigid epoxy may restore continuity but transfer more vibration. A flexible injection may close air and water paths but provide limited structural bond; the repair objective, material properties and expected movement must be explicit; a repair accepted under ACI 562 or a project specification still requires acoustic verification where the path is security-significant. [114]

17.26 Form ties, cone holes, sleeves, embeds and distributed weak paths

Cast-in-place walls contain repeated construction features; form ties pass through or nearly through the section; cone recesses are patched after stripping; sleeves and blockouts reserve service routes; embedded plates support later equipment; each feature can become a local acoustic anomaly; the cumulative effect depends upon number, area, depth, material and continuity.

A tie hole filled only at the surfaces can leave a cylindrical cavity through most of the wall; if the inner fill debonds, the path can act as a short duct; a fully grouted tie system may restore mass but create a stiff steel path. Some ties are removed; others remain. The as-built evidence must identify the system rather than assuming that all tie holes are equivalent.

114 MB-1063. National Park Service, Preservation Brief 2, Repointing Mortar Joints in Historic Masonry Buildings.

Distributed defects can govern a high-performing wall even when each is small; the relevant arithmetic is linear transmission, not average decibel rating; a hundred small recesses with moderate local loss can contribute more than one visible patch. Inspection should therefore be systematic. A sampling plan based only on random visual checks can miss a repeated workmanship defect that occurs at one elevation or one crew's work.

Sleeves require dimensional control. An oversized sleeve leaves an annulus that must satisfy fire, movement and acoustic requirements; a steel sleeve can transmit vibration; a sleeve abandoned after design change remains a path unless removed or permanently closed; the penetration register should include unused blockouts and capped sleeves, not only active services.

Embedded plates are often overlooked. A plate welded to reinforcement and exposed on both sides can form an efficient mechanical path; even when only one face is exposed, attached equipment can excite the wall; a secure-room display, cabinet or door frame should not be fixed to an embed without considering structure-borne transmission. Where heavy support is necessary, isolation may be introduced at the equipment interface or by an independent support structure.

Integrated worked example 17.24. Repeated tie-hole contribution

A 40 m2 wall has direct transmission loss 58 dB at a selected band; it contains 120 tie-hole patches, each with effective area 0.00020 m2 and local transmission loss 30 dB; wall coefficient is 10^-5.8 = 1.58e-6. Patch coefficient is 10^-3 = 0.001; total patch area is 0.024 m2.

Composite coefficient is

[(39.976)(1.58e-6) + (0.024)(0.001)] / 40 = 2.18e-6.

Composite loss is 56.6 dB; the repeated patches reduce the band by about 1.4 dB in this screen; if local patch loss were 20 dB, composite loss would fall to about 51.9 dB; the result shows the sensitivity to patch quality; it assumes independent area paths and ignores structural coupling, so it cannot replace measurement.

17.27 Precast joints, bearings, welds and connection impedance

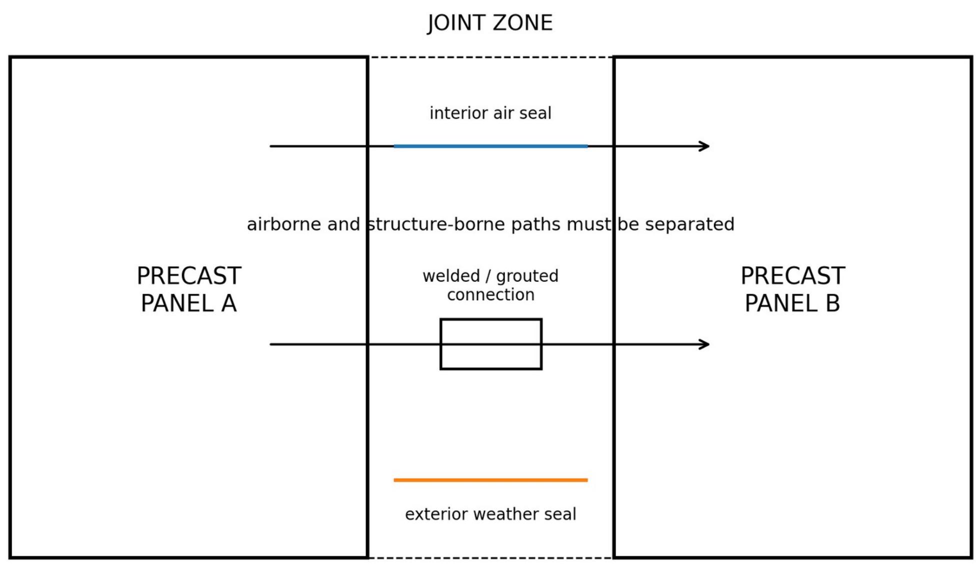

Figure 17-R1. Precast joint topology showing separate air-seal and structural-connection paths. Author's original schematic.

Precast construction transfers much of the acoustic problem from the panel field to the joints and connections; panel concrete may be dense and well controlled, yet the completed boundary includes erection tolerances, bearing pads, welded plates, grouted sleeves, closure pours, sealants and façade cavities. The joint must carry structural movement and weather loads while maintaining the intended air and vibration control.

Vertical panel joints can contain backer rod and sealant on one or both faces; a single exterior weather seal may leave an interior cavity connected to the room; double seals can improve redundancy, but trapped moisture and inspection access must be considered. Interior secure-room boundaries often require a separate continuous air seal that is not dependent solely on the façade joint.

Bearing pads introduce compliance. Their dynamic stiffness depends upon material, area, thickness, preload and temperature; a neoprene pad that supports gravity load can reduce some high-frequency vibration but remain stiff at low frequency; welded plates and reinforcing bars bypass the pad. The connection network therefore requires more than a simple “resilient bearing” label.

Welded connections can create local radiation. A plate welded to an embedded anchor transfers force into the panel; closure pours make connections more continuous after erection; grouted sleeves and dowels create stiff points; the spacing and topology determine whether the panel behaves as a series of bays or as a continuous wall. Structural drawings and erection details are essential acoustic source documents.

Joint inspection should occur during erection and after seal installation; record panel identification, bearing condition, connection completion, closure-pour placement, joint width, backer depth, sealant depth and adhesion; tolerance surveys show whether joints remain within the designed movement range. Later façade maintenance can disturb exterior seals without access to the secure room, so the lifecycle plan should assign responsibility and retest triggers.

Integrated worked example 17.25. Connection-path screening in a precast wall

A panel has six steel connections. Each connection transfers vibration with screened force transmissibility 0.12 at 250 Hz; if source forces at the six points are incoherent and equal, total mean-square transmitted force is six times the contribution of one connection, giving an amplitude factor sqrt(6) times 0.12 = 0.294 relative to one source force. If the forces are coherent and in phase, amplitude factor can approach 6 times 0.12 = 0.72.

The difference is 7.8 dB; the example shows why phase and spatial correlation matter; connection count alone is insufficient; field mobility and coherence measurements can determine whether the coherent or incoherent assumption is more appropriate.

17.28 Tilt-up erection, brace anchors, base joints and patching

Tilt-up panels begin as slabs and become walls through an erection sequence; lifting inserts, brace anchors, temporary connections and casting-bed conditions create features that later require patching; panel bases are grouted or sealed after erection; roof and floor connections complete the load path. Acoustic performance depends upon the final state of all these operations.

Brace anchors can leave deep holes. Patches must bond, fill the recess and remain compatible with the panel; a cosmetic surface patch over a void can create a resonant cavity or leakage route; the repair record should identify depth and material; where anchors fall within a secure boundary, representative destructive verification may be justified before finishes conceal them.

The panel base joint is critical. Levelling shims and grout pads support load; the remaining gap may receive non-shrink grout, sealant or both; differential movement and shrinkage can crack the interface; a continuous floor finish can conceal the joint while also bridging isolation; the detail should distinguish structural bearing, air seal, firestop and finish.

Panel-to-roof connections create a long flanking path; a roof diaphragm can carry vibration beyond the room; interior linings that stop at a suspended ceiling leave the panel and deck connection exposed; where a room requires high isolation, the inner boundary should extend to a controlled structural plane, and roof or deck paths should be assessed separately.

Tilt-up panels may include insulation and composite wythes; connector stiffness and distribution control composite action; a thermally efficient connector may still transmit vibration; the acoustic model should use the actual panel system and not a generic solid-concrete assumption.

17.29 Composite, prestressed and layered concrete systems

Composite concrete systems include topping slabs on precast units, concrete on metal deck, insulated sandwich panels, concrete-filled forms and panels with attached masonry or gypsum linings; each layer contributes mass, stiffness, damping and interfaces; composite action can raise flexural rigidity, while partial interaction can introduce slip and loss.

Prestressing changes cracking and boundary force; precompression can keep sections closed under service load, reducing open cracks; tendons and strands also create continuous stiff paths; hollow-core units contain longitudinal voids that can communicate through cut ends and service penetrations; topping concrete can connect units and alter diaphragm behaviour. The complete assembly should be mapped from room surface to supporting structure.

Metal deck beneath a composite slab provides a corrugated path; deck flutes can continue under partitions; concrete fill may close some cavities but not others; spray-applied fireproofing and suspended ceilings can conceal the geometry. A secure-room wall that terminates at the deck underside must address flute continuity and movement.

Sandwich wall panels present two concrete wythes separated by insulation and connected by ties; the wythes can behave partly independently or as a composite depending upon connector stiffness; the cavity is solid insulation rather than air, but connectors still transfer vibration. Joints between panels and connections to floors may dominate.

Integrated worked example 17.26. Effective stiffness of a partially composite layered panel

Two concrete wythes each have individual flexural rigidity D; if they act independently, total rigidity is approximately 2D; if perfectly composite with substantial separation, transformed-section rigidity can be many times 2D because the parallel-axis term dominates; suppose testing or analysis supports an effective composite factor eta between 0 and 1, and perfectly composite rigidity is 12D. A simple interpolation gives

$D_{eff} = 2D + \eta(12D - 2D)$.

For eta = 0.35, $D_{eff} = 5.5D$; natural frequencies proportional to $\sqrt{D_{eff}}$ are 1.66 times those of the independent 2D state; the interpolation is not a design equation; it illustrates how uncertain connector action can shift modal behaviour and why panel-specific evidence is necessary.

17.30 Concrete repair, compatibility and acoustic verification

Concrete repair changes the mechanical system. Removing unsound concrete alters mass and restraint; reinforcement may be exposed and supplemented; repair mortar, shotcrete, grout or epoxy can have different modulus, shrinkage and damping from the substrate; a structurally acceptable repair can therefore change local vibration and radiation.

Repair selection begins with cause. Honeycombing from poor consolidation differs from delamination caused by corrosion; a dormant crack differs from an active movement joint; injecting an active crack with rigid resin may create a new crack nearby; patching over a leaking sleeve may conceal an air path. The repair objective should distinguish structural capacity, durability, water control and acoustic closure.

Surface preparation is part of acoustic performance; a poorly bonded patch can form a thin plate over a cavity; its local resonance may be audible under tapping or measurable under swept excitation; bond tests, sounding, impact echo or thermography can support quality control, but each method has limits. A repaired zone should be included in post-work acoustic scans where it lies on a protected boundary.

Before-and-after comparison should use the same geometry and state; a change in room furnishing or background can obscure the effect; the report should separate the local repair result from the whole-room result; a 10 dB improvement at the repaired patch may yield little room benefit if a door or duct controls.

17.31 Nondestructive examination and the problem of ambiguous indications

Ultrasonic pulse velocity, impact echo, ground-penetrating radar, infrared thermography, radiography and acoustic emission can reveal aspects of concrete condition; none produces a direct map of sound transmission loss; their value lies in testing specific physical hypotheses.

Pulse velocity can indicate relative continuity and material quality along a path; moisture, reinforcement and coupling affect the result; impact echo can locate reflecting interfaces or thickness changes, but geometry and multiple modes complicate interpretation; radar can locate reinforcement, tendons and some voids, yet dielectric variation and depth limit resolution. Thermography can reveal delamination under favourable heating conditions. Radiography provides direct density contrast but entails access, safety and practical constraints.

A method should be selected from the suspected defect and the required detection limit; searching for a 50 mm deep delamination requires a different tool from locating a tendon or verifying a filled sleeve; calibration blocks and known reference zones improve interpretation. Results should be stored with raw data, instrument settings, coordinate systems and uncertainty.

Controlled opening remains the most direct verification, but it is destructive and samples a small area; it should be targeted by the non-destructive evidence and authorised by the structural and security teams; the opened condition is photographed, measured and preserved as evidence. Restoration is designed and retested.

Integrated worked example 17.27. Detection probability for clustered honeycombing

A wall has three suspected honeycombed zones, each approximately 0.6 m by 0.6 m, within a 60 m2 surface; ten random 100 mm diameter cores have negligible probability of intersecting a zone if the defects are clustered away from the random points. A grid scan with 0.25 m spacing over the three suspect areas yields 49 measurements per area and direct spatial coverage.

The example demonstrates that random destructive sampling and targeted nondestructive mapping answer different questions. An inspection plan should follow the defect mechanism and prior evidence, not a fixed sample percentage.

17.32 Room-within-room design inside a concrete shell

A concrete shell provides mass, fire resistance and physical robustness, but an inner room may be required to control structural flanking, services and openings; the inner shell can use independent walls, a floating floor and an isolated ceiling. Its success depends upon complete separation, load paths and clearances.

The floating floor supports occupants, furniture and equipment; resilient elements are selected for static load, natural frequency, damping, creep and durability; uneven load can create differential settlement; perimeter isolation must remain clear; a screw, grout spill, threshold anchor or service pipe can bridge the system. Inspection before closure is indispensable.

Inner walls should be supported from the floating floor or an independently designed structure, not casually tied to the outer concrete; lateral stability may require resilient restraints; the ceiling must account for self-weight, services, access panels and seismic restraint. Sprinklers, ducts, cable trays and light fittings cross the cavity and require flexible connections or independent support.

The cavity should be accessible or at least inspectable at critical points; water leaks can damage resilient materials. Debris can create bridges. The design should include drainage or leak detection where risk warrants; a room-within-room system that cannot be maintained is not a durable security control.

Commissioning occurs in stages. Structural deflection and clearances are checked before finishes; mobility or transfer tests can identify bridges; airborne tests are performed after the inner shell is complete; operational speech testing follows under defined source and receiving conditions. Formal acceptance remains a separate authority decision.

17.33 Integrated concrete case study. Precast operations room with dual path failure

An operations room occupies a precast concrete building; the separating wall consists of 200 mm precast panels on neoprene bearings, with vertical joints sealed internally and externally; a continuous concrete topping connects the floor system; the room contains a large cable trench and two wall-mounted displays supported from embedded plates.

Laboratory data for a nominal panel indicate strong airborne isolation; field testing shows a broad deficit below 315 Hz and a narrow leak around 1.6 kHz; receiver scans locate the high-frequency leak at one vertical joint. Vibration measurements show high coherence between the source-room floor, topping slab and receiving wall below 315 Hz; the display embeds also respond but contribute less.

Joint inspection finds an interior sealant void behind a cover strip; temporary sealing improves the 1.6 kHz band by 14 dB. The low-frequency deficit remains. A structural model and mobility measurements show that the continuous topping and welded panel connections create a flanking path; improving the panel field would not address it.

The remedy combines local joint reconstruction with an independent inner lining supported on a floating floor zone; the lining is laterally restrained with measured resilient brackets; the cable trench receives flexible, listed service transitions; display frames are floor-supported from the inner system. No attempt is made to cut structural connections.

Post-remediation tests show substantial improvement above 250 Hz and a smaller low-frequency gain limited by the building frame; the acceptance report states the residual curve, authorised source states and listener locations; it does not claim that the concrete shell has a universal rating or that structural flanking has been eliminated. The case demonstrates the proper sequence: identify direct and flanking mechanisms, preserve structural safety, remediate controllable paths and report residual limitations.

17.34 Prestress anchorage zones, closure strips and diaphragm discontinuities

Prestressed and post-tensioned concrete concentrates force at anchorages, transfer zones and closure strips; these regions contain dense reinforcement, bearing plates, ducts, grout and local cracking control; their stiffness and mass differ from the surrounding field; a secure-room wall or slab adjacent to an anchorage zone should not be represented by uniform properties alone.

Closure strips and pour strips create temporary discontinuities that later become structural connections; surface preparation, reinforcement splices, shrinkage and curing determine final continuity; an incomplete closure can carry air or moisture; a highly stiff closure can redirect vibration. The as-built record should identify the closure material, date, joint preparation and inspection.

Diaphragm openings for stairs, shafts and services alter wave paths; a wall connected near an opening can experience higher local mobility; models should include nearby discontinuities when low-frequency flanking is important; field mobility mapping can validate the predicted influence.

17.35 Concrete wall thickness, dimensional tolerance and local minimum sections

Nominal wall thickness is not the minimum as-built thickness; form deflection, offsets, blockouts, chases and surface grinding create variation; a local thin region can have lower mass and stiffness, while a thick repair can create a stiff island. Laser survey, cover meters and targeted ultrasonic thickness methods can document geometry where it matters.

Thickness variation should enter predictive uncertainty. A 10 mm reduction in a 150 mm wall is 6.7 per cent mass loss and a much larger flexural-rigidity change because rigidity scales approximately with thickness cubed; for a simply supported plate, the local modal frequency and radiation can therefore change materially.

Integrated worked example 17.28. Thickness tolerance and flexural rigidity

A wall nominally 180 mm thick is measured at 165 mm in a broad recessed zone; the thickness ratio is 0.917; surface mass falls by 8.3 per cent if density is unchanged; flexural rigidity ratio is 0.917 cubed = 0.771, a twenty-three per cent reduction. The recess may therefore influence structural response more strongly than its mass difference suggests.

The calculation assumes equal modulus and simple plate behaviour. It supports targeted modelling and field scanning rather than a categorical failure statement.

17.36 Concrete-filled forms and stay-in-place systems

Insulating concrete forms, permanent metal forms and composite stay-in-place systems leave materials attached to the concrete; these layers affect cavity geometry, damping, fire behaviour and attachment; a wall may appear to be solid concrete while interior foam, webs or facings create service routes and resonant panels.

Acoustic evidence should identify the complete assembly; product literature for the form does not replace field data; services cut into foam can connect outlets; furring strips embedded in the form can create repeated attachment paths. Fire and smoke requirements may limit exposed foam or cavity materials.

Where an independent lining is added, the existing form layers become part of a triple-layer system; mass-air-mass resonances and rigid bridges should be analysed; a direct-bonded board over foam can radiate even when the concrete behind is strong.

17.37 Construction vibration, early-age cracking and later security implications

Concrete experiences vibration during construction from consolidation, equipment and nearby work; early-age thermal gradients and restraint can create cracks before occupancy; some cracks are repaired and concealed by finishes; the security record should preserve crack maps, repair locations and causes where known.

A crack repaired structurally may remain a future movement plane; monitoring points can be installed at significant locations; later acoustic change should be compared with the baseline rather than assuming that the concrete field remained unchanged.

Construction adjacent to an occupied secure room can also change paths. Saw cutting, coring and demolition introduce transient vibration and may damage seals or linings. Work controls should include pre- and post-condition surveys.

17.38 Concrete-room commissioning sequence

A concrete secure-room shell should be commissioned before inner finishes hide its condition; the sequence begins with dimensional survey, crack and joint mapping, tie-hole and sleeve inspection, and verification of embedded items; local air leakage is tested where appropriate. Structural vibration baselines are recorded at representative junctions.

After linings, doors and services are installed, field airborne and structure-borne tests are performed; the source state includes speech and any amplified audio; receiving locations extend beyond the immediately adjacent room where slabs, columns or façades provide access.

The dossier distinguishes shell evidence, installed-system evidence, operational privacy evidence and authority decision; this structure prevents a strong concrete wall from masking a weak door or service path and prevents a room-level pass from erasing a concealed construction defect that requires maintenance.

17.39 High-density concrete, heavyweight aggregate and radiation control

Heavyweight concrete can increase surface mass through magnetite, barite or other dense aggregates; the mass-law screen may therefore improve for a given thickness. That advantage is not free. Aggregate availability, segregation, workability, structural load, shielding purpose, thermal behaviour and cost affect the design; a heavyweight mixture should be treated as a specific material with trial batches and measured density, not as ordinary concrete multiplied by a catalogue factor.

Higher density does not guarantee proportionately higher sound isolation; elastic modulus, damping, cracking and boundary transmission can change; a heavy wall tied rigidly to a flexible slab may move the controlling path to the slab; a wall with sleeves and joints remains vulnerable. Laboratory test data for the exact mixture and geometry are rare, so prediction uncertainty should be stated.

Placement quality is critical. Dense aggregate can segregate if handling is poor; form pressure and equipment capacity change; honeycombing or voids can negate the intended mass; quality assurance includes unit-weight tests, placement records, consolidation observation and representative cores where authorised.

Integrated worked example 17.29. Heavyweight substitution as a bounded mass screen

Compare 250 mm walls at 2,400 and 3,200 kg/m3; surface masses are 600 and 800 kg/m2; ideal mass-law difference is 20 log10(800/600) = 2.50 dB; the structural load increases by one-third; the calculation shows that a large density increase yields a modest ideal airborne gain, while structural and construction consequences are substantial. The decision should therefore be system-based.

17.40 Shotcrete and pneumatically placed repair layers

Shotcrete can create new walls, strengthen existing concrete and repair irregular surfaces; its quality depends upon mixture, nozzle technique, rebound removal, layer thickness, reinforcement encapsulation and curing; a nominal thickness does not establish density or continuity.

Dry-mix and wet-mix processes have different controls; rebound trapped behind reinforcement can create porous zones; shadowing can occur around bars and embeds. Multiple passes create interfaces. Acoustic performance depends upon the final continuous section and its bond to the substrate.

Where shotcrete is used as an interior secure-room lining, overspray and roughness can complicate later air seals and frames; a smooth finish coat may close surface pores but conceal deeper defects; mock-ups and cores can validate workmanship. Structural acceptance and acoustic field testing remain separate.

17.41 Concrete walls with embedded insulation or sacrificial liners

Some wall systems contain cast-in insulation, drainage mats, form liners or architectural panels; these inclusions can create planes of weakness or damping; a continuous foam layer divides the section and can reduce shear transfer. Discrete ties reconnect the wythes. A sacrificial liner may remain as a thin panel that radiates.

The acoustic model should identify whether the system acts as one thick wall, two coupled walls or a composite with partial interaction; fire and moisture requirements constrain cavity materials; penetrations can connect layers and create local triple-leaf conditions.

Field survey should use construction records and targeted inspection; a surface tap response can reveal debonded liners but not the complete internal state; thermal imaging may show insulation continuity; the final room test remains essential.

17.42 Formwork joints, architectural reveals and surface recesses

Architectural concrete often contains reveals, rustications and panel joints; these reduce local thickness and can align with construction joints or form ties; a deep continuous reveal may create a preferred bending line; surface recesses around lights, displays or signage remove mass and introduce anchors.

The structural drawing should show minimum residual thickness; acoustic review should compare recess location with source and receiving geometry; a recess extending over a large fraction of wall area may require local reinforcement or an independent lining. Filling it later with a light material does not restore concrete mass.

17.43 Concrete-to-steel and concrete-to-masonry transitions

Secure boundaries commonly cross material systems. A concrete wall may meet structural steel, CMU, precast façade or gypsum partition; each interface has different movement, stiffness and fire requirements; the transition is often more important than either field material.

Steel columns and beams provide efficient vibration paths. Fireproofing can conceal connections. Masonry may be tied or isolated. Gypsum linings may bridge across the interface; the detail should identify the air seal, movement joint, structural restraint and inner acoustic boundary.

Field diagnostics should scan both materials and the junction; a local hot spot on the gypsum side may originate in the steel; remediation should address the path, not simply add mass to the visible surface.

17.44 Concrete penetrations under change control

The initial construction can be excellent and later coring can defeat it; a controlled process requires structural scan, approved location, sleeve detail, firestop, acoustic closure and as-built update; abandoned openings are closed with a system appropriate to the wall, not a loose plug.

Penetration work should be witnessed in high-consequence zones; core diameter, angle and edge distance are recorded. Dust and slurry are controlled. The opening surface is inspected for cracking; services receive flexible support where structure-borne transmission is relevant.

A post-work acoustic test may be local or room-level depending upon the change; the penetration register should link to the test and photographs; this is one of the most practical lifecycle controls in a concrete secure facility.

17.45 Concrete-system source hierarchy and report language

A defensible concrete chapter distinguishes product and structural standards, construction records, laboratory acoustic tests, field tests and operational evidence; ACI 318 or a precast code establishes structural requirements; ASTM E90 establishes laboratory transmission loss for a specimen; ASTM E336 establishes field room-to-room measurement; none alone establishes occupied speech security or formal accreditation.

Reports should avoid “concrete wall meets STC” unless the exact basis is stated; better language identifies the tested specimen, measured field pair or predictive model; where data are lower bounds because of background, say so; where a repair improved a local path but the whole room remains limited by a door, preserve that distinction.

This evidence hierarchy is not administrative decoration. It prevents a structurally strong wall from being represented as an accredited room and prevents an acoustic anomaly from being misdescribed as structural failure.

17.46 Reinforcement congestion, consolidation shadows and local acoustic defects

Dense reinforcement is required at boundary elements, coupling beams, transfer zones, anchorage regions and heavily loaded openings; it also makes concrete placement more difficult; aggregate can bridge between bars, vibrators may not reach, and paste can separate. The result can be honeycombing, voids or poor bond behind reinforcement.

The acoustic consequence depends upon location and connectivity; a local porous zone near a surface can create leakage or a thin radiating cover; a deeper void may alter stiffness; a continuous defect along a bar cage can form a preferred path. Structural assessment takes priority, but acoustic investigation can help map the anomaly.

Placement planning should consider access for tremies or pumps, mixture workability, maximum aggregate size, lift height and vibrator insertion. Mock-ups are valuable for congested details. Photographs and inspection reports preserve evidence before formwork closes.

17.47 Concrete shrinkage, creep and long-term joint movement

Drying shrinkage and creep continue after construction; restraint by slabs, columns, reinforcement and adjacent walls generates stress; joints and cracks can change for months or years; a field acoustic test performed early is therefore a baseline, not proof of permanent stability.

Movement monitoring at significant joints and openings supports lifecycle assurance; door frames, precast joints and repair interfaces are particularly sensitive. Environmental records help interpret change. A new crack should be investigated for mechanism before sealing.

A design can reduce risk through joint placement, reinforcement, curing and compatible connections. Acoustic seals should accommodate the predicted movement. Rigid finishes should not bridge intended joints.

17.48 Corrosion, spalling and hidden reinforcement paths

Corrosion expands reinforcement and cracks the cover; spalling can reduce local mass and expose steel; water and chlorides may enter through joints or services; a security-significant wall in a parking, coastal or plant environment requires durability review.

Acoustic symptoms can precede visible spalling if debonded cover forms a resonant plate; tapping, chain drag, infrared thermography and impact echo can identify delamination; repair removes unsound material, treats reinforcement and restores cover; post-repair scans confirm that cavities and leakage were not left behind.

17.49 Embedded mechanical and electrical systems

Conduits, boxes, sleeves, radiant tubing and embedded sensors reduce local concrete and provide paths; a cluster of electrical boxes can create a thin web. Steel conduit transmits vibration. Plastic conduit can form an air channel if unsealed.

The design should route services outside the primary concrete boundary or through controlled zones where possible. Required embeds are mapped. Later drilling is prohibited without review. Penetration seals, flexible connections and equipment supports are coordinated.

17.50 Forensic differentiation of crack leakage and structural radiation

A crack can transmit airborne sound through an opening and structure-borne energy through altered contact; temporary air sealing tests the first mechanism; vibration measurements on both sides test the second; if sealing improves high bands but not low-frequency coherent vibration, both paths may exist.

The report should avoid the statement “the crack caused the failure” unless the intervention demonstrates material change and alternatives are considered; crack width alone is not enough; the complete evidence includes geometry, depth, activity, source state and receiving response.

17.51 Cast-in-place wall design from source spectrum to structural boundary

A cast-in-place secure wall should be designed from the protected source and the complete receiving geometry; the initial mass screen identifies whether the proposed thickness is broadly plausible; frequency-resolved prediction then considers finite dimensions, support, coincidence, openings and flanking; structural design establishes reinforcement, joints and serviceability; construction planning establishes how the wall can actually be placed and inspected. The four records should be coordinated before formwork begins.

Source spectra matter because a conference room may contain ordinary speech, maximum vocal effort and amplified programme; a thick wall can provide excellent mid- and high-frequency direct isolation while a slab or door controls lower bands; increasing wall thickness beyond the crossover point provides little room benefit. The design should identify that crossover and allocate resources to the weakest remaining paths.

Wall support changes the model. A wall monolithic with slabs and columns is not a simply supported panel; edge continuity raises some modal frequencies and transfers energy into the frame; a wall isolated by joints has different movement and fire requirements; the calculation should use a boundary range rather than selecting one ideal condition without evidence.

The design drawing should include concrete strength and density assumptions, minimum thickness, reinforcement, planned joints, form ties, sleeves, embeds, opening frames and surface finishes; the acoustic notes identify protected zones in which later drilling requires review; the construction specification establishes mock-ups, hold points and defect disposition.

17.52 Concrete placement sequence as an acoustic quality plan

The placement sequence determines hidden quality. Wall height, pump access, lift depth, reinforcement congestion and form pressure control how concrete flows and consolidates; an acoustic quality plan does not invent a second concrete specification; it identifies where ordinary structural defects would have disproportionate sound consequences.

Before placement, forms are checked for cleanliness, tightness and dimension. Sleeves and embeds are fixed. Reinforcement clearances are verified. Form-tie systems and planned recesses are photographed; during placement, batch and location are recorded; vibrator access and lift progression are observed; leakage, segregation and interruption are documented.

After stripping, the wall is inspected before patching; honeycombing, fins, tie holes, cracks and cold-joint indications are mapped. Repairs are designed, not improvised. A cosmetic patch should not erase the original condition from the record; where a defect lies in a high-consequence zone, local nondestructive testing or controlled opening may be justified.

Curing and protection affect cracking. Rapid drying or temperature gradients can create defects; the acoustic commissioning schedule should not force testing before repairs and moisture stabilise; equally, it should capture a baseline before the wall is hidden by linings.

17.53 Precast panel joint design as a layered seal system

A precast joint often performs four functions: weather control, air control, movement and structural separation; one bead may not perform all four robustly; a layered joint can use an exterior weather seal, drained cavity and interior air seal. The structural connections remain separate. Acoustic design should identify which layer is relied upon for room closure.

Joint width varies with fabrication and erection tolerance; sealant depth and backer selection should accommodate the measured width; panels move thermally and under frame drift; a narrow joint at one floor may overstress the seal. Survey data should be reviewed before acceptance.

Interior finishes can conceal the air seal. A cover strip is not evidence of closure. Inspection should occur before trim. Where the joint is inaccessible after occupancy, redundancy and monitoring become more valuable.

Panel corners and intersections require special details; four-panel intersections, parapets and floor lines can create cavities; closure pours and fire safing may bridge joints; three-dimensional drawings are preferable to one typical section.

Integrated worked example 17.30. Joint-width tolerance and sealant demand

A nominal 25 mm precast joint has fabrication and erection tolerance of plus or minus 8 mm; measured joints range from 18 to 31 mm; expected movement is plus or minus 6 mm; at the 18 mm joint, one-direction strain is

33 per cent; at 31 mm it is 19 per cent. A single fixed sealant depth and backer size may not suit both extremes.

The installation plan should group widths and select compatible backing and depth. The calculation does not establish product suitability, which depends upon the qualified movement system and substrate.

17.54 Tilt-up base details, roof connections and panel-to-panel returns

Tilt-up panel bases carry gravity and lateral forces through bearing, grout, dowels and anchors; the base joint can be a long air path if closure is incomplete; interior floor finishes may conceal it; the acoustic detail should show the primary seal and its relation to bearing grout.

Roof connections transfer diaphragm forces and can carry vibration; a secure room beneath a flexible roof deck may be limited by the roof rather than the panel; interior return walls at panel joints should create a continuous boundary. A simple line of sealant on the panel face is not enough if the joint cavity opens above a ceiling.

Panel-to-panel corners can contain thickened edges and welds; they are structurally robust but acoustically complex; field scans should include corners and roof lines; temporary sealing can test air paths, while vibration measurements test connections.

17.55 Concrete sandwich panels, insulation and connector families

Sandwich panels use two concrete wythes, insulation and connectors; connectors may be steel, fibre-reinforced polymer or other systems; their stiffness, spacing and thermal role differ; full composite action increases structural rigidity and force transfer. Non-composite systems preserve more wythe independence but require adequate connectors.

Acoustic prediction should not assume an air cavity; solid insulation has its own dynamic stiffness and damping; gaps or poor bond can create local cavities; panel joints and floor connections remain likely weak paths.

A project comparison should use panel-specific laboratory or field evidence. Thermal performance and acoustic performance are related through geometry but not interchangeable. A low-conductivity connector can still transmit vibration.

17.56 Concrete façades, spandrels and exterior listener exposure

A concrete exterior wall may include windows, insulated panels, joints and slab edges; exterior listeners can access façades at ground, roofs or adjacent buildings; the direct concrete field is often strong; openings and joints control.

Traffic and wind background can hide leakage during field tests. Results should be reported as lower bounds where necessary. Night-time or controlled tests may be required, subject to operational and legal constraints.

Interior secondary boundaries can decouple the secure room from the façade. They should address glazing, spandrels, mullions and slab edges as a system. Moisture and fire requirements remain.

17.57 Numerical model validation with measured mobility and room data

A numerical model should be calibrated against quantities that correspond to its variables; if the model predicts wall modes, measure mobility or vibration response; if it predicts airborne transmission, compare band curves under known boundary conditions; if it predicts flanking, measure junction or transfer data.

Calibration should use part of the data and validation another part; fitting every mode to one test can produce a model that does not predict changed conditions. Sensitivity and uncertainty are reported. Discrepancies are retained rather than hidden through arbitrary damping.

The useful question is often comparative. Does an independent lining reduce response robustly across plausible connection stiffness? Does a joint repair change the upper-band leak? The model supports design when those conclusions are stable.

17.58 Concrete technical peer-review checklist

A specialist review should ask whether the structural system, construction sequence, joint details, defects, services and field evidence are aligned; it should confirm current code and specification editions, but it should not equate code compliance with acoustic proof.

Review items include density and thickness assumptions, boundary conditions, reinforcement and prestress, planned and unplanned joints, form ties, embeds, sleeves, repairs, NDE limits, room-within-room supports, fire interfaces and change control; each claim is tied to evidence.

The review closes only when unresolved assumptions are either verified, bounded in the model or identified as residual risk.

17.59 Concrete walls around doors and access panels

A door opening removes a large portion of an otherwise massive wall; jamb reinforcement, lintels, embeds and frame anchors concentrate force around the perimeter; the acoustic result depends upon the complete opening, including rough-opening tolerance, frame cavity, perimeter seal and adjacent concrete quality.

Cast-in frames can improve integration but make later replacement difficult; post-installed frames require anchors and annular closure; grout around hollow frames can leave voids; a local honeycombed zone behind a jamb can bypass the door. Inspection should occur before trim.

Access panels and hatches create similar weaknesses; a rated panel in a concrete wall should be tested as a complete assembly; hardware, seals and frame attachment matter; the panel should be included in lifecycle records and commissioning.

17.60 Concrete walls around large audiovisual systems

Large displays, projection niches and equipment cabinets can reduce wall thickness or introduce embeds; loudspeakers can directly excite the wall. Cable pathways connect cavities. The architectural desire for flush integration can conflict with the acoustic boundary.

A preferred design uses floor-supported independent frames and maintains the concrete field; where recesses are necessary, residual thickness and reinforcement are engineered; back boxes are massive, sealed and separated from receiving spaces. Cooling paths are acoustically controlled.

The operational source includes the audiovisual system at representative level. A wall that contains amplified programme requires different assessment from speech alone.

17.61 Concrete-to-glazing transitions

A concrete wall often contains security glazing or an exterior window; the concrete field may be far stronger than the glass; frames and anchors create a mixed boundary; the composite curve and perimeter detail govern.

Concrete shrinkage and frame thermal movement can open seals. Embedded steel angles transmit vibration. The glazing system should be installed in a controlled subframe with compatible movement. Field scanning focuses on corners and anchors.

17.62 Concrete construction in temporary and relocatable secure rooms

Precast modules and transportable concrete rooms offer rapid construction, but transportation joints, lifting points and module connections create paths; the assembled room should be tested after relocation; a factory result does not establish every site installation.

Module interfaces require gaskets, bolts, grout and service connections. Repeated assembly can wear seals. Foundations and levelling affect alignment. The configuration record includes serialised modules and connection torque.

17.63 Concrete exposure to fire and post-fire acoustic assessment

Fire can dehydrate paste, crack concrete, damage bond and spall surfaces. Cooling introduces further stress. A wall may remain standing yet have altered stiffness and cracks. Firefighting water adds moisture.

Structural assessment controls reoccupation. Acoustic assessment follows. Crack and spall maps, pulse velocity, cores and field tests may be required. Repairs are verified. The pre-fire rating cannot simply be carried forward.

17.64 Concrete under blast or impact damage

Blast and impact can create hidden cracking, debonding and joint movement. Protective design may prevent collapse while allowing damage. A secure room subjected to such an event requires inspection before sensitive use.

The investigation records event data, structural condition, door and service state, and acoustic change. Nondestructive methods guide controlled openings. Operational controls remain until authority disposition.

17.65 Concrete lifecycle monitoring and revalidation triggers

Triggers include new cracks, water intrusion, corrosion, repair, coring, added equipment, nearby demolition, seismic events and unexplained field change. Baseline photographs and curves support comparison.

Monitoring is risk-based. Stable interior concrete may need little routine testing. High-consequence joints, precast connections and repair zones receive focused inspection. The room record links each change to review and retest.

17.66 Final concrete evidence synthesis

Concrete offers high mass and robust construction, but its performance is conditional upon joints, openings, connections, services, boundaries and field state; the final synthesis should state which direct and flanking paths were measured or modelled, which remain uncertain, and which controls are operational.

A concrete wall is not described as secure in isolation. The evidence supports a bounded conclusion about the configured room and the competent authority’s decision.

17.67 Concrete construction tolerances as acoustic variables

Structural tolerances protect buildability and load transfer, but acoustic details can be more sensitive than the primary concrete section; wall plumbness, surface offsets, panel-joint width, sleeve position and edge straightness affect seals, independent linings and door or glazing frames; a deviation that remains structurally acceptable may reduce sealant depth, force a rigid shim or create a local cavity. The acoustic review should therefore identify a limited set of interface tolerances that require inspection before finishes conceal them. [115]

Tolerance should be treated statistically rather than through one nominal dimension; if a precast joint is designed at 20 mm but may vary from 14 to 28 mm, the sealant, backing and cover geometry must work throughout that range. If it does not, the design needs a controlled adjustment detail rather than improvised packing; survey data should be retained as part of

115 MB-0415. Carl Hopkins, Sound Insulation.

the as-built evidence because later leakage can correlate with extreme joint conditions.

17.68 Concrete curing, moisture and the timing of acoustic acceptance

Concrete properties evolve after placement. Moisture content, microcracking, modulus and shrinkage change with curing, environment and restraint; early testing may be useful for detecting gross openings, but it may not represent the final structural or joint condition; conversely, delaying every test until the building is complete can allow hidden defects to become expensive to access.

A staged plan separates early enclosure tests from final acceptance; early tests verify continuity and identify major paths. Final tests occur after joints, penetrations, finishes, services and representative environmental conditions are established; the report records concrete age, temperature, relative humidity and recent wetting; these variables are not used to excuse poor performance; they define the tested state and support later comparison. [116]

17.69 Surface treatments, coatings and attached architectural finishes

Paint, plaster, tile, stone veneer and protective coatings can change surface porosity, mass and damping, but their principal acoustic effect may be closure of distributed discontinuities; a thin coating on a sound concrete wall should not be credited with a large mass-law gain. A continuous render over honeycombed or tie-hole regions can nevertheless improve upper-band isolation by closing air routes; attached rigid finishes can also create local resonators or bridges through anchors.

116 MB-0114. ASTM International, ASTM C119-24.

The tested configuration should identify every finish and attachment; where a finish is likely to be replaced during the room's life, the acoustic boundary should not depend upon an undocumented decorative layer; if a coating is part of the air seal, it should be specified, inspected and protected as a functional component.

17.70 Concrete wall intersections and three-dimensional path control

At corners, T-junctions and wall-to-slab intersections, force can divide among several structural members; a massive separating wall may transmit little direct airborne energy while its intersection feeds a perpendicular wall or slab that radiates into the receiving room; junction geometry, continuity and loss factor determine the path. ISO 10848 methods and ISO 12354 prediction concepts provide a framework for separating direct and flanking contributions, but project-specific geometry still requires measured or validated input. [117]

The design response may involve room layout, breaks in non-structural finishes, independent linings or receiver treatment; structural continuity must not be cut casually; the acoustic engineer should work with the structural engineer to preserve load paths while controlling the surfaces that radiate into the protected or receiving space.

Integrated worked example 17.31. Ranking a concrete corner flank

A direct wall path is estimated at 58 dB transmission loss in a selected band; a slab flank is estimated at 52 dB and a perpendicular wall flank at 55 dB; converting each to a linear transmission coefficient gives 1.58 x 10^-6, 6.31 x

117 MB-0123. ASTM International, ASTM C1242-26.

10^-6 and 3.16 x 10^-6. Their sum is 1.105 x 10^-5, corresponding to 49.6 dB; the 52 dB slab path dominates, but the other paths reduce the combined result by a further 2.4 dB; the calculation assumes comparable receiving normalisation and uncorrelated power addition; it is a ranking screen, not a substitute for complete ISO 12354 input or field measurement.

17.71 Penetration governance in reinforced and prestressed concrete

A penetration through concrete changes more than mass. It can cut reinforcement, enter a tendon zone, compromise fire resistance, intersect a hollow region or create a direct air route; the penetration-control process should begin with structural records and scanning, followed by engineering approval, controlled coring, sleeve installation, closure inspection and update of the as-built model. Work should be prohibited where tendon or embedded-system uncertainty remains unresolved. [118]

Acoustic closure should be designed for the service, movement and maintenance state; a rigid grout annulus may be suitable around a fixed sleeve but not around a vibrating pipe; a removable access penetration requires a repeatable gasket or cover. Every later modification should trigger review of both the local opening and the connected cavity or service route.

17.72 Repair mock-ups and acceptance of repaired concrete

Repairs can close defects yet introduce new interfaces. A mock-up should reproduce substrate condition, preparation, repair material, thickness, reinforcement exposure, curing and finish; structural bond and durability

118 MB-0160. ASTM International, ASTM C615.

are evaluated separately from acoustic continuity; the acoustic check may use local pulse methods, sounding, controlled source measurement or a specimen test, depending upon the mechanism and consequence. [119]

A repair is not accepted because its surface is smooth; the record should show that loose material was removed, the cavity was bounded, the repair was compatible, the air path was closed and the resulting surface did not create a new radiation feature. Repaired regions remain in the lifecycle inspection map.

17.73 Precast erection sequence and temporary conditions

Precast panels may remain temporarily unsealed, braced or supported while adjacent work proceeds; temporary gaps can permit uncontrolled observation or contaminate joint surfaces; welds and closure pours change connection stiffness over time; the construction-security plan should therefore identify when the enclosure first becomes a controlled boundary and what interim measures are needed before permanent seals are completed.

Erection surveys, bearing conditions, weld records and joint photographs should be retained; a final façade or interior finish can conceal the evidence needed to understand a later flanking path; the secure-room project should not rely on memory once the cranes, braces and access platforms have gone.

17.74 Concrete-room fire and emergency alterations

Fire, impact, flooding or emergency service work can change concrete surfaces, joints, seals and embedded systems without producing obvious

119 MB-0156. ASTM International, ASTM C568.

structural failure; post-event assessment should begin with safety and structural authority, then document spalling, cracks, penetrations, wet materials, temporary supports and repaired services; acoustic revalidation is selected according to the changed mechanisms rather than performed as a ritual full test in every case. [120]

Emergency patches and temporary cable routes should be entered in configuration control; a room should not return to sensitive use merely because occupancy approval has resumed; the competent authority needs evidence that the acoustic and technical-security boundary has also been restored.

17.75 Concrete design review questions

The final design review should answer: What concrete system is present? Which surfaces form the acoustic boundary? Where are joints, ties, sleeves, embeds, connectors and repairs? What direct and flanking paths are credible? Which conditions are visible before closure? What test data represent the proposed configuration? How will future coring and service work be controlled? Each answer should point to a drawing, calculation, specification clause, source or test record.

A review that produces only a wall thickness and nominal rating is incomplete; concrete's apparent simplicity can conceal joint, connection and lifecycle complexity; its acoustic value becomes reliable when the physical state and evidence chain remain specific.

120 MB-0154. ASTM International, ASTM C503.

17.76 Concrete chapter synthesis

Concrete provides mass, fire resistance and robust enclosure, yet it also forms a highly connected structural network; cast-in-place, precast, tilt-up, prestressed and composite systems differ in joints, connectors, construction sequence and uncertainty; secure-room design therefore requires a system model that includes openings, repairs, flanking members and future changes. No concrete product or code compliance statement alone proves occupied speech security or formal acceptance.

17.77 Crack mechanics, continuity and acoustic consequence

Concrete cracks differ by cause, width, depth, activity and connectivity; plastic shrinkage, thermal restraint, drying shrinkage, flexure, settlement and corrosion can produce different patterns; a visible surface crack may terminate within a cover layer, while a narrow through-crack can form an efficient air path; structural significance and acoustic consequence must therefore be assessed separately. ACI 224.1R and ACI 562 provide a framework for evaluation and repair, but the project still requires path-specific evidence. [121]

A crack map should record width, orientation, location, moisture and time; repeated measurements establish whether it is active; temporary sealing can test airborne contribution, while vibration and intensity measurements examine structural radiation; the report should avoid calling every crack a leak or every small crack harmless.

121 MB-0161. ASTM International, ASTM C616.

Integrated worked example 17.32. Through-crack area screen

A 4.0 m long crack has mean open width 0.15 mm through a wall; its geometric open area is 4.0 x 0.00015 = 0.00060 m^2; in a 20 m^2 boundary, that is 0.003 per cent of area. If the intact wall screens at 60 dB and the crack is conservatively treated as open, the area-weighted result is approximately 45.2 dB; real cracks have tortuosity, roughness and frequency-dependent impedance, so the result is an upper-bound leakage screen. It shows why continuity matters even when crack area is visually small.

17.78 Restraint, shrinkage and distributed microcracking

Concrete shrinkage is restrained by reinforcement, foundations, adjacent placements and geometry; restraint can create distributed microcracks or concentrated cracks at re-entrant corners and joints; a wall that appears monolithic may therefore contain a network of small discontinuities. Surface coatings can close some routes while hiding the condition.

Design review should identify restraint and curing provisions; field evaluation can combine crack mapping, moisture history, sounding and local transmission scans; ASTM C157 provides material length-change evidence, but project cracking depends upon member size, reinforcement, curing and restraint. [122]

17.79 Precast dimensional variation and seal accommodation

Precast panels arrive with tolerances in length, bow, camber, edge geometry and insert position; erection adds bearing and alignment variation; joint systems must accommodate the combined range without

122 MB-0164. ASTM International, ASTM C629.

losing seal depth or cover; the final survey should identify extreme joints and panel corners, not merely average width.

A joint that is too narrow may over-compress backing and sealant; one that is too wide may exceed movement capacity or expose the secondary seal; connection plates and welds can restrain local movement and transmit vibration; PCI and ACI/PCI guidance support structural design, while acoustic performance remains an assembly question. [123]

17.80 Embedded plates, rails and equipment anchorage

Secure rooms often require screens, cabinets, doors, cable systems or protective equipment anchored to concrete; embedded plates and rails can simplify load transfer but create stiff local connections to linings and equipment; surface-mounted anchors drilled later can encounter reinforcement or create unrecorded penetrations.

The design should separate structural support from the acoustic inner shell where practical; if equipment must connect to the host concrete, the connection is modelled and placed deliberately; backing and embedded items are shown in the penetration and attachment register so that later trades do not improvise.

17.81 Core testing and the limits of material specimens

Drilled cores can provide compressive strength, density and direct observations of voids or cracking. Their removal is destructive and their result is local; a core taken from sound concrete does not prove the absence of honeycombing elsewhere, while a core through a defect may overstate its

123 MB-1063. National Park Service, Preservation Brief 2, Repointing Mortar Joints in Historic Masonry Buildings.

prevalence; ASTM C42 governs obtaining and testing cores, but sampling design and interpretation remain project responsibilities. [124]

Core locations should be approved structurally and checked for reinforcement, tendons and services. The hole becomes a controlled penetration that must be repaired and recorded. Acoustic conclusions should distinguish material property from wall continuity.

17.82 Triangulation of nondestructive examination

Ultrasonic pulse velocity, rebound number, impact echo, radar and thermography respond to different properties; a low pulse velocity can result from cracking, moisture, path geometry or poor contact; rebound number is strongly surface-dependent; radar detects dielectric contrasts rather than acoustic leakage; triangulation is strongest when independent methods converge on the same physical proposition. [125]

The investigation should define the defect size and consequence that each method can resolve. A non-detection below instrument resolution is not proof of absence. Calibration areas and controlled openings can help validate interpretation.

17.83 Patch repair boundaries and debonding

A repair patch introduces an interface with the original concrete; surface preparation, moisture, shrinkage and modulus influence bond; a stiff patch can transfer stress to its perimeter, while a weak patch can debond and radiate as a local plate. Sounding and local vibration can identify suspect regions, but final interpretation may require direct verification.

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124 MB-0123. ASTM International, ASTM C1242-26.
125 MB-1059. National Park Service, Preservation Brief 1, Assessing Cleaning and Water-Repellent Treatments for Historic Masonry Buildings.

Repair specifications should address geometry, edge preparation, reinforcement, material compatibility and curing; ACI 562 and project repair specifications provide the structural framework; acoustic acceptance should confirm that the air path and local radiation mechanism have been resolved. [126]

17.84 Inner-shell supports within concrete rooms

A room-within-room system inside a concrete shell requires support for floors, walls, ceilings, doors and services; the inner shell may be freestanding, resiliently mounted or partly tied for stability; restraints must accommodate seismic and safety requirements without creating uncontrolled bridges.

The support model should include translational and rotational stiffness. A small number of known restraints can be evaluated. Random site attachments cannot. Clearances are inspected under construction load and after equipment installation.

Integrated worked example 17.33. Bridge stiffness relative to resilient support

An inner wall is supported by clips with combined lateral stiffness 2.0 MN/m; one rigid bracket with effective stiffness 30 MN/m is accidentally installed; under common displacement, the bracket carries 30/(30 + 2) = 93.75 per cent of the force; the simplified parallel-spring calculation assumes compatible geometry and linear stiffness; it demonstrates why one bridge can dominate many compliant supports. It does not predict transmitted sound without source and receiver mobilities.

126 MB-0795. International Code Council, 2024 International Existing Building Code, subject to local adoption and amendment.

17.85 Integrated case. Cast-in-place room with sleeve and repair paths

A cast-in-place secure room has excellent wall mass but weak field isolation near one corner; records show a cluster of form-tie patches, a later cable sleeve and a repaired honeycombed zone; temporary closure of the sleeve improves upper bands. Vibration remains high at the repaired area during low-frequency excitation.

The sleeve is rebuilt with a controlled removable closure; the repair zone is opened under structural supervision, revealing a shallow debonded patch over porous concrete; incompatible material is removed, the substrate prepared and a compatible repair installed. Post-work tests show separate gains from the airborne and structural interventions; the result illustrates why concrete defects should be classified by mechanism rather than treated as one generic leak.

17.86 Concrete final verification and residual-risk statement

The final concrete record should include mix and placement information, joint maps, precast or tilt-up surveys, ties, sleeves, embeds, repairs, non-destructive results, controlled openings, field tests and lifecycle triggers; the report identifies unresolved concealed regions and the operational controls applied to them.

Concrete can be a highly effective boundary, but its performance is conditional upon continuity, joints, attachments and connected structure; the final statement should describe the configured room under tested conditions and should reserve accreditation to the competent authority.

17.87 Concrete mix selection and acoustic model inputs

Concrete specifications are usually governed by structural strength, durability, placement and exposure. Acoustic modelling also needs density, elastic modulus, damping and thickness, but these quantities are not fixed by compressive strength alone; aggregate type, air content, moisture, paste volume and cracking influence the dynamic response; the acoustical engineer should therefore avoid assigning one universal modulus or loss factor to all concrete of a stated strength class. [127]

Project models can begin with justified ranges and update them with measured dimensions, density or mobility. The structural specification remains controlling for material acceptance. Acoustic measurements supplement rather than rewrite that acceptance.

Integrated worked example 17.34. Modal-frequency sensitivity to modulus uncertainty

For a plate whose natural frequency scales approximately with the square root of elastic modulus, a nominal modulus of 30 GPa with plausible range 27 to 33 GPa produces frequency ratios sqrt(27/30) = 0.949 and sqrt(33/30) = 1.049. A predicted 80 Hz mode therefore spans roughly 75.9 to 83.9 Hz before thickness, boundary and cracking uncertainty; the calculation is a sensitivity screen, not a complete modal model; it shows why a predicted narrow-band feature should not be reported to unrealistic precision.

17.88 Placement access, congestion and quality at secure-room boundaries

Dense reinforcement, embeds, sleeves and limited form access can make a secure-room wall difficult to place and consolidate; the acoustic boundary

127 MB-0335. ASTM International, ASTM E90-23.

often contains exactly the features that increase congestion: frames, penetrations, grounding components and protective hardware; constructability review should occur before the pour; concrete placement method, lift height, vibration access and inspection windows are part of the quality plan. [128]

A mock-up can demonstrate flow around the most congested zone; the aim is not aesthetic perfection alone; honeycombing and trapped air can create connected porosity or weak repair zones; the accepted method should be carried into the field and documented by placement records.

17.89 Form pressure, tie layout and joint leakage risk

Fresh-concrete pressure drives formwork design and tie spacing; ties are structurally necessary temporary components, but their holes become repeated discontinuities; cone depth, water stops, removable rods and patch details should be shown; a standard architectural patch can be too shallow or debonded to provide reliable closure.

The tie-hole schedule should identify both sides, repair material, depth and inspection; where a waterproofing system is present, acoustic closure must coordinate with it; tie positions should remain visible in the as-built model even after finishes conceal them.

Integrated worked example 17.35. Aggregate effect of repeated tie holes

A 25 m^2 wall contains 80 repaired tie holes; each repair has an uncertain effective leakage area of only 2 mm^2; total effective area is 160 mm^2, or 1.6 x 10^-4 m^2; for a 60 dB intact wall and conservative open-path screen,

128 MB-0272. ASTM International, ASTM E336-25a.

composite transmission loss is approximately -10 log10{[(25 - 0.00016)10^-6 + 0.00016]/25} = 51.3 dB. The tiny repeated defects reduce the screen by about 8.7 dB. Actual patch impedance is frequency-dependent. The calculation illustrates cumulative risk and the need for repeatable repair.

17.90 Waterproofing, vapour control and acoustic closure

Below-grade or exterior concrete can include membranes, waterstops, drainage layers and protection boards; these systems may close air paths, create cavities or constrain access to joints; acoustic repair must not puncture waterproofing or trap moisture; a waterstop at a construction joint does not necessarily form the room-side air seal, and an interior sealant bead does not replace water control.

The section detail should show each functional plane. Inspection responsibilities are coordinated so one trade's work does not conceal another's defect. Post-construction water intrusion can deteriorate repairs and trigger acoustic reassessment.

17.91 Concrete walls adjacent to shafts and service risers

A concrete wall beside a lift, stair, mechanical or electrical shaft can receive airborne and structure-borne energy; shaft walls may have access panels, door frames, sleeves and continuous slabs; the room model should include the shaft as an adjoining environment rather than treating the concrete wall as isolated.

Source testing can use shaft plant, lift operation or controlled loudspeaker excitation; receiver-side vibration and intensity help distinguish direct wall radiation from penetrations and slab paths; remediation may require shaft-side treatment, room-side lining or service control.

17.92 Cold-weather and hot-weather concreting implications

Temperature affects placement, curing, shrinkage and cracking; accelerated heating or inadequate protection can produce gradients and surface defects; hot conditions can increase evaporation and plastic shrinkage risk; the acoustic consequence is indirect but real when cracks, joints or repairs become connected paths.

Construction records should retain temperature and curing measures at critical walls; later investigations can use the chronology to target suspect lifts or joints; these records do not prove an acoustic defect, but they help test plausible mechanisms. [129]

17.93 Concrete façade transitions and spandrel paths

Concrete façades often contain spandrel beams, curtain-wall anchors, insulation, fire safing and interior finishes; a secure room near the façade can flank around an interior concrete wall through the spandrel or slab edge; the exterior panel may also radiate to an accessible location.

The detail should extend the acoustic boundary to a verified air plane at the façade; fire safing and smoke seals must remain compliant; a room-side return may need to be independent from the exterior panel while preserving drainage and movement.

17.94 Concrete acoustical acceptance after repair or alteration

Acceptance should compare the repaired state with the original requirement and baseline; local tests may verify closure, while room-level tests confirm system consequence; where the original room already had a

129 MB-0875. International Organization for Standardization, ISO 16283-1:2025.

measurement floor, the result may be a lower bound rather than a precise improvement.

The report should state what changed, which mechanism was expected, which observations support it and what uncertainty remains. A repair that passes visually but lacks evidence should remain provisional.

17.95 Concrete lifecycle inspection map

The lifecycle map identifies joints, repairs, sleeves, frames, embedded services, façade returns, water-exposed areas and previous anomalies; each location carries a status and retest trigger; the map supports maintenance and prevents later drilling through critical zones.

Photographs should include scale and orientation. A digital model can link records, but durable identifiers must also exist on drawings and schedules. Access control for sensitive facility data is handled by the responsible authority.

17.96 Concrete chapter final statement

Concrete is valuable because it combines mass, robustness and fire resistance, but its performance depends upon placement quality, joints, repeated tie holes, penetrations, repairs and structural continuity; the finished room should be judged through verified construction and measured system behaviour. Structural code compliance, material strength, laboratory transmission loss, field isolation, speech security and formal acceptance remain separate propositions.

Table 17-R1. Concrete construction state, hidden defect, verification method and acoustic implication.

Construction state	Hidden defect	Verification method	Acoustic implication
Cast-in-place lift	Cold joint or honeycombing	Placement record, UPV or targeted opening	Leakage, local radiation or altered stiffness
Precast panel joint	Seal void or stiff connection	Joint survey, temporary seal and mobility test	Mixed airborne and structure-borne path
Tilt-up brace location	Shallow cosmetic patch over cavity	Depth record, sounding and controlled verification	Repeated local weak path
Composite panel	Uncertain connector action	Panel-specific model and field response	Shifted modes and wythe coupling
Repair zone	Debonded or incompatible patch	Bond, sounding and post-repair scan	Local plate response or redirected cracking

17.97 Concrete-system technical schedules

Table 17-1. Concrete system, dominant discontinuity and acoustic evidence

System	Dominant discontinuities	Structural-acoustic concern	Required evidence
Cast-in-place wall	Construction joints, form ties, sleeves, honeycombing and cracks	Nominal monolith can contain repeated local paths and rigid flanking	Placement sequence, tie-closure schedule, consolidation records, crack map and field spectrum
Precast panel wall	Erection joints, bearing pads, welded plates, grout pockets and closure pours	Panel field may be strong while joints and connections dominate	Shop drawings, panel survey, connection photographs, sealant geometry and joint scan
Tilt-up wall	Panel joints, lifting inserts, brace anchors, roof and foundation connections	Erection tolerance changes joint width; insert recesses can remain hollow	Casting records, lift plan, insert closure, alignment survey and field test
Sandwich panel	Wythe connectors, panel edges, insulation discontinuities and openings	Connectors couple wythes; thermal classification does not prove acoustic isolation	Exact connector system, wythe dimensions, tested panel report and façade junction data
Composite deck/slab	Deck flutes, shear connectors, beam interfaces and penetrations	Thin steel and shared flutes create bypasses at wall heads	Deck profile, flute closures, fireproofing record, beam map and plenum inspection
Room within room	Resilient supports, service transitions, doors and thresholds	One rigid bridge can control an otherwise isolated inner shell	Support schedule, static deflection, bridge register, vibration test and operational room test

Table 17-2. Concrete defect and investigation method

Suspected defect	Useful method	What the method can establish	Important limitation
Honeycombing near reinforcement	Visual opening, sounding, ultrasonic pulse velocity and local core where approved	Location, relative material quality and direct sample properties	UPV is influenced by moisture and reinforcement; one core is local
Unknown wall thickness	Survey, impact echo and controlled core	Geometric thickness at tested locations	Complex geometry and reinforcement create interpretation ambiguity
Open form-tie sleeve	Borescope, air-leak test and local acoustic scan	Continuity of sleeve and contribution under controlled sealing	Surface patch can obscure path; pressure test may not match sound impedance
Precast-joint debonding	Close inspection, adhesion probe and reversible membrane test	Seal continuity and frequency-specific path contribution	Temporary membrane adds mass and stiffness as well as air closure
Delamination or shallow repair failure	Impact echo, sounding and infrared under suitable conditions	Potential reflector or thermal anomaly	Not every anomaly is an acoustic path or structural defect
Post-tensioned tendon location	Ground-penetrating radar or approved scanning	Probable tendon corridor for safe work	Scanning uncertainty requires a protected margin and structural procedure

Table 17-3. Construction-surveillance hold points for concrete boundaries

Stage	Condition visible	Release criterion	Permanent record
Before placement	Reinforcement, embeds, sleeves, blockouts, joint preparation and form ties	Geometry agrees with coordinated drawings and no unapproved penetration exists	Coordinate photographs, inspection report and nonconformance disposition
During placement	Concrete flow, consolidation, lift sequence and interruption	Placement follows procedure; congestion and interruptions are recorded	Batch tickets, times, environmental data and zone map
After stripping	Surface voids, tie recesses, cracks and dimensional tolerance	Defects classified and approved repair method issued	Survey, defect map, repair authorisation and samples where taken
Precast erection	Bearings, connections, shims, joint widths and temporary braces	Alignment and structural connection accepted before concealment	Joint-width survey, weld/grout inspection and photographs
Before lining	Concrete repairs, primary air seal, cavity and service routes	All concealed acoustic and fire conditions accepted	Lining hold-point checklist and bridge inventory
Before commissioning	Doors, ducts, services and equipment in operational state	Room configuration matches test plan	As-built drawings, equipment schedule and field-test baseline

Table 17-4. Repair method and proof boundary

Repair class	Appropriate purpose	Acoustic expectation	Evidence that remains necessary
Flexible crack seal	Active non-structural crack requiring air closure	Can reduce leakage while preserving movement	Crack monitoring, adhesion, before-and-after spectrum and lifecycle inspection
Epoxy injection	Structural bonding of suitable dormant crack	May restore continuity but increases local stiffness	Structural design, injection record, cure and flanking review
Cementitious patch	Restore cover or fill surface defect	Adds mass and closes pores if well bonded	Substrate preparation, depth, curing and local acoustic scan
Grout or closure pour	Complete precast connection or deep void	Can restore mass and continuity but also increase coupling	Volume, placement, connection design and post-cure inspection
Independent lining	Create secondary boundary over uncertain or porous concrete	Potentially large airborne gain if bridges are controlled	Cavity, support, service and perimeter evidence plus room test
Source isolation	Reduce machinery or loudspeaker force entering structure	Addresses structure-borne path directly	Force spectrum, mount design, bridge audit and vibration retest

17.98 Conclusions

Concrete can provide formidable direct airborne isolation, but secure-room performance depends upon joints, penetrations, connections, cracks and adjoining structure; cast-in-place work contains ties, lifts and construction joints; precast work contains erection joints and connections; tilt-up adds lifting and bracing evidence; composite systems add decks, connectors and interfaces. Room-within-room systems add resilient supports whose bridges must be controlled.

A rigorous design preserves the distinction among structural compliance, material quality, laboratory performance, field performance, occupied speech security and formal approval. Each has its own evidence. The heaviest wall does not rescue an open sleeve, failed panel joint or continuous slab flank.

Chapter 17 Glossary

Closure pour. Concrete placed after primary elements are erected to complete a connection, joint or diaphragm region.

Cold joint. An interface formed when later concrete is placed after earlier concrete has advanced beyond the intended monolithic placement condition.

Composite action. Structural interaction between connected materials or elements so that they resist load together.

Form tie. Device that holds opposing form faces at the required spacing during concrete placement and leaves a penetration or recess requiring treatment.

Grout pocket. Recess in a precast element or connection that is filled after erection to develop bearing, anchorage or continuity.

Honeycombing. Concrete defect containing visible voids or poorly consolidated aggregate, often near reinforcement or congested details.

Impact echo. Stress-wave method used to investigate thickness and certain internal reflectors in plate-like concrete elements.

Precast connection. Structural assembly joining precast elements or joining them to the supporting structure.

Room within room. Secondary isolated enclosure constructed inside an outer shell to reduce airborne and structure-borne transmission.

Tilt-up panel. Concrete wall panel cast horizontally and lifted into its final vertical position.

Anchorage zone. Region of concentrated force, reinforcement and hardware at a prestress or structural connection anchorage.

Closure strip. Concrete placed after primary construction to connect adjacent slabs, panels or placements.

Heavyweight concrete. Concrete made with high-density aggregate to increase unit weight for shielding, mass or other specialised purposes.

Partial composite action. Intermediate interaction between layered elements that is neither fully independent nor perfectly composite.

Shotcrete rebound. Material that bounces from the receiving surface during pneumatic placement and must not be trapped in the work.

Stay-in-place form. Permanent forming material that remains attached to concrete and becomes part of the completed layered assembly.

Chapter 18. Concrete Slabs, Foundations, Structural Continuity, and Vibration Transmission

18.1 The floor is often the longest uninterrupted path

Concrete walls attract attention because they define the visible room perimeter; slabs and foundations can be more consequential because they extend beneath several rooms, connect columns and cores, support mechanical equipment and provide efficient structure-borne paths; a secure wall built from slab to slab does not interrupt vibration travelling through that slab. Improving the wall can therefore reveal a floor path that was previously masked.[130][131]

The analysis begins with structural topology. The engineer identifies slab type, thickness, spans, supports, beams, drop panels, columns, walls, joints, toppings, ceilings, raised floors, foundations and equipment; post-tensioned tendons, hollow-core voids, metal deck, shear connectors and resilient layers alter wave propagation; the record distinguishes the structural slab from finishes and floating systems. A catalogue floor rating cannot substitute for the actual junction network.

130 MB-0903. International Organization for Standardization, ISO 717-1:2026.
131 MB-1059. National Park Service, Preservation Brief 1, Assessing Cleaning and Water-Repellent Treatments for Historic Masonry Buildings.

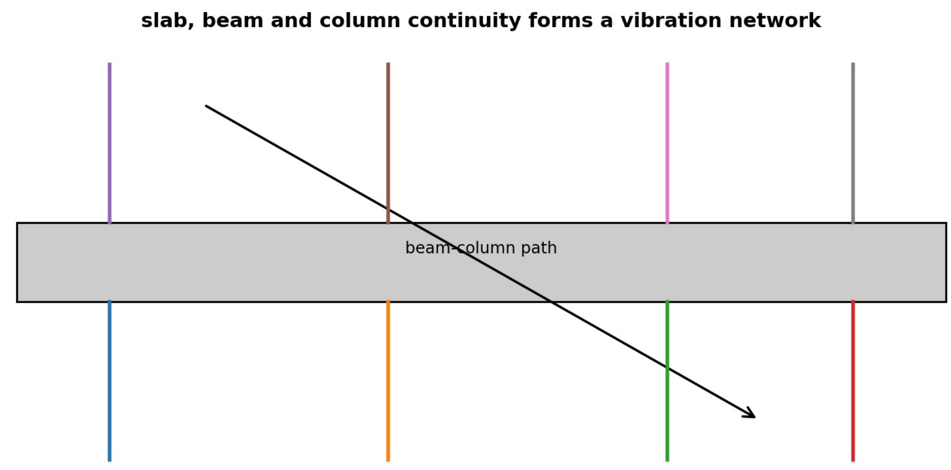

Figure 18-1. Structural continuity from protected room through slab, beam, column and adjacent radiator. Author's original schematic. Energy can bypass a high-isolation wall without crossing its central field.

Worked example 18.1. Slab surface mass

A 175 mm normal-weight slab with density 2,400 kg/m³ has surface mass

m' = 0.175(2,400) = 420 kg/m².

A 50 mm topping at 2,200 kg/m³ adds 110 kg/m², for 530 kg/m² total. This supports preliminary airborne and impact analysis but does not describe bending stiffness, continuity or flanking.

18.2 Slab systems and their acoustic identities

A flat plate is continuous across columns and can distribute vibration widely; a beam-and-slab system introduces stiff lines and changes modal shapes; one-way joist construction has ribs and thin slabs; concrete on metal deck combines a stiffened profile, shear connectors and flutes; hollow-core units introduce longitudinal cavities and joints. Post-tensioned slabs contain tendons and sustained compression. Each system requires its own model.[132][133]

132 MB-0123. ASTM International, ASTM C1242-26.
133 MB-0004. A. C. C. Warnock, Sound transmission through concrete blocks with attached drywall.

The same nominal thickness can produce different bending stiffness because section geometry and composite action differ; hollow-core voids reduce mass and create waveguide-like geometry. Ribbed slabs are directionally stiff. Metal deck can radiate from thin steel surfaces or create air paths at wall intersections; a design that assumes an equivalent homogeneous slab should state the frequency range and uncertainty.

Worked example 18.2. Flexural rigidity comparison

For a homogeneous plate, bending rigidity per unit width is

$D = (Et^3)/(12(1-\nu^2))$.

Using $E = 30$ GPa, $\nu = 0.20$ and $t = 0.175$ m,

D = 1.40 × 10^7 N m.

Increasing thickness to 200 mm increases rigidity by $(200/175)^3 = 1.49$, much faster than the 14 per cent increase in mass; this changes modal and flanking behaviour; the formula applies to an ideal homogeneous plate and not directly to ribbed or cracked slabs.

18.3 Foundations, grade beams and ground coupling

Foundations connect walls, columns and slabs to soil; ground-bearing slabs may be isolated by joints yet remain coupled through subbase, utilities and foundations; suspended slabs transfer vibration through columns and cores; grade beams can bridge nominal slab separations. A room built on a separate housekeeping slab is not isolated if reinforcement, drains or rigid conduits connect it to the main foundation.

Soil provides frequency-dependent radiation damping and wave propagation; nearby machinery, rail or traffic can excite foundations;

conversely, protected-room speech generally produces small forces, but high-isolation conditions make weak structural paths measurable; the source model should distinguish building-service vibration from speech-induced boundary vibration.

Foundation modifications are high-risk. Saw cuts, isolated pads and trenches require structural and geotechnical review. Acoustic goals cannot justify compromising waterproofing, seismic load paths or settlement performance.

Worked example 18.3. Rigid bridge across an isolation joint

A nominally isolated 6 m by 4 m slab has four steel conduits crossing its perimeter; each conduit has axial dynamic stiffness 1.5 × 10^7 N/m; parallel bridge stiffness is 6.0 × 10^7 N/m. If the intended resilient supports provide 2.0 × 10^7 N/m, the conduits triple total stiffness and raise natural frequency by

sqrt ((8.0)/(2.0)) = 2.

The nominal isolation frequency doubles. The simple lumped model shows why service bridges require explicit stiffness control.

18.4 Hollow-core slabs and longitudinal communication

Precast hollow-core planks combine efficient structure with longitudinal voids. The voids reduce mass and can connect penetrations or openings over long distances; end grouting, cores, topping and plank joints influence airborne and structure-borne paths; a wall placed over plank joints may not interrupt the cavities; services cored into one void can communicate with another location.[134]

134 MB-1182. The Masonry Society, ASTM C476-23, ASTM C1019-26.

The acoustic record should identify plank depth, void geometry, span, topping, end closure, joints and penetrations; drilling must follow manufacturer and structural guidance; filling a void for acoustic reasons can add load or obstruct drainage and should not be improvised.

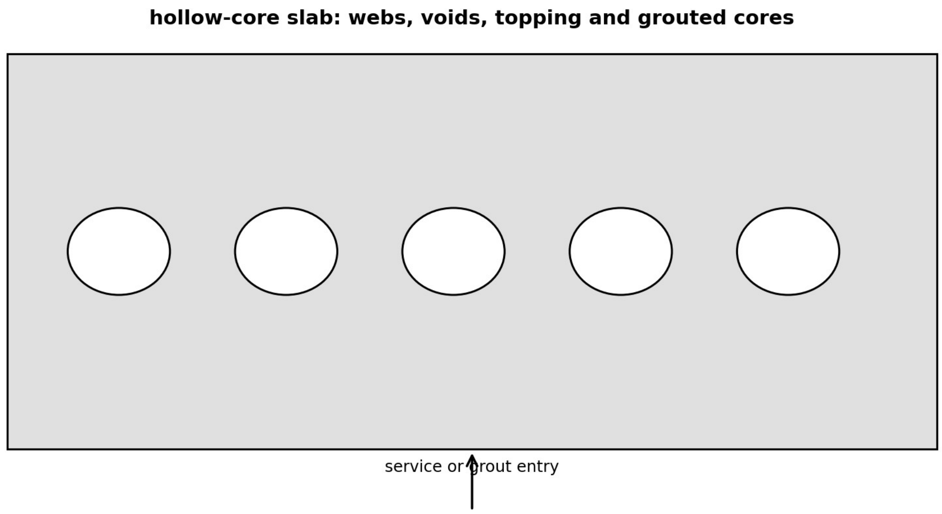

Figure 18-2. Hollow-core slab with longitudinal voids, plank joint, topping and wall intersection. Author's original schematic. A penetration can enter a cavity extending beyond the room boundary.

Worked example 18.4. Void-volume screening

A 9 m plank contains five circular-equivalent voids of area 0.010 m^2. Total air volume is

$V = 5(0.010)(9) = 0.45\ m^3$.

A 40 mm core hole into one void connects to a substantial cavity. The volume alone does not determine transmission, but it explains why surface sealing at one end may be inadequate.

18.5 Post-tensioned slabs and tendon-controlled work zones

Post-tensioned slabs contain stressed tendons whose accidental damage can be catastrophic. Acoustic retrofits, coring, anchors and floor boxes require tendon scanning, structural approval and controlled procedures.[135] Tendons also create continuous high-stiffness paths and sustained compression that influence cracking and vibration.

A tendon layout constrains room placement and later modifications; door thresholds, sound-lock partitions and isolated-floor anchors should be coordinated before stressing; drilling exclusion zones belong in the facility configuration record; a later contractor should not rely on generic spacing assumptions.

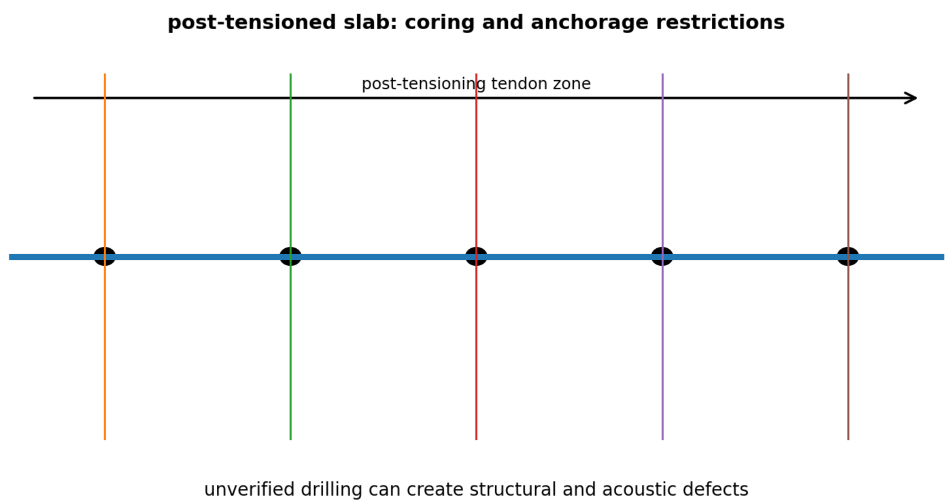

Figure 18-4. Post-tensioned slab with tendon profile, anchor zone, protected drilling corridor and secure-room penetration. Author's original schematic. Acoustic work must remain subordinate to tendon safety.

Worked example 18.5. Tendon exclusion margin

Scanning locates a tendon centreline with positional uncertainty ±12 mm. Proposed anchor radius is 8 mm, and project safety clearance is 40 mm. Minimum centre-to-anchor distance is

$d_{min} = 12+8+40 = 60$ mm.

135 MB-0162. ASTM International, ASTM C62-23, ASTM C216-26a.

The calculation formalises one conservative rule. Actual structural procedures and scan confidence govern.

18.6 Impact sound and airborne speech are related but different problems

Impact sound begins with mechanical force applied to the floor. Airborne speech begins as fluctuating pressure; both can excite the slab, but test methods and source spectra differ; ASTM E492 and E989 address laboratory impact transmission and IIC classification; ASTM E1007 addresses field tapping-machine measurements; ISO 16283-2 and ISO 717-2 provide corresponding international field and rating methods.[136][137][138][139][140]

An IIC value does not establish speech privacy; a floating floor that improves tapping-machine results may also reduce structure-borne speech paths, but the relation is not automatic; low-frequency machinery, chair movement and footfall can mask or reveal speech at different times. The room assessment should treat operational sources separately.

Worked example 18.6. Combining impact and airborne background

A corridor background from HVAC is 31 dB in a band, and intermittent footfall contributes 35 dB during an event. Combined event level is

L = 10 log_10(10^(3.1)+10^(3.5)) = 36.5 dB.

136 MB-0141. ASTM International, ASTM C34-23.
137 MB-0955. J. A. Díaz-Cereceda et al., Sound transmission loss analysis through a multilayer lightweight concrete hollow brick wall by FEM and experimental validation.
138 MB-0195. ASTM International, ASTM C920-18, ASTM C1193-25.
139 MB-0187. ASTM International, ASTM C919-24.
140 MB-0194. ASTM International, ASTM C920-18, ASTM C1193-25.

Speech may be less audible during the event and more audible between steps. Time-averaged background can therefore misrepresent listener opportunity.

18.7 Floating floors

A floating floor adds a wearing slab or panel layer supported on resilient material and separated from surrounding structure; performance depends on supported mass, dynamic stiffness, damping, perimeter isolation, joints, penetrations and workmanship; a resilient layer compressed by concentrated loads can bottom. A perimeter screed can bridge. A pipe sleeve or door threshold can short-circuit the system.

The design checks static deflection, natural frequency, load distribution, creep, fire, moisture and access; the floor should be tested or inspected before finishes conceal its perimeter; equipment bases may require separate supports; the resilient layer should remain continuous under joints or be detailed with compatible transitions.

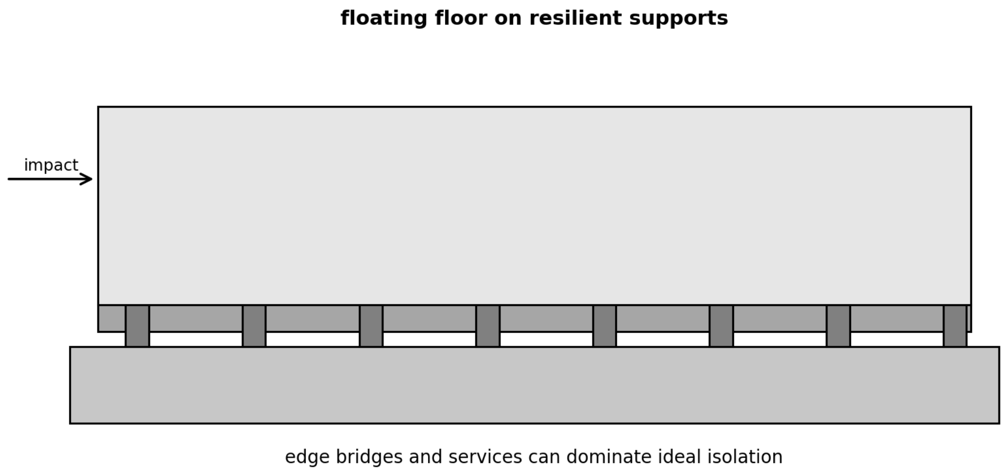

Figure 18-3. Floating floor with resilient layer, isolated perimeter, door transition and service bridge. Author's original schematic. The weakest rigid connection can control the system.

Worked example 18.7. Floating-floor resonance

A floating slab has mass 180 kg/m². Resilient layer dynamic stiffness is 18 MN/m³. For unit area, stiffness is 18 × 10^6 N/m and mass 180 kg. Natural frequency is

$f_n = \frac{1}{2\pi} \sqrt{\frac{18 \times 10^6}{180}} = 50.3$ Hz.

This is high for demanding low-frequency isolation. A softer layer or greater supported mass may be needed, subject to deflection and load limits.

18.8 Ceiling plenums and slab undersides

A suspended ceiling does not normally replace the slab as a secure boundary; ceiling tiles, grids, luminaires and services provide limited isolation and can create a shared plenum; the slab underside may contain deck flutes, beams, fireproofing and penetrations. A wall terminating at the ceiling leaves an uncontrolled path unless the entire plenum is designed and verified.

Isolated ceilings can form part of a room-within-room system; hangers then require dynamic design and fire/seismic coordination. Perimeter joints must remain separated. Ducts and cable trays should not bear on the ceiling; access hatches become openings requiring tested or engineered treatment.

Worked example 18.8. Shared-plenum opening area

A partition stops 450 mm below slab over a 7 m length. Uncontrolled plenum cross-section is

$S = (0.45)(7) = 3.15\ m^2$.

No wall-field STC can compensate for this opening. Ceiling attenuation may reduce some energy, but the path must be assessed as a plenum system.

18.9 Machinery vibration and building services

Pumps, fans, transformers, lifts and generators can excite slabs and foundations. Their vibration may mask speech, create nuisance or overload sensitive instruments; isolation mounts, inertia bases, flexible connectors and structural separation are selected from force spectra and support mobility; ASHRAE's sound and vibration guidance provides practical design frameworks, while ISO 20816-1 addresses evaluation of machine vibration in its proper machinery context.[141][142]

A mount is not effective simply because it is labelled "vibration isolator"; natural frequency, damping, load distribution and short circuits determine

141 MB-0192. ASTM International, ASTM C920-18, ASTM C1193-25.
142 MB-0403. Carl Hopkins, Sound Insulation.

performance; flexible connectors under misalignment can become stiff. Pipe supports can bypass mounts. Housekeeping pads can bridge isolation joints.

Worked example 18.9. Ideal force transmissibility

For frequency ratio r = 4 and damping ratio ζ = 0.08, force transmissibility is

$T = (\mathrm{sqrt}\ (1+(2\zeta\ r)^2))/(\mathrm{sqrt}\ ((1-r^2)^2+(2\zeta\ r)^2)) = 0.079$.

Isolation is

20 log_10(0.079) = -22.0 dB.

The result assumes a single-degree-of-freedom system and no rigid bypass.

18.10 Structural mobility and path ranking

Mobility is velocity divided by force at a point and direction; it describes how readily a structure responds; transfer mobility relates response at one point to force at another; these quantities support comparison of slab paths, junctions and equipment supports; calibration, mounting, coordinate definition and force measurement are essential.[143][144]

A high vibration level does not prove high radiated sound; radiation efficiency and receiving-room modes matter; conversely, a low point reading can miss a mode antinode; spatial grids and multiple axes reduce misinterpretation. Coherence with the source helps distinguish causal response from unrelated building vibration.

Worked example 18.10. Point mobility

A calibrated shaker applies 12 N RMS at 80 Hz. Measured velocity is 0.36 mm/s RMS. Mobility magnitude is

143 MB-0332. ASTM International, ASTM E90-23, ASTM E336-25a.
144 MB-1184. The Masonry Society, ASTM C920-18, ASTM C1193-25.

$|Y| = (0.00036)/(12) = 3.0 \times 10^{-5}$ m/(N s).

A second location at 8.0×10^{-6} is 11.5 dB lower in mobility. The result is configuration-specific.

18.11 Joints, saw cuts and slab discontinuities

Construction joints, contraction joints, isolation joints and saw cuts change force transfer and cracking; a saw cut may reduce tensile continuity near the surface while reinforcement remains continuous; an isolation joint may be bridged by dowels, reinforcement, finishes or services. A post-installed repair can change the joint's dynamic behaviour.

Acoustic design should not direct cutting without structural review; where an existing joint is useful for isolation, the project should preserve it by preventing rigid finishes and service bridges; sealants maintain air and debris closure while allowing movement. Fire and waterproofing requirements remain.

Worked example 18.11. Bridge stiffness from floor finish

A terrazzo topping bridges a 15 mm isolation joint over 8 m length; assume cracked bridging strips collectively provide equivalent stiffness 4 × 10^7 N/m, while intended resilient system is 1.5 × 10^7 N/m. Total stiffness increases by factor 3.67, raising natural frequency by sqrt (3.67) = 1.92; a thin finish can therefore defeat a deep isolation detail.

18.12 Field testing and uncertainty

Impact and airborne tests require controlled source, microphone positions, background correction and room data; vibration tests add transducer mounting, orientation, calibration and loading; accelerometers can mass-load light elements, though this is less severe on concrete; magnetic mounts do not apply directly to concrete; adhesive, wax, stud or fixture methods have different bandwidth and repeatability.

A field result should identify slab state, finishes, furniture, ceiling, doors, equipment and operating systems; comparing before and after construction requires equivalent states; a lower vibration level after carpet installation may reflect source coupling rather than structural change.

Worked example 18.12. Uncertainty in a level difference

Two independent level estimates have standard uncertainties 0.7 and 0.9 dB. Standard uncertainty of their difference is

$u = \text{sqrt}(0.7^2+0.9^2) = 1.14$ dB.

A measured 1.5 dB change is not strong evidence of improvement without further repeats and model review.

18.13 Forensic case study. The conference room above the plant room

A secure conference room is built above a mechanical plant; walls and doors perform as expected, but low-frequency speech-modulated noise is detectable in an adjacent office; vibration mapping shows strong slab response at fan rotational harmonics; the conference-room loudspeaker is mounted to the same slab and excites a nearby mode.

The problem has two sources. Plant vibration raises background and can modulate surfaces; the loudspeaker creates structure-borne transmission through its bracket; temporary resilient suspension of the loudspeaker reduces the speech-correlated component; fan isolation repair reduces the unrelated tonal background. The final assessment separates these effects rather than treating all low-frequency energy as one leak.

The case demonstrates why slab vibration can both conceal and convey information. A stable background may mask speech; amplitude-modulated vibration can create recognisable patterns. Operational testing must include conferencing equipment and representative plant states.

18.14 Construction and lifecycle controls

Slab evidence is acquired before toppings, ceilings and equipment conceal it; tendon scans, joint maps, penetration records, resilient-layer inspections and equipment-mount records become part of the room baseline; new cores or anchors require change control; floating-floor perimeters and door transitions are inspected periodically. Plant replacements trigger vibration review.

Access procedures should protect post-tensioned zones and isolation boundaries; contractors receive marked drawings and supervision; emergency leaks or repairs are documented; a secure room cannot remain accredited or trusted through memory alone.

18.15 Plate waves, critical frequency and slab radiation

Bending waves in a slab are dispersive; their phase velocity rises with frequency and can coincide with airborne sound speed, increasing radiation efficiency; the critical frequency depends on thickness, density, modulus and Poisson ratio; for massive concrete slabs it often lies below or within building-acoustics bands, but cracking, ribs, toppings and restraint modify the ideal value.

A slab can therefore carry vibration efficiently without radiating equally at every location; radiation depends on modal shape, receiving-room dimensions and surface finishes; a ceiling below the slab can become the actual radiator if hangers and cavity pressure couple it strongly.

Worked example 18.13. Ideal critical-frequency screen

For an isotropic plate, a common screening expression is

$f_c = (c^2)/(2\pi)\ \mathrm{sqrt}((m')/(D))$.

Using $c = 343$ m/s, $m' = 420$ kg/m^2 and $D = 1.40 \times 10^7$ N m,

$f_c \approx 323$ Hz.

The result identifies a region requiring measured data. It is not exact for cracked, continuous or ribbed slabs.

18.16 Damping and loss-factor estimation

Structural damping controls resonance amplitude and decay; concrete damping arises from material hysteresis, cracking, joints, finishes, soil and connected structure; it is not a fixed universal number; small-amplitude speech excitation may experience different damping from machinery or impact.

Decay tests, mobility fits and modal analysis can estimate loss factor; the excitation and estimator should be reported; added viscoelastic treatments may increase damping locally, but they need strain to dissipate energy; applying a damping sheet to a very thick slab can have little effect if the surface strain is minute.

Worked example 18.14. Loss factor from half-power bandwidth

A resonance occurs at 80 Hz with half-power frequencies 77.6 and 82.5 Hz. Approximate loss factor is

$\eta = (82.5-77.6)/(80) = 0.061$.

The estimate assumes a lightly damped isolated mode. Overlapping modes and non-proportional damping require more advanced treatment.

18.17 Stairs, ramps and core flanking

Stairs and ramps connect floors through landings, stringers and walls; a stair landing cast monolithically with a corridor slab can carry vibration around a room boundary; precast flights use bearings and connections that create discrete paths; handrails and balustrades can rattle or transmit structure-borne energy.

A protected room beside a stair core should be surveyed vertically; accessible landings above or below may provide listener positions; door openings in the core add airborne paths; room relocation can be more reliable than attempting to isolate an entire structural stair.

Worked example 18.15. Stair-path level combination

Direct wall contribution is 28 dB and stair-core flank 32 dB in a band; combined level is 33.5 dB; improving the wall by 10 dB changes total to only 32.2 dB. The stair path remains decisive.

18.18 Raised access floors

Raised floors provide cable distribution but create shared cavities, panel joints and pedestal bridges; a secure-room wall that stops at the raised floor leaves an open path; a wall that extends to the structural slab can still be bypassed by underfloor ducts, cable openings and perimeter gaps.

Pedestals transfer vibration from panels to slab. Stringers create networks. Heavy equipment can rock panels or compress gaskets; the boundary detail may use sealed curb construction, barriers beneath the floor and controlled cable transitions; panels near the perimeter should remain removable for inspection without damaging seals.

Worked example 18.16. Underfloor opening

A 150 mm high raised-floor cavity extends 6 m along a partition. If uncontrolled, cross-section is 0.90 m^2. Even with carpeted panels, this is a large shared-plenum path requiring a designed barrier.

18.19 Soil-borne and external vibration

Road, rail, construction and nearby plant can introduce vibration through soil and foundations; these sources may mask speech or excite room surfaces; site measurements distinguish transient and steady sources, frequency content, direction and operating schedule; a building response measured during train passage should not be attributed to internal speech.

Foundation isolation is difficult after construction. Sensitive rooms are better located away from major sources or on structurally favourable zones. Trenches, base isolation and resilient supports require specialist structural and geotechnical design.

Worked example 18.17. Geometric attenuation screen

If a surface-wave amplitude decreases approximately with 1/sqrt (r), increasing distance from 10 m to 40 m reduces amplitude by factor sqrt (10/40) = 0.5, or 6 dB; soil layering and source geometry can produce very different behaviour, so the relation is only a screening law.

18.20 Time synchronisation and correlation

Multi-channel acoustic and vibration diagnosis benefits from a common time base; source signal, microphones, accelerometers and operational logs should be synchronised; unsynchronised recorders complicate coherence and causal analysis; clock drift can become significant over long tests.

The record states sampling rate, anti-alias filtering, clock source, channel delay and processing; trigger pulses or loopback channels can verify alignment; this discipline is particularly valuable where intermittent lift, pump or traffic events overlap speech tests.

Worked example 18.18. Clock-drift error

Two recorders differ by 20 parts per million. Over 30 minutes, relative drift is

$\Delta t = 20 \times 10^{-6}(1{,}800) = 0.036$ s.

At 100 Hz, this is 3.6 cycles, enough to destroy phase comparison unless corrected.

18.21 Plate-wave propagation, coincidence and radiation from slabs

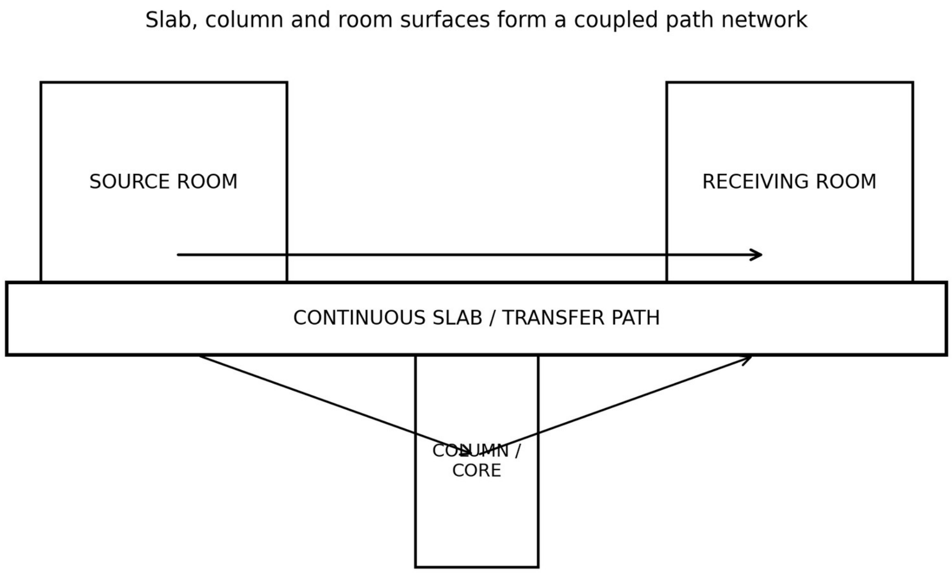

Figure 18-R1. Coupled slab, column and room path network. Author's original schematic.

A concrete slab is a dispersive plate rather than a rigid separator; bending-wave speed increases with frequency, and the relationship among bending wavelength, room dimensions and airborne wavelength determines how efficiently vibration radiates; at low frequency, the slab responds through a small number of global modes. At higher frequency, modal density increases and local excitation can propagate over substantial distances before damping and junction losses reduce it. [145]

Critical frequency is often high for thick concrete, but it should not be dismissed; lightweight toppings, screeds, soffit panels and composite decks can introduce layers with lower critical frequencies; openings, ribs and beams alter the field; the receiving room may be excited by radiation from the slab, a ceiling, a wall attached to the slab, or a service supported from it.

145 MB-0193. ASTM International, ASTM C920-18, ASTM C1193-25.

A measured low-frequency deficit should therefore be mapped to radiating surfaces rather than attributed automatically to “the floor”.

The plate-wave field is directional. Reinforcement, ribs, beams and post-tensioning create orthotropy; a flat plate can transmit differently along column strips and middle strips; a one-way slab channels energy differently from a two-way slab; hollow-core units favour longitudinal propagation along their voids. Measurement grids should follow the structural axes.

A structural intensity estimate can clarify power flow when simultaneous force and velocity or stress and velocity can be obtained; in practice, point mobility, transfer functions and coherence are often more accessible; the measurement model must state sensor orientation, mass loading, attachment and phase calibration. An accelerometer attached with wax may be adequate for one band and unreliable for another.

Integrated worked example 18.19. Bending wavelength screen for a concrete slab

For an isotropic plate, bending wavenumber k_b satisfies k_b^4 = rho h omega^2 / D, where rho is density, h thickness, omega angular frequency and D flexural rigidity per unit width; consider a 200 mm slab with rho = 2,400 kg/m3, E = 30 GPa and Poisson ratio 0.20. Flexural rigidity is approximately 20.8 MN m.

At 125 Hz, omega = 785 rad/s; the screened bending wavenumber is about 1.94 1/m, giving wavelength lambda_b = 2pi/k_b = 3.24 m; a 6 m room therefore spans fewer than two bending wavelengths at this frequency, so global and boundary effects remain important. At 500 Hz, wavelength falls by the square root of frequency ratio to about 1.62 m; the calculation supports sensor spacing and model scale; it does not predict received sound without damping, junctions and radiation efficiency.

18.22 Hollow-core, ribbed, waffle and composite slab topologies

Hollow-core slabs contain longitudinal voids that reduce mass and create directional stiffness; the voids can communicate through cut ends, service penetrations or damaged webs; a wall placed across the units may close the room boundary at the soffit while the cores continue beyond it. Airborne and structure-borne paths can coexist. End grouting, closure details and service openings should be documented.

Ribbed and waffle slabs concentrate stiffness in beams or ribs; bending waves scatter at rib intersections, and services often occupy the coffers; a suspended ceiling can hide long cavities; a partition terminating at the underside of a ribbed slab requires a three-dimensional head detail. Sealing the flat surface between ribs does not address paths along the rib or through the coffer.

Composite metal-deck slabs add a corrugated steel layer; the deck can form continuous flutes and provide a high-mobility path; concrete may fill above the deck while leaving flute geometry below; fireproofing, ceiling hangers and service supports connect to the deck. A secure-room assessment should identify whether the partition reaches concrete, deck, spray fireproofing or a secondary ceiling system.

Hollow-core and composite systems complicate later drilling; a core hole can enter a void or cut reinforcement; post-tensioned and prestressed units require scan and authorisation; the penetration-control programme should contain structural drawings, verified scanning, exclusion zones and post-work inspection. Acoustic repairs must not conceal unreviewed structural damage.

18.23 Post-tensioning, tendon zones and later penetrations

Post-tensioning introduces high-force tendons, anchorages and grouted or unbonded ducts; tendon layout controls safe work zones; coring without verified tendon location can cause catastrophic damage; acoustic remediation that proposes anchors, sleeves or floor boxes must therefore begin with structural records and scanning. [146]

Tendons also affect dynamic response. Precompression changes cracking and stiffness. Bonded tendons interact with the concrete along their length, while unbonded tendons transfer force primarily at anchorages. The acoustic significance is configuration-specific. A generic increase in “mass” does not represent these effects.

Anchor zones can transmit vibration into walls and columns; a secure room near a slab edge or stressing pocket may experience different mobility from a central bay; construction pockets and pour strips are additional discontinuities; the as-built structural model should include them when low-frequency flanking is important.

A controlled penetration workflow includes archival review, survey control, approved scanning, engineering disposition, core location marking, witnessed drilling and as-built update; the acoustic record adds sleeve, annulus, firestop, flexible connection and retest information; this prevents

146 MB-1183. The Masonry Society, ASTM C919-24.

structural safety and acoustic closure from being treated as separate afterthoughts.

Integrated worked example 18.20. Tendon-location uncertainty and exclusion margin

A scanner reports tendon centre at x = 420 mm with expanded positional uncertainty plus or minus 15 mm; tendon duct outside diameter is 20 mm; a proposed 50 mm core has radius 25 mm; a conservative minimum centre-to-centre separation is 15 + 10 + 25 = 50 mm before adding project-specific construction tolerance and safety margin.

If the proposed core centre is 55 mm from the reported tendon centre, only 5 mm remains beyond the measurement and geometric envelope; that is not a robust construction margin; the structural engineer may require relocation or a larger exclusion distance. The calculation is a geometry screen, not authorisation to drill.

18.24 Floating floors and isolated ceilings as a coupled room system

A floating floor and isolated ceiling are often designed separately, yet they share the inner-room walls, services and equipment loads; the floor has a vertical natural frequency, rocking modes and local stiffness variations; the ceiling has hanger resonances and lateral restraints. The walls couple them. A bridge at any interface can bypass the intended isolation.

Resilient elements should be selected from the actual load distribution; uniform load assumptions can fail beneath safes, conference tables, equipment racks or movable partitions; overloaded mounts compress excessively and may become stiff or contact stops; lightly loaded mounts can sit above their design range and permit excessive movement. A load map and mount schedule are therefore part of the acoustic design.

Perimeter isolation is fragile. Screed, sealant, skirting, door thresholds and floor finishes can bridge to the outer slab; a threshold crossing from floating floor to fixed corridor requires a purpose-designed transition; the door frame may be supported from the inner or outer system, and that choice affects both alignment and transmission.

Ceiling services should not hang from the isolated ceiling unless designed for it; ducts, pipes and cable trays crossing the cavity need flexible transitions and independent supports; seismic restraints require measured or specified dynamic properties; a rigid safety cable can become an acoustic bridge under normal conditions if it is taut.

Commissioning should include clearance inspection, mount deflection, resonance testing and bridge search before finishes make access difficult; transfer measurements at representative mounts can identify outliers; the final airborne test is necessary but not sufficient because a bridge may become significant only when machinery or impact excitation occurs.

18.25 Foundations, grade beams and soil-borne vibration

Foundations connect the building to the ground and to adjacent structures; soil-borne vibration from rail, road traffic, construction, generators or nearby plant can enter through footings and slabs; the propagation depends upon soil layering, groundwater, foundation type and frequency. A room in a massive basement can have excellent airborne isolation yet experience low-frequency vibration that modulates panels or creates audible secondary radiation.

Screening begins with source characterisation and site response; free-field ground measurements are compared with foundation and room measurements; transfer is not necessarily stable because soil moisture and operational state change; a single daytime survey may miss night freight trains or intermittent plant. Long-term logging can establish distributions and event rates.

Isolation joints between building sections can reduce some transmission but are easily bridged by slabs, finishes, utilities and waterproofing; the joint must satisfy structural, water and fire requirements; a small concrete spill can create a stiff path. Construction surveillance is therefore as important below grade as it is at a wall head.

Remediation options are limited after construction. Source isolation, trench barriers, local floating rooms and operational scheduling may be more practical than foundation alteration; the report should distinguish environmental vibration from speech leakage; detection of vibration does not establish recoverable information.

18.26 Rotating machinery, pumps, lifts and building-service excitation

Mechanical equipment applies periodic and broadband forces through mounts, pipes, ducts and electrical conduits; rotational frequency, blade-pass frequency, pump pulsation and harmonics can excite slab and wall modes; variable-speed drives shift these components across resonances; equipment operating state should therefore be recorded with speed, load and control mode.

Mount selection requires both static and dynamic analysis; a mount with nominal deflection yields an estimated natural frequency, but real systems have centre-of-gravity effects, frame flexibility and restraint; pipe and duct connections can bypass the mounts; housekeeping pads can be cracked or rigidly connected across an intended isolation joint.

Lifts create transient and periodic forces through rails, machines, ropes, counterweights and doors; a room adjacent to a lift core may receive structure-borne sound even when the machine room is remote; testing should include representative journeys, door cycles and braking. The receiving metric may need time histories rather than only steady spectra.

Pumps and hydronic systems can transmit through incompressible fluid and pipe walls; flexible connectors are not universal isolators; their effectiveness depends upon pressure, length, braid, alignment and frequency; pipe supports downstream can reintroduce force. A system review should follow the path to the structure.

Integrated worked example 18.21. Variable-speed fan crossing a slab resonance

A fan operates from 600 to 1,200 rpm, corresponding to 10 to 20 Hz shaft frequency; a six-blade impeller produces blade-pass frequency from 60 to 120 Hz; slab mobility testing shows a strong resonance at 96 Hz. The fan crosses that resonance when speed is 960 rpm.

A receiving-room complaint occurs only near that operating point; the evidence supports a resonance interaction rather than a constant construction defect; remediation can consider speed exclusion, fan balancing, mount and connection review, or structural modification; the calculation does not establish the dominant path without coherence and transfer measurements.

18.27 Stairs, ramps, cores and façade connections

Stairs connect floors with inclined plates, landings and stringers; they can bypass slab discontinuities and carry impact forces; a stair enclosed by masonry or concrete walls can excite the enclosure. Ramps provide continuous structural paths. Lift and service cores connect many levels; façade anchors tie slab edges to exterior panels.

The path network should be traced beyond the adjacent room; a stair landing may connect directly to the receiving wall; a core wall may radiate into rooms above and below; a façade spandrel can carry sound around an interior partition. These paths are often missed when the survey is limited to the nominal separating plane.

Field testing can use controlled impact, shaker or operational excitation; response decay with distance is mapped. Junctions are perturbed where safe. The source should be chosen to illuminate the suspected path without damaging finishes or disturbing sensitive operations.

18.28 Mobility, transmissibility and structural-intensity measurements

Point mobility relates velocity to applied force at a location and direction; transfer mobility relates response at one point to force at another; transmissibility compares responses or forces across an isolation system. Structural intensity estimates power flow. Each quantity requires defined reference directions and phase integrity.

An impact hammer is convenient but supplies finite energy and can excite nonlinear contacts; a shaker provides controlled steady excitation but requires attachment and reaction; operational transfer-path analysis uses natural sources but may suffer from correlated inputs. The method should follow the question.

Sensor mass loading can alter thin panels or resilient elements; on concrete slabs the mass effect is usually small, but mounting stiffness and orientation remain important; magnet mounts do not work on non-ferrous surfaces without plates; adhesive and stud mounts have different bandwidths. Calibration and channel synchronisation must be documented.

The interpretation should not reduce every result to a coloured contour; a high response can reflect high source force, high mobility or both; a low response can reflect cancellation; coherence, phase and source state are needed. Raw time data and processing settings should be retained.

18.29 Isolation joints, bridge surveillance and post-construction change

An isolation joint is only as effective as its least controlled bridge; reinforcement, dowels, membranes, firestops, finishes, pipes, conduits and debris can connect the two sides; some bridges are required for safety or service; the design should identify them and evaluate their dynamic role rather than assuming perfect separation.

Construction surveillance should occur before the joint is concealed; photographs show clear width and continuity; temporary spacers and formwork are removed; concrete spills are chipped without damaging edges. Waterproofing and fire systems are installed according to their tested details. Floor finishes terminate with movement-compatible transitions.

Later work is a major risk. A contractor may drill a threshold across the joint, add a pipe support or fill the gap with rigid grout; the protected-zone drawing and permit system should flag the joint. Any crossing requires review. Post-work inspection and targeted transfer measurement may be necessary.

Integrated worked example 18.22. Small bridge across a floating slab perimeter

A floating slab is supported by mounts with combined vertical dynamic stiffness 45 MN/m; a rigid grout bridge at one corner has estimated stiffness 180 MN/m; in a simple parallel-stiffness screen, the bridge carries 180/(180+45) = 80 per cent of quasistatic force. The sophisticated mount system is therefore largely bypassed.

Removing the bridge restores the intended path. The estimate ignores frequency dependence and slab rotation, but it shows why a visually small rigid contact can dominate.

18.30 Integrated forensic case study. Conference room above a variable-speed plant room

A conference room above a mechanical floor exhibits intermittent low-frequency noise and reduced speech privacy; the wall and door field tests are acceptable when the plant is off; when two pumps and a variable-speed air-handling unit operate, receiving levels rise from 63 to 160 Hz and some wall panels vibrate.

The investigation records equipment speed, pump duty, valve state and room HVAC mode; accelerometers are placed on pump bases, pipes, plant-room ceiling, conference-room slab, walls and ceiling. Microphones record both rooms. Coherence shows strong transfer from one pump at 75 Hz and from fan blade-pass frequency sweeping through 90 to 110 Hz; a rigid pipe support attached to a beam beneath the conference wall creates a secondary path.

The pump mounts have adequate nominal deflection, but a short flexible connector is misaligned and a downstream support is rigid; the fan isolation is effective except near a slab mode at 98 Hz; the conference-room suspended ceiling is fixed to the slab and radiates strongly. The door is not the controlling path under plant operation.

Remediation realigns and lengthens the pump connector, relocates the rigid support, balances the fan, introduces a control-speed exclusion band around the slab resonance and replaces selected ceiling hangers with an engineered isolated system; fire and seismic restraints are retained with verified clearances. Post-work measurements show 10 to 18 dB reduction in the affected bands.

The final report separates two states. With plant off, airborne room isolation governs; with plant on, background and structure-borne excitation govern privacy; the room’s authorised use therefore depends upon both construction and operational state; the case demonstrates why floor systems, machinery and speech privacy must be commissioned together.

18.31 Slab-edge façades, curtain walls and exterior flanking

At a building perimeter, the slab edge connects interior floors to façade anchors, spandrels and curtain-wall frames; a secure-room partition that meets the façade can be bypassed through the mullion, spandrel cavity, slab edge or raised-floor zone. Exterior listener access adds a second concern: the façade itself can radiate speech energy.

The survey should trace the interior partition to the exterior air and water barriers; fire safing at the slab edge may not provide acoustic closure; curtain-wall anchors create discrete force paths; a continuous mullion can pass around the partition. Secondary interior glazing and an independent return wall can establish a more controlled boundary.

Field testing should include façade-adjacent receiving positions and, where lawful and practical, exterior positions; wind and traffic background may limit results; the report should state lower bounds rather than assuming high isolation from a background-limited measurement.

18.32 Floor finishes, underlays and the difference between impact improvement and speech isolation

Carpet, resilient flooring and underlays can reduce tapping-machine impact levels without materially changing low-frequency airborne speech transmission through a concrete slab; a floating screed can improve both in some bands, but its perimeter and service bridges govern. Product claims should identify the test method and base slab.

An underlay tested on a 150 mm concrete slab cannot be applied automatically to a ribbed deck or timber overlay; the floor covering may also change door thresholds and floating-floor clearances; replacement finishes can bridge perimeter joints or alter room absorption, affecting occupied speech levels.

The commissioning record should therefore distinguish impact metrics, airborne field metrics and room-acoustic effects. A quieter footfall does not prove better speech security.

18.33 Long-duration vibration logging and event attribution

Intermittent structural excitation is easily missed by short surveys; rail passages, lift cycles, pump changes and traffic events may occur only at certain times; long-duration logging records acceleration, sound pressure and equipment state with synchronised clocks.

Event detection should preserve raw data around triggers; automatic spectral summaries can obscure short transients; operational logs and building-management data help attribute events; privacy assessment considers whether events raise background and mask speech or excite boundaries and increase transmission.

Clock integrity is essential. NTP steps, recorder drift and unsynchronised sample rates can create false phase relations. Loopback channels or common timing references should be used where transfer analysis depends upon phase.

18.34 Slab remediation decision hierarchy

Slab remediation begins with the path. If airborne leakage occurs through a floor penetration, closure may be local; if impact noise dominates, a floor finish or floating floor may help; if machinery vibration enters through supports, source isolation is preferable; if the building frame provides distributed flanking, a room-within-room solution may be required.

Interventions should be ranked by expected system gain, structural risk, fire impact, access and reversibility; thickening the slab may add mass but do little for a column or pipe path; an isolated ceiling may reduce radiation but create maintenance complexity. The decision record should show why the selected measure addresses the demonstrated mechanism.

18.35 Transfer slabs, podiums and mixed structural systems

Transfer slabs and podiums redistribute loads between incompatible grids; they are thick, heavily reinforced and connected to columns, walls and cores; their mass can reduce direct airborne transmission, yet their continuity makes them efficient flanking structures; a secure room on or below a transfer level should be analysed in relation to the whole structural node.

Mixed systems complicate the path. A concrete podium may support steel framing or timber construction; interfaces contain bearings, plates, anchors and joints; the receiving surface may be a lightweight partition attached to a massive slab; energy can travel through the slab and radiate from the light element.

Field mobility mapping should include the transfer slab, connected columns and partitions. Remediation may require local inner shells or source isolation rather than changes to the transfer structure.

18.36 Slab penetrations, floor boxes and service trenches

Floor boxes, trenches and poke-through devices interrupt mass and create service paths; a flush cover can appear closed while the box communicates with a raised floor or ceiling below; fire-rated systems have specific components and fill limits. Acoustic closure must be coordinated with them.

A trench can behave as a long duct; covers and gaskets determine leakage; cables and pipes create structure-borne connections; the register should identify every box, trench and abandoned opening; later cable additions are controlled.

Integrated worked example 18.23. Floor-box composite path

A 40 m2 slab has screened loss 60 dB; four floor boxes have effective area 0.04 m2 each and local loss 25 dB; composite calculation gives a result near 48 dB in the selected band; the boxes occupy only 0.4 per cent of area but dominate. Actual performance depends upon cover, gasket, cavity and flanking, so measurement remains necessary.

18.37 Structural damping treatments and their practical limits

Constrained-layer damping, tuned absorbers and local treatments can reduce vibration in plates, but concrete slabs are massive and often boundary-dominated; a thin damping layer on one surface may have limited strain and therefore limited loss; treatments are more effective on attached metal panels, ceilings or lightweight linings.

A tuned mass damper can target a narrow resonance, but occupancy, temperature and structural change can detune it; it should not replace source control or broad path treatment; the design requires measured modal data and maintenance access.

18.38 Acceptance of slab and vibration performance

Acceptance should identify source types, operating states, receiving positions, metrics and decision rules. Impact, machinery and speech-induced vibration are different. A room may pass airborne tests and fail operational vibration criteria.

The dossier includes structural drawings, equipment states, sensor calibration, time synchronisation, transfer functions, uncertainty and remedial records. Formal authority considers the complete room and operational controls.

18.39 Column strips, beam bands and directional slab transmission

Flat plates and flat slabs are often divided conceptually into column strips and middle strips. Reinforcement and stiffness differ. Beam bands and drop panels further concentrate rigidity; structure-borne energy can follow these zones, so a uniform slab model may obscure directional paths.

Sensor grids should align with the structural layout; a source near a column may couple efficiently into several floors; a source in a flexible middle strip can excite a local mode; transfer functions measured along and across the strip reveal anisotropy.

18.40 Hollow-core end closures and service intersections

Hollow-core unit ends may be grouted, capped or open within beams and walls; cut openings can expose several cores; services can run through or across voids; an apparently solid floor edge can therefore contain longitudinal air paths.

End closures should be inspected before toppings and ceilings conceal them; a borescope or smoke test can identify continuity; repairs must preserve structural bearing and fire resistance; filling cores indiscriminately can add load and trap moisture.

18.41 Raised floors, cable plenums and pressure coupling

Raised access floors create a horizontal plenum that can bypass walls. Pedestals and stringers transmit vibration. Perforated tiles, floor boxes and cable openings couple air; a partition that stops at the raised floor leaves a direct route.

The secure boundary should extend to the structural slab or use tested plenum barriers; floor panels at the wall are sealed and mechanically stable. Cable changes are controlled. Underfloor pressure from HVAC can alter leakage.

18.42 Suspended ceilings and isolated ceiling failures

An isolated ceiling can reduce radiation from a slab, but hangers, perimeter angles, light fixtures, ducts and seismic restraints can bridge it; ceiling tiles in a grid are not a high-isolation boundary; a plenum can carry speech to adjacent rooms.

Inspection should distinguish decorative ceilings from structural acoustic ceilings. The latter require continuous mass, sealed joints and engineered supports. Access panels and services are part of the system.

18.43 Floor vibration criteria and speech-security relevance

Human comfort criteria for floor vibration do not directly establish acoustic security; a vibration too small to be felt can still radiate measurable sound from a light partition; conversely, perceptible vibration may be outside speech bands.

The assessment should relate vibration spectrum to radiating surfaces and receiving background. Metrics such as velocity or acceleration are interpreted through transfer functions. Detection alone is not evidence of intelligible information.

18.44 Structural modification near an occupied secure room

Cutting, demolition, strengthening and new equipment can change slab paths; before work, baseline crack maps, vibration and acoustic measurements are recorded; work zones and protected boundaries are identified; temporary supports and penetrations are reviewed.

After work, the room is reinspected and tested where risk warrants. A change in structure may require updated models and authority review. This is especially important for post-tensioning, transfer slabs and core modifications.

18.45 One-way slabs, two-way slabs and beam-supported floors

One-way slabs carry load primarily between parallel supports, while two-way slabs distribute load in both directions; beam-supported floors add discrete stiff lines; these structural distinctions shape vibration propagation; a source aligned with the flexible span can excite different modes from a source near a beam.

The acoustic survey should identify span direction, beam depth, continuity and support; sensor grids are placed along principal axes; a one-dimensional decay assumption is inappropriate where beams reflect and channel waves; in two-way slabs, column and middle strips may require separate evaluation.

Suspended ceilings and partitions attach at different points; a partition beneath a beam can receive strong force; a wall between beams may be more flexible but still flank through the slab; the structural plan is therefore indispensable.

18.46 Waffle slabs, pan joists and local cavity response

Waffle and pan-joist floors contain repeated ribs and thin slabs; the coffers can host services and ceilings; local plate areas between ribs have lower mass and stiffness than solid slabs; ribs create periodic scattering and strong directional paths.

A wall head beneath a coffered slab is geometrically complex; closure must follow ribs and pans. A suspended ceiling can conceal open paths. Field scans should include rib lines and coffer centres.

Predictive models may homogenise the floor at low frequency and use detailed rib geometry at higher frequency. The transition should be justified by wavelength relative to rib spacing.

18.47 Mass-spring-mass behaviour of floating screeds

A floating screed or topping consists of a mass layer over a resilient underlay; its resonance depends upon area mass and dynamic stiffness per unit area; below resonance, the system can amplify. Above resonance, isolation improves. Bridges at perimeters and services bypass the system.

Dynamic stiffness should be measured under relevant load; creep and moisture can change it; a thin resilient layer compressed by heavy equipment may become locally rigid; the load map should include furniture and movable partitions.

Integrated worked example 18.24. Floating screed resonance

A screed has surface mass 110 kg/m2. The resilient layer has dynamic stiffness 18 MN/m3. Natural frequency is f_n = (1/2pi) sqrt(s'/m') = (1/2pi) sqrt(18,000,000/110) = 64.4 Hz.

At 63 Hz the system is near resonance and should not be assumed isolating; increasing screed mass to 180 kg/m2 lowers the screen to 50.3 Hz; the calculation assumes uniform support and no damping or bridges.

18.48 Impact excitation, tapping machines and real operational events

Standard tapping-machine tests provide reproducible impact data, but actual sources include footsteps, dropped objects, rolling carts and furniture movement; their force spectra and locations differ; a secure-room floor may require both standard metrics and operational tests.

Soft floor coverings reduce high-frequency footfall but can have limited effect on low-frequency slab modes. Rolling equipment can excite joints. A dropped metal object produces a transient with broad bandwidth; time histories and percentile levels may be needed.

Impact testing should not be interpreted as direct speech isolation. It characterises a different source class. The two records can share structural-path information but remain distinct.

18.49 Structure-borne sound from pipes embedded in slabs

Hydronic, drainage and fire-protection pipes may be cast into or supported from slabs; fluid pulsation, valve operation and flow noise transmit through pipe walls and anchors; a sleeve can create an air path while the pipe creates a mechanical path.

The investigation records pipe type, flow, pressure and support; controlled valve operation or pump-speed change can identify the source; flexible connectors and resilient supports are evaluated under load; encasing a noisy pipe in concrete can increase force transfer even while reducing airborne radiation locally.

18.50 Lift-rail and guide-shoe excitation of cores

Lift rails are anchored repeatedly to core walls; guide shoes, rollers, doors and machines apply transient forces; the core can transmit those forces to adjacent rooms over many floors; machine-room location alone does not define the path.

Testing should include travel at different speeds, acceleration, braking and door operation. Sensors on rails, core walls and receiving surfaces establish coherence. Maintenance records help distinguish wear from construction.

Remediation may involve guide adjustment, isolation, rail support or receiver treatment. Structural and safety requirements govern.

18.51 Low-frequency background and measurement-floor problems

Concrete systems can achieve high isolation, leaving receiving levels close to background. Low-frequency HVAC, traffic and vibration limit measurement. A reported high class may rely on censored bands.

The test plan should reduce background where practical, extend averaging and report lower bounds; turning plant off can change room pressure and operational state, so the limitation must be considered; a result should not be extrapolated beyond the measured dynamic range.

18.52 Slab-path remediation case. Raised floor, trench and curtain wall

A secure room has a heavy slab and strong walls but poor isolation near the façade; investigation finds a raised-floor plenum crossing the partition, a cable trench opening at the slab edge and a continuous curtain-wall mullion; temporary plenum barriers improve upper bands; sealing the trench adds further gain. Low-frequency response remains at the mullion and slab edge.

The permanent design extends a tested barrier to the structural slab, closes the trench with a removable fire-rated system and constructs an independent interior façade return. Cable routes are reorganised. The raised floor at the boundary uses sealed cut panels and controlled access.

Post-work tests show the expected staged gains. The case demonstrates that floor and façade paths must be treated together.

18.53 Vibration data quality and coordinate control

Structural measurements require a coordinate system. Sensor directions, polarity and locations are marked on drawings. Channel names are not enough. Calibration, mounting, sample rate, filters and clock are recorded.

Data processing preserves units. Integration from acceleration to velocity requires control of low-frequency drift. Windowing and averaging affect spectra. Coherence is interpreted with source stationarity. Raw data remain available.

A later reviewer should be able to reproduce the transfer function from the stored record. This is especially important when results influence security or litigation decisions.

18.54 Slab and foundation commissioning checklist

The commissioning checklist includes structural system, penetrations, joints, floating elements, machinery states, service supports, raised floors, ceilings, façades and external sources. It identifies which tests are airborne, impact, vibration or operational.

Acceptance requires closure of physical defects, verified measurement state, uncertainty and responsibility. Residual paths are recorded. A floor is not declared secure as a material; the configured room is assessed under authorised conditions.

18.55 Slab thickness, density and flexural-rigidity uncertainty

Nominal slab depth is not the same as the minimum local section; camber, soffit tolerance, formed recesses, conduits, embedded boxes and topping variations change mass and bending stiffness; because flexural rigidity varies approximately with the cube of thickness for a homogeneous plate, modest geometric variation can shift modal frequencies and mobility. The structural record should therefore distinguish design depth, measured depth and local reductions. [147]

A thickness survey need not be exhaustive to be useful; locations are chosen at spans, supports, penetrations, trenches and suspected anomalies; measurement uncertainty and reinforcement or tendon constraints are recorded; acoustic models should not silently use the nominal drawing value where local geometry governs a path.

Integrated worked example 18.25. Thickness sensitivity of slab rigidity

Consider a uniform concrete plate whose thickness changes from 200 mm to 180 mm, with elastic modulus and Poisson ratio held constant; flexural rigidity is proportional to h^3, so the ratio is (0.180/0.200)^3 = 0.729. A ten per cent reduction in thickness produces approximately a 27.1 per cent reduction in rigidity; the calculation is dimensionless and neglects

147 MB-0031. American Concrete Institute, ACI CODE-318-25, ACI SPEC-301-20.

reinforcement, cracking and boundary changes; it shows why a shallow service recess can affect local vibration more strongly than its mass fraction suggests.

18.56 Composite floor decks and rib-to-slab interaction

Composite steel-deck floors combine a corrugated steel sheet, concrete topping, shear connection and supporting beams; the deck profile creates orthotropic stiffness and longitudinal cavities at wall heads; composite action varies with construction, span, cracking and fire protection. A room-to-room path can involve slab bending, beam transmission, deck-flute leakage and suspended-ceiling radiation at the same time.

The survey should record deck orientation, flute closure, beam lines, slab thickness above ribs, penetrations and ceiling attachments. A model that replaces the floor with a uniform plate may be valid at wavelengths much larger than the rib spacing, but it can miss local deck or flute behaviour. The transition between homogenised and detailed modelling should be justified. [148]

18.57 Post-tensioned slabs, tendon force and service-change restrictions

Post-tensioning alters stiffness, cracking and construction sequence. Tendons can be bonded or unbonded, distributed or banded, and their paths may curve through the depth; later coring can create catastrophic safety risk; the acoustic penetration register must therefore be subordinate to the structural tendon-control process; no test or remediation justifies drilling where tendon location and approval remain uncertain. [149]

148 MB-0032. American Concrete Institute, ACI CODE-562-25.
149 MB-0029. American Concrete Institute, ACI CODE-318-25, ACI SPEC-301-20.

Tendon bands and anchor zones can also create directional stiffness; a vibration map may show lower mobility along a band and concentrated response near anchor regions or slab discontinuities; these observations should be interpreted with structural drawings. They do not authorise alteration of the tendon system.

18.58 Hollow-core slabs as coupled ducts and plates

Hollow-core units carry load through webs and prestressed concrete while longitudinal cores reduce mass; the cores can become acoustic routes if their ends, penetrations or joints remain open; a core may cross a room boundary or connect to a façade, shaft or floor box. Topping concrete does not necessarily close the core; end closures and service intersections therefore require direct inspection.

The structural response is also directional. Webs carry shear and influence bending waves; joints between planks can crack or transmit force; a ceiling below the slab may conceal both airborne core paths and structure-borne radiation; the investigation should combine drawings, borescope inspection, tapping or local excitation, pressure tests where safe and room-level spectra.

Integrated worked example 18.26. Core opening as a parallel path

A 24 m^2 boundary has direct transmission loss of 58 dB in a selected band; one hollow core presents an effective open area of 0.0025 m^2 after allowing for tortuosity and partial closure. Treating that route conservatively as unit transmission, the area-weighted coefficient is approximately [(24 - 0.0025)10^-5.8 + 0.0025]/24 = 1.058 x 10^-4, corresponding to 39.8 dB; the opening occupies roughly 0.010 per cent of the boundary yet controls the screen. Real core impedance reduces transmission, while connected length and terminations shape resonances; the result is a conservative path-ranking calculation, not a measured wall rating.

18.59 Floating-floor mount layout and load redistribution

A floating floor is a distributed isolation system; its behaviour depends upon mount stiffness, spacing, preload, edge clearance, topping stiffness and the distribution of permanent and movable loads; a heavy cabinet placed between mounts can deflect the slab locally. A partition built on the floating slab changes the load map; unequal mount deflection can tilt the floor and close a perimeter gap.

The design should retain a mount schedule and load map; commissioning includes survey of deflection or natural frequency at representative locations; later furniture, safes and equipment are reviewed against the original assumptions; a nominal mount type cannot guarantee isolation when preload and bridge conditions differ. [150]

18.60 Floating-floor perimeters, ramps and door interfaces

The perimeter is the most common place for a floating floor to become rigidly connected to the host structure; screed can overflow a resilient upstand; skirting, thresholds, ramps, conduits and door frames can span the isolation joint. A bridge may be hidden beneath flooring and become active only under load.

The detail should show continuous resilient separation, fire and smoke treatment, cover geometry and inspection access; thresholds require special coordination because accessibility and door sealing demand stable surfaces;

150 MB-0199. ASTM International, ASTM C94, ASTM C31.

a designed transfer plate can accommodate movement without rigidly tying the floating slab to the host. The final contact survey should include loaded operational conditions.

18.61 Isolated ceilings and suspended service loads

An isolated ceiling can reduce radiation from a structural slab and form part of an inner shell; its effectiveness depends upon hanger dynamic stiffness, ceiling mass, cavity depth, perimeter separation and service attachments; ducts, cable trays, luminaires, sprinkler pipes and access panels can bridge the ceiling. Flexible service connections must carry operational movement and pressure without becoming taut.

A ceiling should not be judged from hanger data alone; the complete installed transfer path includes inserts, wires or rods, channels, board layers, perimeter details and services; ceiling plenum background and air paths are measured separately from structure-borne transmission.

18.62 Machinery force characterisation and receiver-side response

Equipment catalogues often report sound power or vibration velocity but not the blocked force applied to the building; for structure-borne prediction, the source and receiver impedances matter; a pump on a flexible base can behave differently when connected to a stiff slab; pipe strain, misalignment and short flexible connectors can bypass mounts. The survey should record equipment state, speed, load, mount deflection and connected services. [151]

Order tracking is useful for rotating machinery; a line that follows speed is distinguished from a fixed building resonance; coherence between source

151 MB-0833. International Organization for Standardization, ISO 12354-1:2017, ISO 10848-4:2017.

and receiving sensors supports a path, but low coherence can arise from multiple sources or non-stationarity. The diagnosis combines spectral, time and operational evidence.

Integrated worked example 18.27. Isolation efficiency at an operating speed

A machine-isolation system has natural frequency 6 Hz and negligible damping for a screening calculation; at an operating forcing frequency of 30 Hz, the frequency ratio is r = 5; for base excitation well above resonance, approximate transmissibility is 1/(r^2 - 1) = 1/24 = 0.0417, or minus 27.6 dB in amplitude. The screen assumes linearity, no rocking, no service bridges and stable preload; if a rigid pipe support bypasses the mounts, the system result can be much worse. The calculation does not establish room isolation; it tests whether the nominal mount frequency is plausibly separated from one operating order.

18.63 Soil-borne and external transportation vibration

Road, rail, construction and underground services can excite foundations; propagation depends upon soil layering, source distance, foundation type and building modes; a short indoor survey cannot separate external events from plant unless time records, external reference sensors and event logs are coordinated. Long-duration monitoring may be needed when sensitive discussions occur during quiet periods or when intermittent events dominate.

Mitigation can involve source coordination, foundation isolation, local inner shells or operational scheduling; the acoustic report should distinguish detectability of vibration from recoverability of speech; a structural response at a sensor is not itself evidence that intelligible information leaves the room.

18.64 Structural joints, movement gaps and acoustic closure

Expansion and seismic joints interrupt slabs or walls structurally but can remain open air routes through finishes and plenums; covers must accommodate movement while maintaining fire, smoke and acoustic functions; rigid closure defeats movement; soft packing without an air seal can leak. The joint should be detailed as a layered assembly with accessible inspection points.

Field testing under one static position does not demonstrate performance throughout movement. Mock-up cycling, dimensional inspection and alternative-state testing may be necessary where consequence is high. [152]

18.65 Slab vibration measurement geometry

Accelerometer orientation, mounting and reference coordinates must be explicit. A vertical measurement alone can miss in-plane or rotational motion at a junction; sensor mass and adhesive can influence thin panels, while poor mounting can create local resonances; calibration under ISO 16063-21 supports the transducer chain but does not validate the installed mounting or geometry. [153]

A useful grid includes source-side, path and receiver-side locations; phase and coherence are retained where path direction matters; repeated measurements after sensor remounting help quantify mounting uncertainty; results are reported as velocity, acceleration, mobility or transfer functions with units, not as unlabelled decibel traces.

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152 MB-0028. American Concrete Institute, ACI CODE-318-25, ACI/PCI CODE-319-25.
153 MB-0144. ASTM International, ASTM C42, ASTM C597-22.

18.66 Structure-borne radiation and receiving-room surfaces

Vibration becomes an acoustic exposure when receiving surfaces radiate; radiation efficiency depends upon panel size, frequency, boundary condition and coincidence; a low-mobility massive slab may feed a lightweight ceiling or façade that radiates efficiently; receiver-side intensity or surface-velocity measurements can identify the radiating element.

Remediation should target the dominant combination of energy flow and radiation; treating the highest vibration point is not always optimal if another surface radiates more effectively; the analysis should preserve the distinction between structural transmission and room sound level.

18.67 Embedded pipes, conduits and floor boxes

Slab services create both openings and force paths; a conduit may connect boxes on opposite sides of a boundary; a drain or hydronic pipe can transmit pump and flow vibration through rigid supports; firestop and acoustic closure must remain compatible with movement and maintenance. Floor boxes require lids, gaskets, internal partitions and controlled cable routes.

The penetration register should include exact location, core or trench geometry, service type, support and closure. Temporary empty conduits are not benign. They can form efficient acoustic ducts until sealed at both ends.

18.68 Structural remediation and the risk of path displacement

Adding a topping, beam, brace or patch changes mass, stiffness and force distribution; it may reduce one response while increasing another; a local repair can shift a mode toward an operational frequency or redirect energy to a façade. The remediation model should therefore include neighbouring members and receiving surfaces.

Before-and-after tests should use comparable source states, sensor coordinates and environmental conditions. A changed spectrum is interpreted through the physical intervention, not merely through a single-number improvement. Residual paths remain in the report.

18.69 Commissioning of slab and foundation systems

Commissioning begins with drawings and records, then verifies joints, penetrations, floating elements, ceilings, machinery mounts, service connections and façade interfaces; measurements are selected from the threat and path model; airborne, impact and vibration tests answer different questions and should not be combined into one unsupported acceptance label.

The commissioning dossier includes raw data, calibration, coordinate drawings, operational states, uncertainty and corrective actions. Formal use remains a decision for the competent authority after the engineering evidence is reviewed.

18.70 Lifecycle triggers for retesting

Retesting is considered after major equipment replacement, floor penetration, tendon work, raised-floor alteration, ceiling access, façade repair, water damage, structural cracking or unexplained change in background; the trigger should be proportional to the changed mechanism; a local inspection may be sufficient for a documented gasket replacement; a new floor trench can justify comprehensive testing.

Lifecycle control prevents gradual erosion of the boundary. It also preserves a baseline that allows future anomalies to be interpreted rather than rediscovered from first principles.

18.71 Slab-path design review checklist

The design review identifies structural topology, spans, beams, columns, cores, joints, penetrations, floating elements, ceilings, services, machinery, façades and external sources; it names the quantities used to rank each path and the evidence required before closure; the review also states which changes require structural approval and which tests are prohibited because of tendon, safety or operational constraints.

A floor assembly is not accepted by material description. The configured room, path network and measured state form the engineering object.

18.72 Chapter synthesis. Slabs and foundations as distributed transmission systems

Slabs and foundations extend beyond the room and can carry vibration around excellent partitions; their behaviour depends upon topology, plate waves, joints, supports, voids, services, machinery and receiver radiation; floating floors and isolated ceilings can be effective only when every bridge and load state is controlled. The final conclusion must distinguish direct airborne isolation, impact performance, structure-borne response, occupied speech exposure and formal acceptance.

18.73 Structural mobility as a design and diagnostic quantity

Structural mobility is velocity divided by applied force at a defined point and direction; it expresses how readily a slab or supporting member responds to excitation; the quantity is local and frequency-dependent; it changes with position, boundary condition, cracking, attached partitions and nearby masses. A mobility measurement at one floor location cannot be transferred uncritically to another bay or to a different direction.

For design, mobility helps compare source and receiver impedances and estimate whether machinery force will enter the structure efficiently; for diagnosis, a grid of point and transfer mobilities can distinguish a stiff support line from a flexible plate region; the force transducer, hammer tip, sensor mounting, windowing and averaging must be documented. Calibration of the acceleration chain does not establish the force channel or the repeatability of impact location. [154]

Integrated worked example 18.28. Mobility and injected vibrational power

A machine applies a harmonic force of root-mean-square magnitude 120 N at 31.5 Hz; the measured driving-point mobility magnitude is 2.5 x 10^-5 m/(N s), and the force and velocity are assumed in phase for a conservative screen. Velocity is v = YF = 2.5 x 10^-5(120) = 0.0030 m/s; average active power under the in-phase assumption is P = Fv = 0.36 W; if phase is actually 70 degrees, active power becomes 0.36 cos 70 degrees = 0.123 W; the units reduce to watts because newtons multiplied by metres per second give joules per second. The calculation shows why complex mobility and phase are needed; it does not predict receiving-room level without propagation and radiation models.

154 MB-0033. American Concrete Institute, ACI CODE-562-25.

18.74 Structural intensity and direction of energy flow

Structural intensity combines stress and particle velocity to estimate directional vibrational energy flow; in plates it can indicate whether energy moves directly across a boundary or circulates around a junction; the method is more demanding than a simple vibration map because multiple components, phase accuracy and spatial derivatives are required. It is best used where path direction matters and the measurement system has been validated.

A structural-intensity arrow should not be interpreted as proof of speech recovery; it identifies energy flow under the applied excitation; receiver radiation, background and information content remain separate; the method can nevertheless guide placement of breaks, inner shells or damping treatments.

18.75 Finite-element models of slabs and their validation

Finite-element models can represent irregular slab geometry, beams, cores, openings and boundary conditions; their apparent precision can conceal uncertainty in cracking, composite action, damping, soil support and service attachments; mesh size should be related to bending wavelength, and results should be checked for convergence. Model damping should not be adjusted merely to match one peak while other response features remain unexplained.

Validation uses independent measurements, such as modal frequencies, mobility at several points and transfer response across a junction. A model that reproduces one source-receiver path but fails elsewhere should be treated as local. Sensitivity analysis identifies which uncertain parameters control the decision. [155]

18.76 Dynamic loads from walking, carts and furniture movement

Operational loads are not limited to standard tapping machines; walking produces repeated heel and forefoot impulses with cadence harmonics; carts excite joints and small floor irregularities; movable partitions and furniture can create impact and scraping forces. The protected-room test plan should identify credible activities in the source and receiving spaces.

A standard impact rating remains useful for comparison, but it should not be reinterpreted as speech isolation. Operational time histories can be compared with structural modes and room sound; where an adjacent corridor is accessible, trolley and maintenance events may raise background and mask speech, or may excite the structure and create additional noise; both effects should be documented rather than assumed beneficial. [156]

18.77 Foundations, tunnels and buried service routes

Basements and underground rooms can be coupled through foundations, retaining walls, utility tunnels and buried pipes; a tunnel can form an airborne duct and a structure-borne connection; foundation walls may be continuous around several rooms; soil contact adds damping but also transmits external vibration.

Inspection should include utility drawings, tunnel access, drainage, joints and structural continuity; pressure and airflow in service spaces may change with plant operation; a secure-room boundary that appears isolated above

155 MB-0032. American Concrete Institute, ACI CODE-562-25.
156 MB-0132. ASTM International, ASTM C157, ACI CODE-318-25.

grade can be bypassed below the floor. The design should close or control the route without compromising drainage, ventilation or access.

18.78 Floating-floor specification and submittal review

A floating-floor specification should identify design load, surface mass, mount or mat dynamic stiffness, natural-frequency objective, damping, perimeter separation, service details, construction sequence and acceptance measurements; product submittals should provide data at relevant preload and frequency; static deflection alone may not define dynamic stiffness.

Mock-ups or first-of-type zones can test concrete placement, resilient upstands, penetrations and door interfaces; the inspection plan should occur before the topping hides mounts and bridges; photographs, mount locations and load records become part of the as-built dossier.

Integrated worked example 18.29. Mount count and static load

A 48 m^2 floating slab has area mass 180 kg/m^2 and carries 6,000 kg of permanent partitions and equipment; total supported mass is 48(180) + 6,000 = 14,640 kg; with 120 mounts and a 10 per cent allowance for unequal load, design average mass per mount is 14,640(1.10)/120 = 134.2 kg. The corresponding static force is approximately 1.32 kN per mount; the calculation assumes the loads are distributed according to the mount layout. Concentrated equipment and edge effects require a detailed load map. It establishes a preliminary preload, not isolation performance.

18.79 Forensic case. Intermittent low-frequency disclosure path

A secure conference room above a central plant area exhibits occasional low-frequency receiving sound during meetings. Routine airborne testing passes. Long-duration records show that the anomaly coincides with a variable-speed pump crossing 27 Hz; slab accelerometers and room microphones show coherent response at that order; the partition and door are not controlling.

Inspection finds that a pipe riser is rigidly clamped to the slab at both rooms and that the pump flexible connectors are misaligned; correcting the connector geometry and replacing one rigid support with an engineered resilient support reduces the structural order. Post-work airborne isolation is unchanged, while operational receiving levels fall; the case demonstrates why an apparently acoustic leak can be a machinery path and why source-state records are essential.

18.80 Slab and foundation acceptance language

A defensible acceptance statement identifies the tested structural and operational state; it states which airborne, impact and vibration methods were used, which plant modes were active, what uncertainty applies and which residual paths remain; it avoids declaring the slab itself "secure". The result belongs to the configured room and adjoining environment.

The acceptance dossier should also state triggers for reassessment: new coring, tendon work, equipment replacement, floor build-up change, façade alteration, water damage or unexplained vibration; this closes the chapter's lifecycle logic and connects construction evidence to continuing use.

18.81 Foundation isolation and building-within-building systems

Some high-isolation spaces use isolated slabs or foundations to reduce structure-borne transfer; the isolation system may consist of springs, elastomeric pads, air mounts or layered mats; its performance depends upon total supported mass, centre of gravity, mount distribution, damping, lateral restraint and service connections. Foundation isolation is not merely a larger floating floor; it must carry structural and seismic loads and remain stable under construction and maintenance states.

The design should define six-degree-of-freedom modes and avoid operating excitations near rigid-body resonances; snubbers, stops and restraints can become bridges if clearances close; flexible utilities must accommodate movement without fatigue; commissioning records mount deflection, level, clearance and modal response. [157]

Integrated worked example 18.30. Rigid-body resonance screen

An isolated room has supported mass 180,000 kg and total vertical spring stiffness 320 MN/m; the ideal vertical natural frequency is f_n = (1/2pi)sqrt(k/m) = (1/2pi)sqrt(320,000,000/180,000) = 6.71 Hz. A generator order at 13.4 Hz has frequency ratio 2.0, only just beyond the ideal isolation transition near sqrt(2); the screen assumes uniform load, no damping and no rocking coupling; it shows that a nominally isolated foundation can remain sensitive to low-order machinery forces.

157 MB-0018. ACI/PCI CODE-319-25, ISO 10848-4:2017.

18.82 Building expansion joints and separated structural blocks

A structural expansion joint can interrupt one path while creating an open cavity through façades, roofs, floors and services; covers, fire barriers and waterproofing cross the joint; acoustic treatment must permit movement and avoid rigid continuity; the joint geometry changes with temperature and seismic state, so one static test is only part of the evidence.

Where a secure room straddles or approaches a building joint, the design should model both sides and every crossing service; it may be preferable to place the room wholly within one structural block; if that is impossible, independent inner construction can bridge operationally without structurally tying the blocks.

18.83 Rooftop plant and roof-slab transmission

Fans, air-handling units, chillers and screens on roofs can excite roof slabs and structural frames; curbs and rails may bypass nominal isolators; wind and rain add variable background; a secure room below rooftop plant requires source-state measurements during startup, normal load, speed control and shutdown.

Roof penetrations also create airborne routes. Ducts, drains and cable risers must be inspected through the complete roof and ceiling system. Remediation may combine source balancing, curb isolation, flexible connections, receiver ceiling treatment and operational restrictions. [158]

158 MB-0145. ASTM International, ASTM C42, ASTM C642-21.

18.84 Transformers, generators and electrical plant

Transformers produce magnetic forces at twice supply frequency and harmonics, while generators add rotational orders, combustion and exhaust forces; electrical conduits and bus ducts can transmit vibration from plant rooms; emergency modes are particularly important because they may coincide with crisis operations inside protected spaces.

Testing should include normal and standby states; source sensors, structural references and room microphones allow order and coherence analysis; flexible electrical connections require safety and electrical engineering; acoustic work must not compromise bonding, fault protection or fire separation.

18.85 Rail, road and aircraft excitation

Transportation sources generate transient and quasi-periodic vibration; rail wheel and track conditions, road speed, vehicle weight and aircraft operations create variable spectra; their low-frequency components can travel through soil and foundations; a secure-room survey should include representative periods rather than one quiet laboratory-like interval.

Event logs, external sensors and synchronised time support attribution; the conclusion should identify frequency, duration and probability of occurrence; external vibration may mask speech at times or create additional receiving sound; neither effect should be assumed uniformly protective.

18.86 Time-frequency analysis of non-stationary events

Averaged spectra can hide short transients. Short-time Fourier transforms, wavelets or order tracking can show when energy appears and whether it follows source speed; window length trades time and frequency resolution; processing settings must be recorded because they influence the displayed event.

A coloured time-frequency plot is not self-explanatory; the report should retain numerical data, scales, calibration and source chronology; where legal or security decisions depend on an event, raw time histories and processing scripts should be preserved.

18.87 Operational deflection shapes and modal interpretation

Operational deflection shapes describe relative motion under actual excitation; they can identify a radiating panel or structural route without requiring a controlled modal hammer at every point; they do not necessarily represent true normal modes because multiple forces and damping act simultaneously.

The measurement grid should include phase-consistent channels and known coordinate directions; a shape that changes with source speed can indicate forced response rather than a fixed mode; interpretation should be checked against drawings and simpler transfer measurements.

18.88 Uncertainty budget for structure-borne measurements

Uncertainty contributors include transducer calibration, mounting, orientation, position, force repeatability, clock synchronisation, background, windowing, averaging, integration, source state and structural non-stationarity; correlation between channels and repeated positions should be considered; a single instrument tolerance is not an adequate uncertainty statement.

For path ranking, uncertainty can be propagated into differences or ratios; where two paths differ by less than the combined uncertainty, the correct conclusion may be that they are not resolved; remediation should then target a common control or obtain better evidence.

Integrated worked example 18.31. Uncertainty in a transfer-level difference

Two transfer levels are 72.0 dB and 68.5 dB; their standard uncertainties are 1.2 dB and 1.0 dB, assumed independent; the difference is 3.5 dB and its standard uncertainty is sqrt(1.2^2 + 1.0^2) = 1.56 dB. Expanded uncertainty with k = 2 is 3.12 dB; the apparent ranking is only marginal. Correlated calibration terms could reduce or alter the difference uncertainty. The result supports cautious prioritisation, not a categorical claim that one path is dominant.

18.89 Integrated design case. Secure room beside lift and mechanical shaft

A proposed secure room shares a structural core with lifts and a mechanical riser; initial wall specifications are strong, but the path model identifies rail anchors, slab edges, pipe supports and a shared ceiling plenum; the design relocates the most sensitive wall away from the core, uses an independent ceiling, isolates selected pipe supports and creates controlled shaft closures.

Commissioning tests lift travel, door operation, pump states and speech sources; one low-frequency residual follows lift acceleration and is managed through guide adjustment and receiver treatment; the room is accepted on system evidence, not on wall rating alone.

18.90 Verification after structural modification

New openings, strengthening, equipment bases and floor repairs can change structural response; verification should compare pre-work and post-work conditions using common coordinates and source states; if the source or environment has changed, the limitation is stated.

A local improvement can redirect energy. The review should include adjacent surfaces and not merely the repaired point. As-built drawings and models are updated so that future investigators do not rely on obsolete topology.

18.91 Source-to-receiver structural ledger

A structural ledger lists each credible source, force path, junction, radiating receiver and control; it links drawings, measurements and responsible disciplines; the ledger can distinguish active plant paths from dormant or inaccessible routes and can identify which changes require retesting.

The ledger should not become an unverified catalogue. Each entry carries status: hypothesised, observed, measured, remediated or closed. This supports cumulative reasoning and prevents rediscovery during later maintenance.

18.92 Slab and foundation evidence synthesis

The final evidence package combines structural topology, source states, service routes, isolation systems, measurements, uncertainty and lifecycle controls; it states which bands and paths were resolved and which remain bounded by measurement floor or access. The conclusion is room-specific.

Slabs and foundations are distributed transmission networks. They can bypass walls through plate waves, cores, columns, equipment and external ground. Reliable control requires source engineering, structural-path analysis, receiver treatment and continuing configuration discipline.

18.93 Soil-structure impedance and foundation response

Foundation vibration depends on both the structure and the supporting soil; soil stiffness, damping, layering and groundwater affect translational and rocking response; a foundation model that assumes a fixed base can overstate natural frequencies and underestimate energy loss, while an overly soft model can exaggerate motion. Geotechnical data and measured response should inform the range.

The secure-room assessment should identify whether the concern is external ground vibration, internal machinery or force transmitted between foundation elements. Each source requires different reference sensors and operating records. The purpose of modelling is to rank plausible paths and controls, not to manufacture certainty from sparse soil data. [159]

18.94 Basement retaining walls and slab-on-grade interfaces

A basement room may share retaining walls, footings and slab-on-grade with plant or exterior ground; joints between wall and slab can leak air or carry force; under-slab drainage and utility trenches can connect spaces; a topping or finish can conceal movement and previous repairs.

Inspection should include construction joints, waterstops, cracks, drains, sumps and penetrations. Where exterior access is impossible, interior path tests and environmental history become more important. Remediation must preserve waterproofing and structural function.

159 MB-0157. ASTM International, ASTM C597-22, ASTM C805.

18.95 Long-span floors and perceptible vibration

Long-span floors can have low natural frequencies and low damping; occupant movement, rhythmic activity or equipment can produce perceptible vibration even when structural safety is satisfactory; a secure meeting room may experience fluctuating background or surface motion that affects recordings and acoustic tests.

The design should consider room placement relative to midspan, supports and active areas; operational tests can reveal whether common traffic excites the room; added partitions and raised floors can change mass and damping after structural design.

Integrated worked example 18.32. Frequency shift from added fit-out mass

A floor mode is 8.0 Hz before fit-out; the effective modal mass is estimated at 40,000 kg; fit-out adds 6,000 kg participating in the same mode, while stiffness is assumed unchanged; new frequency is 8.0 sqrt[40,000/(46,000)] = 7.46 Hz. The screen assumes full mass participation and unchanged boundary conditions. It shows that architectural fit-out can shift low-frequency response and should be included in final commissioning.

18.96 Stair flights, landings and handrail connections

Stairs connect floors structurally and can transmit footfall, door slams and impact into adjacent rooms; landings may be cast integrally with cores or supported on bearings; handrails and balustrades can rattle or connect lightweight finishes; a room near a stair should be tested during representative traffic.

Isolation joints at stair landings must satisfy structural and fire requirements; receiver-side treatment may be more practical than altering the stair; the path model should include the core and slab, not only the shared wall.

18.97 Structural response of raised access floors

Raised access floors consist of panels, pedestals, stringers and a plenum; they can transmit rolling and impact noise, bridge partitions and form air paths; pedestal attachment to the slab creates repeated force points; cut panels and floor boxes can leak.

The protected boundary should extend through or below the raised floor in a controlled manner; panel layout, gasket condition and plenum barriers are inspected; equipment loads and underfloor airflow influence operation; a catalogue panel rating does not establish room isolation.

18.98 Ceiling-hanger layout and slab-path interaction

Ceiling hangers sample slab motion at discrete points and deliver it to channels and boards; their spacing and location relative to beams or ribs affect response; a hanger attached near a high-mobility zone can dominate; service hangers that touch the ceiling grid create additional paths.

A diagnostic test can compare ceiling and slab transfer functions. Temporary support changes may be unsafe and require engineering control. The design should instead use known resilient elements and verified clearances.

18.99 Vibration from water hammer and transient service events

Valve closure, pump starts and water hammer produce short, high-force transients. Averaged spectra can understate them. Pipes embedded in or rigidly supported from slabs transmit the event over distance; time histories and event triggers are needed.

The remedy may involve valve timing, arrestors, support changes or pipe isolation. Pressure-system safety remains controlling. The acoustic report should distinguish transient disturbance from speech transmission while recognising that the same structural path can carry both.

18.100 Correlated structural and airborne measurements

Simultaneous microphones and accelerometers can show whether receiving sound follows a vibrating surface; coherence, phase and transfer functions support the mechanism; correlation alone can be misleading when both channels respond to a common airborne source; control tests, source relocation or local damping can help distinguish paths.

Channel clocks and delays must be verified. A small timing error can destroy phase at high frequency. The record states sample rate, anti-alias filters and processing.

Integrated worked example 18.33. Timing error and phase

A two-channel system has relative delay 0.25 ms. At 500 Hz, phase error is 360 f delta-t = 360(500)(0.00025) = 45 degrees; at 2 kHz it becomes 180 degrees; the calculation shows that sub-millisecond timing errors can reverse apparent phase. It does not establish the magnitude error, which depends on the processing and coherence.

18.101 Structural-path specification clauses

Specifications should identify isolated elements, mount properties, load states, service-flexibility requirements, bridge prohibitions, inspection points and acceptance measurements; drawings show perimeters, thresholds, penetrations and supports; submittals include dynamic data at relevant preload rather than only static load capacity.

Construction surveillance occurs before toppings, ceilings and access floors conceal the work. Nonconformances are resolved through engineering review and retest where required.

18.102 Slab and foundation chapter final statement

Horizontal structure connects rooms, façades, cores, plant and foundations across large distances; reliable control requires topology, source force, mobility, junction and radiation evidence; impact ratings, machinery vibration, airborne isolation and speech security are distinct; the final room conclusion should state the tested system, uncertainty and lifecycle triggers.

18.103 Tendon, reinforcement and slab-wave interaction

Reinforcement and post-tensioning primarily serve structural functions, yet their distribution influences cracking, stiffness and load transfer. Tendon bands, column strips and reinforced beam lines can channel force; the steel itself is a small fraction of slab mass, but its prestress and continuity alter boundary conditions; acoustic interpretation should use structural drawings and should not infer tendon condition from vibration alone. [160]

Where a measured ridge follows a tendon band, the observation supports a directional structural path but not a defect; remediation should target

160 MB-0032. American Concrete Institute, ACI CODE-562-25.

source, receiver or non-structural interfaces; cutting, drilling or locally weakening the slab is not an acoustic option.

18.104 Foundation cracks, construction joints and water-control interfaces

Foundation walls and slabs contain construction joints, waterstops, cracks and penetrations; a crack can carry air where it connects occupied spaces, or vibration where the structure remains in contact; water-control repairs can close one route while creating rigid patches or drainage changes.

Investigation should establish whether the feature is active, wet, through-thickness and connected; temporary interior sealing may test airborne contribution, but permanent work requires structural and waterproofing review; a dry surface after repair does not prove the underlying joint is acoustically continuous.

18.105 Pneumatic and hydraulic isolation systems

Air springs and hydraulic mounts can provide low natural frequencies and load levelling; their performance depends upon pressure, reservoirs, valves, hoses, leakage and control logic; a levelling valve can transmit slow force or create noise; loss of pressure can close clearances and activate stops.

Commissioning records pressure, ride height, resonances, control settings and failure modes. Alarms and maintenance are integrated with facility operations. The system should remain safe and structurally stable under loss-of-power or leakage conditions. [161]

161 MB-0030. American Concrete Institute, ACI CODE-318-25, ACI SPEC-301-20.

Integrated worked example 18.34. Air-spring stiffness screen

An air spring supports 25 kN and has effective vertical stiffness 0.90 MN/m at the operating condition; supported mass is 25,000/9.81 = 2,548 kg; ideal natural frequency is (1/2pi)sqrt(900,000/2,548) = 2.99 Hz. If an auxiliary hose or snubber adds 0.60 MN/m in parallel, total stiffness becomes 1.50 MN/m and frequency rises to 3.86 Hz; the calculation assumes linear stiffness and one degree of freedom. It demonstrates that auxiliary components materially affect isolation.

18.106 Constrained-layer damping and local slab treatments

Damping treatments can reduce resonant response of thin plates or metal deck, but massive concrete slabs often store energy across large structural regions; a small local layer may reduce one surface response without altering the main force path. Bond, temperature and fire properties also matter.

Before applying damping, the engineer should confirm that a resonant local panel controls the receiving sound. A temporary mass or damping intervention can test sensitivity. Permanent treatment is then designed for durability and access.

18.107 Integrated case. Post-tensioned office floor with later service trench

A secure room is constructed on a post-tensioned office floor; several years later, a shallow service trench is cut outside the protected boundary under an approved tendon-avoidance plan; after the renovation, low-frequency isolation worsens; survey shows that the trench intersects a raised-floor plenum and removes topping that previously stiffened a slab-edge zone.

The remedy closes the plenum at the boundary, reconstructs the topping with structural approval and isolates the new service supports; common-coordinate measurements show restoration of the previous transfer response; the case illustrates why safe structural approval alone does not preserve acoustic configuration and why later work must update both records.

18.108 Slab and foundation chapter closure

Slabs, foundations, tendons, joints, mounts and services form one dynamic system; their performance cannot be reduced to thickness or an impact rating; the engineering process should identify source force, structural mobility, transfer paths, receiver radiation, uncertainty and operational state. The configured room remains the object of acceptance.

Table 18-R1. Slab-path source, governing diagnostic quantity and preferred control level.

Path or source	Diagnostic quantity	Preferred control level	Common misinterpretation
Rotating machinery	Coherence, speed order and transfer mobility	Source, mount and service connection	Treating all low-frequency sound as airborne leakage
Continuous slab flank	Mobility map and receiving-surface radiation	Inner shell or receiver treatment	Adding mass only to the separating wall
Hollow-core void	End inspection, tracer and local acoustic scan	Core closure and service control	Assuming topping closes every core
Floating-floor bridge	Mount deflection and bridge stiffness	Remove rigid contact and restore clearance	Judging isolation from nominal mount data
Soil-borne event	Long-duration synchronised vibration record	Source control, local isolation or operations	Using one short daytime survey

18.109 Slab and vibration technical schedules

Table 18-1. Slab system and flanking characteristics

Slab system	Directional or modal feature	Common hidden path	Diagnostic emphasis
Flat plate	Two-way continuity around columns	Column strips, punching zones and continuous finishes	Multi-axis mobility grid and column/slab junction mapping
Beam-and-slab	Stiff beam lines and local panel bays	Beam crossing protected boundary and ceiling hangers	Response along beam axis compared with slab field
Ribbed or joist slab	Strong orthotropy and thin topping	Rib cavities and services parallel to joists	Directional scans and exact section model
Hollow-core plank	Longitudinal voids and plank joints	Core penetrations, end openings and topping cracks	Void tracing, end closure inspection and plank-joint mapping
Concrete on metal deck	Corrugated profile and composite connectors	Open flutes at wall heads and steel deck radiation	Deck-profile closure, beam map and plenum inspection
Post-tensioned slab	Sustained compression and tendon paths	Unsafe retrofit cores, anchor zones and rigid tendons	Scanning, protected work zones and low-frequency response
Floating slab	Resilient support and rigid-body modes	Perimeter bridges, pipes, thresholds and bottoming	Static deflection, natural frequency, bridge register and force transmissibility

Table 18-2. Vibration measurand and inferential limit

Measurand	Instrument or method	Supports	Does not establish alone
Acceleration at a point	Calibrated accelerometer	Local motion versus frequency and time	Radiated sound power or source identity
Velocity mobility	Shaker or impact force with velocity response	Dynamic compliance and resonance at defined coordinates	Whole-slab transmission under another force distribution
Transfer mobility	Force at source and response at remote point	Path attenuation and junction behaviour	Speech intelligibility at receiving location
Structural intensity	Multi-sensor phase-related measurement	Direction and magnitude of vibration power flow	Airborne leakage through openings
Impact level	Standard tapping machine and room microphones	Field or laboratory impact-sound performance	Airborne speech isolation
Coherence	Synchronous source and response records	Linear association over frequency	Causation where common sources or nonlinearities exist
Decay rate	Impulse or interrupted excitation	Modal damping and energy loss	Steady operational force or room acceptance

Table 18-3. Floating-floor failure modes

Failure	Mechanism	Inspection	Corrective principle
Perimeter screed bridge	Rigid finish contacts surrounding wall	Concealed perimeter photograph and tapping/vibration scan	Cut and reconstruct perimeter with durable resilient separation
Pipe or conduit bridge	Service bypasses resilient layer	Bridge inventory and force-response test	Use flexible transition and independently supported service
Support bottoming	Load compresses resilient layer to hard contact	Static deflection survey and load map	Redistribute load or redesign support stiffness
Threshold bridge	Door transition spans isolation joint rigidly	Threshold removal inspection and comparative mobility	Use structurally supported but isolation-compatible transition
Debris beneath slab	Construction fragments create point contacts	Borescope, sounding and local transfer map	Controlled opening and removal where feasible
Unequal support load	Mount tolerances shift load and natural frequency	Jack-down or load-cell record, deflection grid	Level and rebalance supports within design limits

Table 18-4. Lifecycle triggers for slab retesting

Change event	Why it matters	Minimum review
New core or floor box	Cuts mass, may intersect tendon or void and creates air path	Structural approval, scan, penetration record, closure inspection and acoustic spot test
Replacement mechanical plant	Changes force spectrum and mount loading	Equipment data, isolation design, flexible connections and vibration baseline
New raised floor or ceiling	Introduces shared cavities, pedestals and hangers	Boundary-extension review, bridge inventory and plenum inspection
Door threshold alteration	Can bridge floating floor or expose underfloor path	Door and floor detail review, contact test and field measurement
Water event	Changes resilient materials, toppings and cracks	Moisture survey, support condition, crack map and comparative response
Structural repair	Changes stiffness, mass and load path	Repair record, updated model and targeted transfer measurement

18.110 Conclusions

Slabs and foundations create long, stiff paths that can bypass excellent walls; their acoustic behaviour follows structural topology, frequency, junctions, supports, voids, finishes and services; airborne, impact and machinery-vibration metrics answer different questions; floating floors and isolated ceilings can improve performance only when bridges are controlled.

The defensible record combines structural drawings, construction evidence, calibrated measurement and operational states. It does not infer speech security from slab thickness or IIC alone.

Chapter 18 Glossary

Floating floor. Secondary floor layer supported on resilient material and isolated at its perimeter to reduce force transmission.

Force transmissibility. Ratio of transmitted dynamic force to applied force for a defined mechanical system.

Hollow-core plank. Precast prestressed floor element containing longitudinal voids.

Impact insulation class. Single-number classification derived from laboratory impact-sound measurements under the applicable standard.

Mobility. Velocity response divided by applied force at a specified point and direction.

Post-tensioned slab. Concrete slab compressed by tendons stressed after concrete placement.

Shared plenum. Ceiling or floor cavity communicating between rooms or boundary zones.

Structural continuity. Physical load path permitting force and vibration to pass among connected members.

Bending wavelength. Spatial period of a flexural wave in a plate or slab at a stated frequency.

Blade-pass frequency. Frequency equal to rotational speed multiplied by the number of blades or vanes passing a fixed point per revolution.

Column strip. Design and structural zone of a flat slab associated with column lines and usually greater reinforcement or stiffness.

Floor-box path. Airborne or service route through a recessed floor box, trench or poke-through assembly.

Structural intensity. Directional rate of vibrational energy flow per unit width or area in a structure.

Transfer slab. Thick structural slab that redistributes loads between differing column, wall or framing grids.

Chapter 19. Natural Stone, Engineered Stone, Historic Massive Construction, and Conservation-Compatible Isolation

19.1 Visible thickness is not an acoustic test

Historic stone walls invite confidence because they appear massive, cool and permanent. Their actual construction can be profoundly heterogeneous; ashlar facing may conceal rubble, voids, timber bonding pieces, flues, pockets, later brick infill and loose core material; mortar can be sound at the face and absent deeper within the wall; floors and roofs may be pocketed into the masonry. Chimneys, garderobes, ducts and blocked openings create hidden networks; a measured field result belongs to the configured wall and room, not to "stone" as an undifferentiated material.[162][163]

The evidence hierarchy begins with archival drawings, measured survey, material identification, joint mapping and nondestructive observation. Controlled openings are used only where justified and authorised; product standards for newly quarried dimension stone identify properties of specimens; they do not certify a centuries-old composite wall; ASTM C119-24 supplies current dimension-stone terminology, and ASTM C1242-26 addresses the selection, design and installation of attachment systems for dimension-stone cladding.[164][165]

162 MB-0036. American Concrete Institute, ACI SPEC-301-20, ASTM C94.
163 MB-0035. American Concrete Institute, ACI SPEC-301-20, ASTM C94.
164 MB-0835. International Organization for Standardization, ISO 12354-1:2017, ISO 10848-4:2017.
165 MB-0024. American Concrete Institute, ACI CODE-318-25, ACI/PTI CODE-320-25.

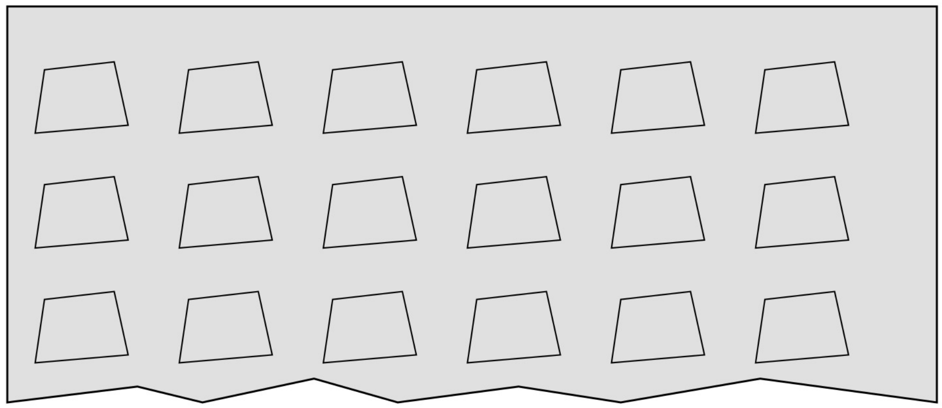

Figure 19-1. Historic rubble wall with irregular wythes, voided core, timber pocket, mortar loss and later service chase. Author's original schematic. The acoustic path cannot be inferred from visible thickness alone.

Worked example 19.1. Gross mass estimate and uncertainty

A 700 mm wall has two 180 mm dense stone wythes at 2,550 kg/m³ and a 340 mm rubble core whose effective bulk density is estimated at 1,650 kg/m³. Surface mass estimate is

$m' = 2(0.180)(2,550)+(0.340)(1,650) = 1,479$ kg/m².

If core density uncertainty is ±300 kg/m³, surface-mass uncertainty from the core alone is ±102 kg/m². The wall is unquestionably heavy, but the mass estimate says nothing about connected voids or flanking.

19.2 Stone families and anisotropy

Granite, limestone, marble, sandstone, slate and other stones differ in mineralogy, pore structure, bedding, foliation, weathering and fracture; granite is generally dense and low in absorption, though microcracking and joints matter; limestone ranges widely in density and porosity; marble can exhibit veining and anisotropic deformation. Sandstone and other quartz-based stone can be strongly bedded; slate is cleaved and highly directional. Engineered stone introduces resin, aggregate and manufacturing variables.[166][167][168][169][170]

Acoustic models often begin with density and elastic properties, but anisotropy changes wave speed and bending response; a thin stone panel oriented across its weak plane can behave differently from one cut in another direction; moisture modifies mass and stiffness and can open freeze-thaw damage. Historic walls add mortar and interfaces whose properties may dominate.

Worked example 19.2. Moisture uptake from absorption data

A limestone sample has dry density 2,200 kg/m^3 and water absorption 4 per cent by dry mass; a 100 mm solid wythe has dry surface mass 220 kg/m^2; saturated water mass at the reported absorption is

$\Delta m' = 0.04(220) = 8.8$ kg/m^2.

The ideal mass-law change is only 20 log_10(228.8/220) = 0.34 dB. Moisture-driven cracking, salt crystallisation and interface degradation can be more important than added mass.

19.3 Ashlar, rubble and multi-wythe walls

Ashlar masonry uses dressed units in regular courses, but the rear construction may differ from the visible face; rubble walls use irregular stones and abundant mortar, often with a core of smaller fragments; multi-

166 MB-0026. American Concrete Institute, ACI CODE-318-25, ACI/PCI CODE-319-25.
167 MB-0027. American Concrete Institute, ACI CODE-318-25, ISO 12354-1:2017.
168 MB-0016. ACI/PTI CODE-320-25.
169 MB-0300. ASTM International, ASTM E492-25, ASTM E1007-25.
170 MB-0860. International Organization for Standardization, ISO 16063-21:2003, ISO 20816-1:2016.

wythe work can contain through-stones or ties that connect faces. Later pointing can mask deep joint loss.

A through-stone increases local mass continuity and structural tying while also transferring vibration between faces; a voided core can create cavity resonances and air communication; loose rubble can dissipate energy or rattle; the wall should be mapped as zones rather than represented by one homogeneous plate.

Worked example 19.3. Connected-void Helmholtz screen

A hidden cavity volume is estimated at 0.18 m^3 and connects through a 0.002 m^2 opening of effective neck length 0.25 m. Ideal resonance is

f_H = (c)/(2π) sqrt ((S)/(V L)) = (343)/(2π) sqrt ((0.002)/(0.18(0.25))) = 11.5 Hz.

The low result indicates that this simple cavity alone is unlikely to create a narrow speech-band resonance, but branching passages, smaller volumes and radiating panels can. The geometric uncertainty is large.

19.4 Mortar, pointing and depth of repair

Mortar is the continuous matrix that closes joints and accommodates movement. Historic mortars are often softer and more vapour-permeable than modern Portland-cement-rich materials; incompatible hard pointing can force moisture and stress into stone, causing spalling or edge loss; NPS Preservation Brief 2 emphasises matching the historic mortar in physical properties and removing deteriorated mortar carefully.[171]

Acoustically, shallow pointing may close the visible surface while leaving deep voids; that can improve air leakage at the room face, but it does not

171 MB-0792. International Code Council, ASTM E90-23, ASTM E336-25a.

reconstruct the internal wall; deep repointing can be beneficial where joints are empty, yet excessive removal can destabilise rubble and damage arrises. The conservation and structural team determine permissible depth and method.

Worked example 19.4. Mortar-joint volume

A 12 m^2 ashlar wall face has estimated visible joint fraction 8 per cent. Repointing depth is 35 mm. Mortar volume is

$V = (12)(0.08)(0.035) = 0.0336\ m^3$.

At 1,750 kg/m^3, dry mortar mass is about 58.8 kg. The mass addition is negligible relative to the wall, but air closure can be significant.

19.5 Chimneys, flues, floor pockets and concealed passages

Historic rooms often contain chimney breasts, blocked fireplaces and flues; a flue can extend to roofs or adjacent rooms, acting as an acoustic duct; closing the fireplace opening at the room face may leave a large resonant cavity; floor beams pocketed into masonry create structural coupling and air gaps. Abandoned services can connect voids.

The survey traces these features vertically and horizontally; smoke tests, borescopes, drawings and cautious acoustic excitation can help, subject to fire and conservation controls; no invasive test should introduce soot, moisture or damage; a flue used for ventilation or required by code cannot be sealed casually.

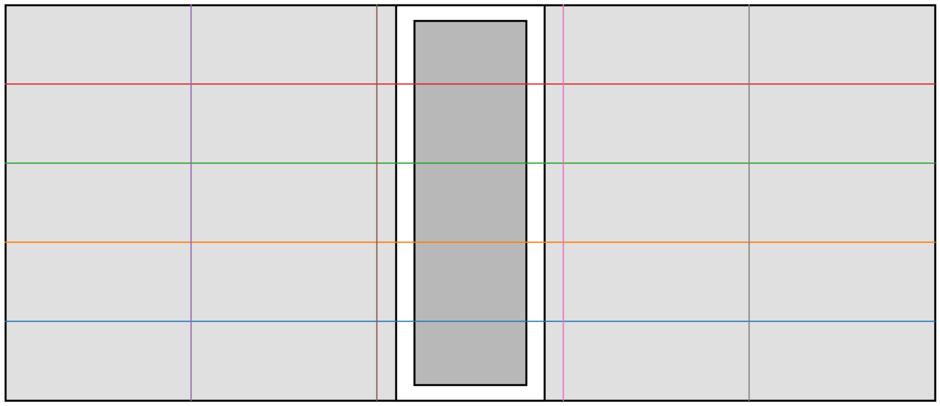

Figure 19-2. Ashlar wall with concealed flue, timber floor pocket, later infill and room-side closure. Author's original schematic. A surface patch can leave a connected vertical acoustic path.

Worked example 19.5. Flue cross-section and attenuation need

A rectangular flue is 250 mm by 400 mm, area 0.100 m^2; a room wall is 20 m^2; the flue opening is 0.5 per cent of wall area; if untreated, it can dominate a high-performing wall. To reduce an open-path coefficient by 50 dB requires effective treatment transmission coefficient 10^{-5}, a demanding system that usually needs depth, mass, absorption and multiple turns rather than a thin grille.

19.6 Mechanically anchored stone panels

Modern stone may be thin cladding rather than loadbearing masonry; panels are attached to subframes, curtain walls or concrete using kerfs, dowels, clips and anchors; the cavity, support frame, insulation, air barrier and backup wall govern acoustic performance; stone density alone is a minor part of the system. ASTM C1242-26 requires engineering consideration of attachment design, documentation, material compatibility and installation workmanship.[172]

Rigid anchors transmit vibration from stone to structure; panel joints permit weather drainage and pressure equalisation and are not necessarily airtight; the interior backup wall is usually the primary acoustic boundary; a secure-room façade should be analysed as a layered system, including mullions, slab edges, spandrels and perimeter seals.

Worked example 19.6. Thin granite panel mass

A 30 mm granite panel at 2,700 kg/m³ has surface mass

$m' = 0.030(2{,}700) = 81$ kg/m².

The panel is heavy compared with glass but far lighter than a massive wall. Open joints and cavity paths mean it cannot be treated as the sole acoustic barrier.

19.7 Engineered stone and composite panels

Engineered stone can include crushed mineral aggregate bound in resin, thin stone laminated to honeycomb or concrete backing, and other composite products; fire, smoke, thermal expansion, adhesive ageing and structural attachment require product-specific evidence; the composite panel may possess resonances absent from solid stone.

Manufacturer data should identify exact panel construction, dimensions, supports and test specimen; substituting a visually similar product can change mass, stiffness and damping; field cuts and penetrations need

172 MB-0858. International Organization for Standardization, ISO 16063-21:2003.

approved details; a proprietary panel rating does not establish the façade or room result.

Worked example 19.7. Two-layer composite surface mass

A panel comprises 12 mm stone at 2,600 kg/m^3 and 25 mm cementitious backing at 1,900 kg/m^3. Surface mass is

$m' = 0.012(2{,}600)+0.025(1{,}900) = 78.7$ kg/m^2.

The calculation excludes adhesive and frame. Coupled bending, not mass alone, controls its spectrum.

19.8 Conservation-compatible independent isolation

Where historic fabric cannot be drilled, chased or coated, a reversible independent lining can create a new internal boundary; the lining stands clear of stone, uses limited approved stabilisation, keeps services on the room side and preserves ventilation or inspection of the cavity; secondary glazing and an internal door can complete the envelope. The intervention should be removable without irreversible loss of significant fabric.[173][174]

The cavity needs moisture assessment. A warm inner lining can alter condensation risk at the cold stone; hygrothermal analysis, drainage and monitoring may be required; absorber should be compatible and not trap water. Fire and egress must remain.

173 MB-0859. International Organization for Standardization, ISO 16063-21:2003.
174 MB-0834. International Organization for Standardization, ISO 12354-1:2017, ISO 10848-4:2017.

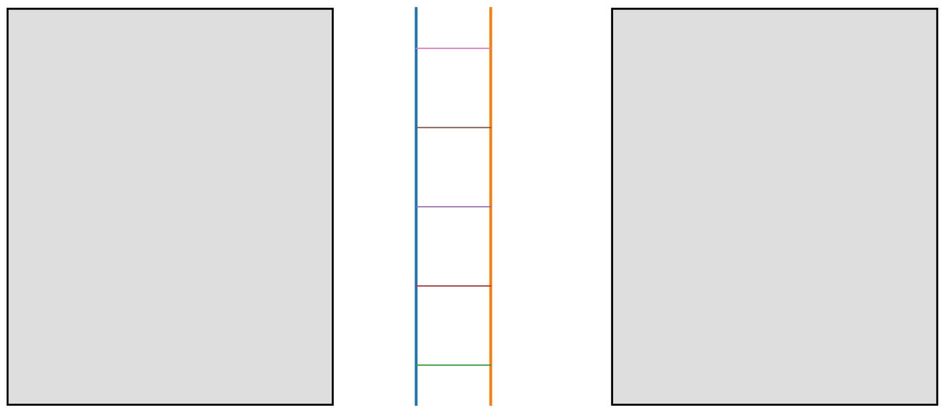

Figure 19-3. Reversible independent lining inside historic stone construction with inspection cavity, secondary glazing and isolated service zone. Author's original schematic.

Worked example 19.8. Independent lining resonance

A 20 kg/m^2 inner leaf stands 150 mm from a massive stone wall. Ideal rigid-backing resonance is

$f_r = \frac{1}{2\pi} \sqrt{\frac{1.2(343)^2}{0.150(20)}} = 34.5$ Hz.

The deep cavity places ideal resonance below most speech bands, but bridges, finite geometry and the non-rigid historic wall remain.

19.9 Windows, doors and historic joinery

Historic windows and doors frequently control room performance; thick walls can contain deep reveals, sash boxes and shutters that form complex cavities; secondary glazing can improve isolation while retaining external fabric, but frames, ventilation and condensation require design. An internal secondary door can create a compact sound lock.

Original joinery may be protected. Compression seals, automatic bottoms and new hardware can alter appearance and operation. Reversible additions should be preferred where feasible. Fire and egress requirements override purely acoustic preferences.

Worked example 19.9. Secondary-glazing cavity

Existing 6 mm glass is supplemented by 10 mm laminated inner glass with 180 mm cavity; the large spacing reduces coupled-pane resonance relative to a narrow insulating unit, while unequal panes separate coincidence features; exact performance requires tested or modelled panes, frames and seals; the cavity dimension alone is not a rating.

19.10 Forensic evidence map for historic construction

A historic-room investigation should separate observation, archival evidence, inference and test result; the wall face is mapped by grid; cracks, joints, patches, timber, services and moisture are photographed; archival plans are overlaid but not assumed correct. Borescope openings are numbered and restored. Material samples carry provenance.

Acoustic data are linked to coordinates. Temporary sealing of a flue or crack tests path contribution; vibration measurements at floor pockets or ties test structural routes; the final drawing marks known, inferred and unknown zones distinctly.

historic-fabric evidence map

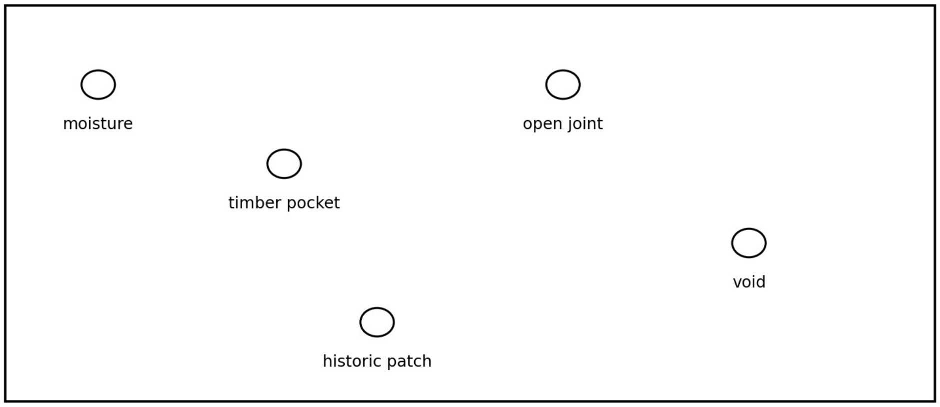

Figure 19-4. Historic evidence map combining archival hypothesis, surface survey, controlled openings, material samples and acoustic observations. Author's original diagram.

Worked example 19.10. Survey coverage

A wall elevation is divided into 0.5 m by 0.5 m cells. For a 6 m by 3.5 m wall, grid count is

$N = ((6)/(0.5))((3.5)/(0.5)) = 84.$

Each cell receives photographs and condition codes. The grid creates traceability, not proof of concealed conditions.

19.11 Field measurement and bounded conclusions

Laboratory E90 data may exist for new stone panels or test walls, but historic room performance is usually established in the field under ASTM E336 or ISO 16283-1;[175][176][177] the result belongs to the configured room, including doors, windows, floors, roofs, flues and services; weighted ratings

175 MB-0301. ASTM International, ASTM E492-25, ASTM E1007-25.
176 MB-0061. ASHRAE, ASHRAE Handbook - HVAC Applications, chapter on sound and vibration control.
177 MB-0887. International Organization for Standardization, ISO 20816-1:2016.

under ISO 717-1 or ASTM E413 are accompanied by the underlying spectrum.[178]

Massive walls create dynamic-range limits. Receiving bands near background are reported as bounds. Irregular rooms require careful spatial averaging. Threat-oriented measurements at accessible windows, corridors and adjoining rooms supplement standardised room results.

Worked example 19.11. Lower-bound reporting

Source level is 98 dB, receiving level with source 18.5 dB and background 18.0 dB. Subtraction is unstable. The field attenuation is reported as at least approximately 79.5 dB for that configuration, subject to method limits, rather than an exact value.

19.12 Case study. Historic diplomatic salon

A nineteenth-century stone salon is proposed for sensitive diplomatic meetings; the walls are 650 to 900 mm thick, but one fireplace connects to a disused flue and timber joists pocket into the party wall; original windows and doors are protected. Baseline testing shows high mid-band isolation through the wall field and pronounced weakness at the fireplace, sash boxes and door.

The design uses a reversible internal flue closure with inspection access, secondary glazing in independent frames, a conservation-compatible inner door forming a small sound lock, and local independent lining at the party wall; floor treatment avoids cutting historic joists. Services are surface-routed within removable joinery.

178 MB-0888. International Organization for Standardization, ISO 20816-1:2016.

Post-work measurements improve the weak paths. No assumed STC is assigned to the historic stone; the report describes the configured room, states dynamic-range bounds and records the conservation limitations; formal use remains with the competent authority.

19.13 Weathering, salts and acoustic discontinuity

Stone deterioration changes the acoustic path by opening joints, scaling surfaces, cracking laminations and loosening attachments. Salt crystallisation can occur beneath surfaces and within pores. Freeze-thaw cycles enlarge defects. Biological growth retains moisture. Water-repellent treatments can alter drying and should not be applied as a generic cure.[179]

The survey relates moisture sources to acoustic findings; a damp stain may indicate a connected path, but water and sound do not follow identical impedances; temporary sealing and moisture monitoring provide complementary evidence; treatments are selected for material compatibility and conservation, not simply because they close pores initially.

Worked example 19.12. Joint-loss area

A 20 m^2 rubble wall has 9 per cent visible joint area. Survey finds 6 per cent of that joint area deeply eroded. Affected area is

$20(0.09)(0.06) = 0.108\ m^2$.

This is only 0.54 per cent of wall area, yet connected recesses can control leakage.

179 MB-0025. American Concrete Institute, ACI CODE-318-25, ACI/PTI CODE-320-25.

19.14 Marble bowing and thin-panel instability

Thin marble cladding can bow under thermal and moisture cycling; bowing changes joint width, anchor load and cavity geometry; a panel may remain intact yet lose consistent seal contact; the issue is different from massive marble masonry and must be treated as a cladding-system problem.

Inspection records panel flatness, anchors, joints and temperature. Acoustic analysis focuses on the backup wall and perimeter. Attempting to stiffen bowed panels without stone engineering can create fracture.

Worked example 19.13. Bow-induced joint change

A 1.2 m panel bows outward 4 mm at centre; if adjacent panels remain flat, local joint faces rotate and seal compression changes; mean curvature screen is approximately $8w/L^2 = 0.022\ m^{-1}$; the geometric result supports inspection but not structural capacity.

19.15 Slate, foliation and discontinuous backing

Slate's cleavage permits thin durable panels but creates strong directional properties; fastener holes and edge notches can split along foliation; interior slate slabs may be adhered to backing; exterior slate may use hooks or pins; the acoustic system is governed by panel joints and backup construction.

A slate wall should not be modelled as an isotropic concrete plate. Product tests establish stone properties in specified orientations. Field panels, supports and cavities require separate evidence.

Worked example 19.14. Slate surface mass

A 25 mm slate panel at 2,750 kg/m^3 has surface mass 68.8 kg/m^2; open joints and sparse anchors mean the panel cannot provide the isolation expected of a continuous barrier with that mass.

19.16 Sandstone bedding and moisture paths

Sandstone can be highly anisotropic and porous; bedding orientation affects strength, moisture transport and weathering; delamination parallel to bedding can create shallow resonant plates; hard cement pointing can trap stress at stone edges. Compatible mortar and drainage are central.

Acoustic inspection may detect hollow-sounding regions, but impact sounding is qualitative and can damage friable surfaces. Infrared or ultrasonic methods require calibration and conservation approval. The report separates suspected delamination from confirmed air leakage.

Worked example 19.15. Delaminated surface-plate resonance screen

A shallow 20 mm sandstone layer over a 0.5 m by 0.5 m debonded area behaves approximately as a plate; because boundary conditions and modulus are uncertain, frequency estimates can vary by more than an octave. The useful conclusion is that a local radiating panel is plausible, not a precise resonance value.

19.17 Engineered anchors and galvanic compatibility

Stone anchors must resist gravity, wind, seismic and handling loads while remaining durable. Stainless steel, aluminium and other metals can interact galvanically in the presence of moisture. Anchor holes concentrate stress. C1242-26 treats attachment systems as engineered components integrated with the building skin.[180]

Acoustically, anchors create discrete bridges. Resilient washers may reduce high-frequency transfer but cannot be introduced without structural and

180 MB-0887. International Organization for Standardization, ISO 20816-1:2016.

durability analysis. The backup wall and subframe usually dominate room isolation.

Worked example 19.16. Anchor density

A façade bay has 24 stone panels, each supported by four anchors, over 30 m^2; anchor density is 3.2 anchors/m^2; even if each anchor area is tiny, the repeated stiffness network can couple the cladding to the structure.

19.18 Conservation law, significance and decision records

Historic work is governed by the significance of fabric and applicable law, not acoustics alone; the project identifies character-defining elements, permissible interventions, review authorities and documentation requirements; reversibility is desirable but not absolute; safety and use may require carefully justified permanent work.

The decision record explains alternatives considered, expected acoustic benefit, fabric impact and monitoring. A minimal intervention with measured performance can be more defensible than a visually hidden but destructive alteration.

Worked example 19.17. Weighted option comparison

Three options are scored from 1 to 5 for acoustic benefit, reversibility and moisture compatibility; applying weights 0.5, 0.3 and 0.2 makes the assumptions visible; the resulting rank is an administrative aid, not a substitute for statutory review or engineering evidence.

19.19 Long-term monitoring of historic rooms

Historic materials continue to move and weather; baseline crack maps, humidity, temperature, joint photographs and acoustic tests support later comparison; monitoring should be non-invasive and proportionate; sensors and cables themselves must not damage fabric or create uncontrolled penetrations.

A change in sound isolation can precede visible deterioration or can result from a door or service alteration unrelated to stone. The lifecycle review examines the complete room before attributing change to historic masonry.

Worked example 19.18. Humidity-cycle comparison

A room is tested at 38 per cent and 68 per cent relative humidity; a 2 dB band change is observed, while repeatability uncertainty is 1.2 dB; the evidence suggests possible environmental sensitivity but is insufficient for a categorical causal claim without repeats and joint measurements.

19.20 Petrography, anisotropy and microcracking in natural stone

Natural stone is a geological material whose properties depend upon mineral composition, grain size, fabric, porosity, weathering and direction; granite may appear homogeneous at room scale yet contain preferred mineral orientation and microcracks; limestone can vary from dense crystalline material to highly porous fossiliferous stone. Sandstone has bedding planes and cementation that govern moisture and fracture. Slate is strongly foliated. Marble can display veining, anisotropic thermal expansion and bowing; product names alone are therefore weak engineering descriptors. [181]

Petrographic examination supports identification of minerals, pores, veins, altered zones and weathering; it does not directly provide airborne transmission loss. Its value is mechanistic. A porous limestone may admit

181 MB-0112. ASTM International, ASTM C119-24, ASTM C97.

distributed air movement through joints and surface-connected pores; a foliated slate can delaminate into thin radiating leaves; a marble panel can bow and open perimeter joints. A granite block can remain massive while a cracked mortar core creates the actual path.

Anisotropy should be recorded with orientation; flexural strength measured across bedding is not equivalent to strength parallel to bedding; wave speed can differ by direction; in a wall, block orientation may vary; a model that assumes one modulus and density should carry uncertainty or use a range. For historic rubble walls, the heterogeneity may be so large that field testing is more reliable than material prediction.

Microcracks influence damping and moisture. Their apertures can change with temperature and stress; freeze-thaw, salt crystallisation and thermal cycling can enlarge them; a visible polished surface may conceal subsurface cracking; tapping, ultrasonic pulse, infrared response and petrography can provide complementary evidence, but the conclusion should distinguish surface condition from through-thickness continuity.

Integrated worked example 19.19. Directional wave-speed uncertainty

Ultrasonic measurements on representative stone show 4,800 m/s parallel to bedding and 3,900 m/s normal to bedding; a wall contains blocks with unknown orientation; if a pulse path is 0.60 m, travel time ranges from 0.125 ms to 0.154 ms before coupling and joint effects. The twenty-three per cent speed difference is larger than typical instrument timing uncertainty.

A field survey that ignores orientation could misclassify normal material variation as damage. The example supports directional reference samples and uncertainty bands. It does not convert pulse velocity into sound insulation.

19.21 Rubble and multi-wythe walls as uncertain void networks

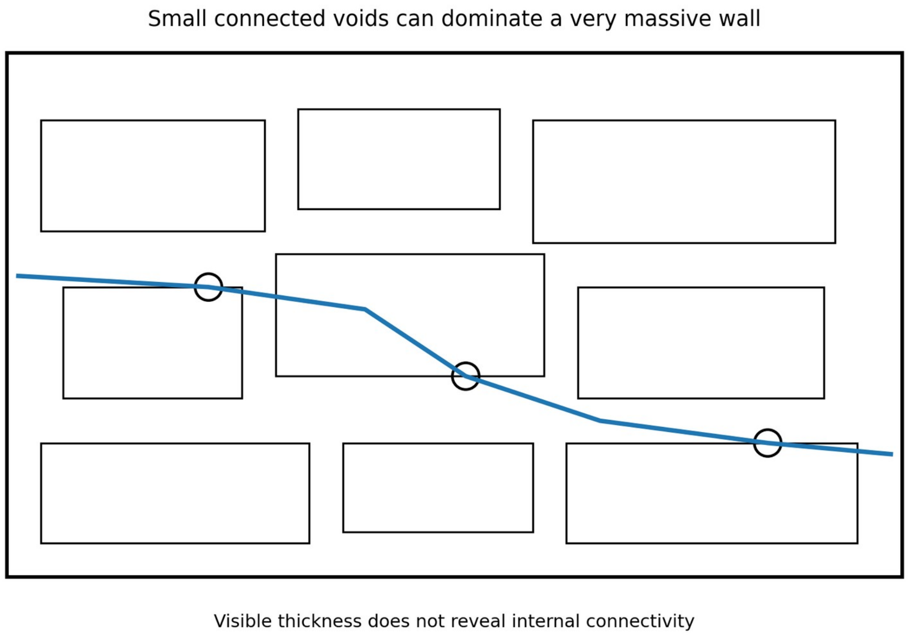

Figure 19-R1. Connected void route through a heterogeneous rubble wall. Author's original schematic.

A rubble wall may contain outer faces, irregular hearting, mortar, voids, through-stones, timber fragments and later injections; the visible faces reveal little about the core. Some voids are isolated. Others connect vertically through settlement gaps or horizontally to floor pockets, flues and service chases; acoustic transmission can therefore follow a sparse network that occupies a small fraction of wall volume.

Traditional construction often relied on large through-stones or bond stones to tie wythes; these improve structural integrity but also couple vibration; timber floor beams may be pocketed deeply into the wall, creating paths between rooms and floors. Later cement repointing can stiffen the surface while trapping moisture and accelerating internal deterioration.

A void model should separate geometry from connectivity; total void percentage is less important than whether openings connect source and receiver; a large isolated cavity may have little effect; a narrow continuous passage can dominate; tracer gas, smoke, borescope, acoustic pulse and microgravity or radar methods can provide different evidence. No method should be represented as a complete three-dimensional map without validation.

The investigation should proceed from archival research to non-invasive survey, then to targeted opening; old plans, photographs and repair records can identify chimneys, blocked doors and former floor levels; thermography under suitable environmental conditions can reveal voids or moisture; sonic transmission can identify relative changes. Borescope openings should be few, reversible and placed with conservation approval.

Integrated worked example 19.20. Connected-void path versus total porosity

A 0.8 m thick rubble wall has estimated total void volume of 6 per cent. Most voids are isolated. One connected path has average cross-section 0.002 m2 and length 1.4 m, linking a former flue to a floor pocket; the connected path represents less than 0.01 per cent of wall volume, yet it can dominate high-frequency airborne transmission because it forms a continuous route.

The example shows why bulk porosity is not a security metric. Connectivity and termination control the path.

19.22 Mortar compatibility, moisture, salts and freeze-thaw deterioration

Mortar is both structural bedding and environmental control; historic lime mortars are generally more permeable and compliant than dense Portland cement mortars; repointing with an incompatible hard mortar can concentrate stress in softer stone, impede drying and promote spalling; acoustic closure that accelerates material loss is not a durable improvement. [182]

Moisture changes mass, stiffness, damping and salt transport; rising damp, rain penetration, condensation and leaking services create different patterns; salts crystallise as moisture evaporates, exerting pressure in pores; freeze-thaw expands water and can widen cracks. A joint that is acoustically tight during a dry survey may open seasonally.

The conservation strategy should establish the moisture source before sealing; a vapour-impermeable lining can move condensation into the historic wall; a sealed flue can trap moisture; reversible inner isolation may be preferable to aggressive surface treatment. Ventilation and drainage functions should be preserved.

Monitoring should record humidity, temperature, moisture content and crack condition; acoustic tests are interpreted against that record; a two-decibel seasonal change may be real but not necessarily security-significant if another path dominates; the report should avoid attributing every change to stone moisture without corroboration.

182 MB-1061. National Park Service, Preservation Brief 1: Assessing Cleaning and Water-Repellent Treatments for Historic Masonry Buildings.

19.23 Timber pockets, chimneys, flues and concealed service chases

Historic massive walls frequently contain materials other than stone; timber beams, joists and lintels are embedded in pockets; chimneys and flues may be blocked only at visible openings; bell pulls, speaking tubes, gas pipes and later electrical chases create small channels. These features can bypass metres of masonry.

Timber provides a structure-borne path and can shrink away from masonry, creating air gaps. Decay can enlarge pockets. Fire-stopping added during later work may be incomplete or incompatible; a floor beam that passes into two rooms can transmit vibration even when the pocket is sealed acoustically.

Flues are particularly deceptive. A fireplace may be closed with masonry at the room face while the flue remains open above; sound can travel vertically and re-enter through another fireplace or roof opening; soot, bends and roughness add attenuation but should not be relied upon. A secure-room survey should trace the flue to its termination and adjoining rooms.

Service chases can be identified from archival plans, electrical routes and wall thickness changes. Non-invasive survey may locate them. Any closure must preserve fire and moisture behaviour; a permanent fill can be inappropriate if the chase contains heritage fabric or requires ventilation; an independent inner boundary may again be the safer solution.

Integrated worked example 19.21. Former flue as a parallel path

A stone wall field is screened at 65 dB transmission loss in a selected band; a blocked fireplace connects to a flue with effective 0.03 m2 opening and path loss 35 dB. Wall area is 24 m2. Linear combination gives a composite result near 55 dB, despite the flue occupying only 0.125 per cent of area.

The calculation is a screen because flue geometry and losses are uncertain. It demonstrates the leverage of a connected concealed path.

19.24 Thin anchored stone, façade cavities and secondary radiation

Modern stone cladding often consists of thin panels mechanically anchored to a backup wall; the visible stone is not the primary air barrier; joints may be open and pressure-equalised; the cavity, insulation, membrane, anchors and backup determine acoustic transmission; treating the stone panel as a monolithic wall is a category error. [183]

Panel thickness and dimensions control modal behaviour; large thin panels can radiate efficiently. Anchors provide discrete force paths. Cavity resonances and insulation affect response. Wind-induced vibration or rain impact can excite the façade; interior secure rooms adjacent to such façades require a separate, continuous inner acoustic boundary.

Anchor systems must satisfy structural and durability requirements; reducing anchor stiffness or count for acoustics is not permissible without façade engineering; instead, internal linings, secondary glazing and slab-edge treatment can control the room; the façade cavity should be inspected for unintended openings into ceilings or raised floors.

Engineered stone and stone-faced composite panels require product-specific evidence. Resin content, backing, honeycomb cores and adhesives

183 MB-0120. ASTM International, ASTM C1242-26.

change fire, moisture and acoustic behaviour. Product standards for dimension stone do not automatically apply.

19.25 Conservation-compatible inner shells and reversible isolation

A protected historic room often cannot accept destructive alteration to stone, plaster, joinery or decoration; acoustic improvement must therefore be reversible, visually discreet and compatible with moisture; an inner shell can provide a controlled boundary while leaving the historic wall largely untouched.

The design begins with significance mapping. Highly significant surfaces may remain exposed. Less significant service zones can receive independent linings; secondary glazing can be installed in reversible frames; a second door can form a small sound lock without cutting historic fabric; floors can receive floating platforms over protective layers, provided moisture and load are addressed.

Supports should be located in verified structure and minimised; freestanding frames can reduce anchors but require stability. Resilient restraints may be needed. The cavity should permit inspection and environmental monitoring; materials should be removable without irreversible residue.

The inner shell must not create a hidden damp environment; hygrothermal analysis considers vapour drive, air leakage and thermal bridges; ventilation may be required, but any vent path must be acoustically controlled; leak detection is prudent near roofs and plumbing.

Fire, egress and accessibility remain controlling. A secondary door cannot obstruct escape or damage listed historic hardware; added linings must not conceal fire detection or create combustible voids; conservation approval and fire review belong in the same decision record as acoustic performance.

19.26 Diagnostic methods and their evidentiary limits

No single diagnostic method can characterise a historic massive wall; visual survey identifies joints, cracks and alterations; infrared thermography reveals temperature patterns under suitable excitation; sonic and ultrasonic tests indicate relative continuity; radar can identify some embedded features; borescopes provide direct local views; acoustic field tests show actual room transmission. The evidence is strongest when the methods converge.

Thermography is sensitive to environmental conditions. Solar loading and indoor heating can create useful contrasts, but reflective surfaces and moisture complicate interpretation; a cold stripe may indicate a void, metal tie or moisture. It is not self-explanatory.

Sonic testing through thick irregular walls suffers from scattering and uncertain path length. Reference areas are essential. Radar resolution decreases with depth and conductive moisture; borescope openings sample only their line of sight; endoscopic images should include orientation and scale.

Field acoustic testing remains the direct evidence of room performance; it cannot identify every hidden cause by itself; local source and receiver scans, temporary sealing and structural measurements can refine the path model;

controlled opening is reserved for questions whose consequence justifies intervention.

19.27 Heritage governance, professional roles and evidence preservation

Historic work adds a governance layer. The owner, conservation authority, architect, structural engineer, fire professional, acoustical engineer and security authority may have distinct responsibilities; no discipline should assume that its preferred intervention controls all others.

The decision record should state significance, authorised alterations, reversible measures, testing, monitoring and residual risk; public secure-room guidance does not override heritage law; conversely, heritage status does not remove the obligation to protect sensitive information; the project may require operational controls where physical alteration is limited.

Evidence preservation includes archival drawings, photographs, material samples, mortar analyses, sensor data, acoustic measurements and approvals; removed material may have heritage value; chain of custody matters where failure or dispute is investigated; a later reviewer should be able to distinguish historic fabric, previous repair and current intervention.

19.28 Integrated case study. Diplomatic salon in a rubble-stone building

A nineteenth-century diplomatic building contains a salon proposed for sensitive meetings; exterior walls are 700 to 900 mm rubble stone with lime plaster; the room has tall sash windows, a marble fireplace, timber floor beams pocketed into the walls and decorative plaster. Destructive alteration is restricted.

Baseline field testing shows strong direct isolation through much of the wall but severe local transmission at the fireplace, windows and floor perimeter; borescope inspection finds a blocked fireplace opening connected to a continuous flue; smoke testing identifies air movement at one sash pocket. Vibration measurements show floor-beam response extending into an adjacent room.

The design rejects injected foam and rigid cement filling because of moisture, reversibility and unknown fabric; the flue receives an inspectable, fire-compatible acoustic closure at two locations; secondary glazing is installed in reversible interior frames with asymmetric panes and controlled perimeter seals. A freestanding inner lining is placed on the party-wall side, supported from a reversible platform and restrained at limited approved points; a small floor isolation zone reduces beam excitation around the meeting table. A secondary internal door creates a vestibule without removing historic joinery.

Hygrothermal monitoring is installed in the new cavities; the HVAC system is modified so that ventilation does not rely upon uncontrolled leakage; all new services use a controlled route; the room is commissioned in furnished and occupied states, including maximum authorised vocal effort and representative external listener positions.

Post-work measurements show large improvements at the flue and windows; low-frequency structural transmission through floor beams remains measurable, so seating and source placement are controlled; the report states that the configured room meets the project's public-source field and operational criteria subject to authority approval. It does not assign a laboratory STC to the rubble wall and does not claim that heritage construction has been made universally secure.

19.29 Lifecycle monitoring for historic secure rooms

The monitoring plan should be proportionate and non-invasive; annual visual surveys record cracks, joints, secondary-glazing seals, door alignment and evidence of moisture; environmental sensors track humidity and temperature in critical cavities; acoustic baseline measurements are repeated after significant repair, water intrusion, structural movement or service change rather than on an arbitrary calendar alone.

Change control is essential. A picture hook, curtain track or new cable can penetrate the inner shell. Window maintenance can disturb seals. Chimney work elsewhere in the building can reopen a flue; contractors should receive drawings showing protected boundaries and prohibited fixing zones.

Trend interpretation separates measurement variability from physical change; a small band difference may result from furniture or background; repeated, spatially consistent change associated with a visible defect warrants investigation; the room’s heritage and security records should be maintained together so that one programme does not unknowingly compromise the other.

19.30 Historic floors, vaults and massive ceilings

Historic secure rooms may be bounded above or below by masonry vaults, timber floors with heavy infill, jack arches, terracotta units or stone slabs; these systems combine mass with discontinuities and long structural ties; a room assessment should identify the floor or ceiling construction rather than assuming that thick walls define the entire envelope.

Vaults transmit force along curved compression paths into walls and piers; cracks at haunches or springings can create air routes; timber floors can contain voids and service paths; jack arches connect steel beams through masonry units. Suspended decorative ceilings can re-radiate sound and conceal openings.

Reversible inner ceilings or floor platforms may improve isolation, but load, moisture, fire and heritage significance must be considered; supports should avoid fragile plaster and unknown masonry; access for inspection is valuable where cavities contain historic services or leak risk.

19.31 Stone-to-window and stone-to-door interfaces

Historic openings concentrate uncertainty. Stone jambs may be irregular, cracked or repaired. Timber frames shrink and move. Leaded glazing, shutters and secondary frames create multiple layers; a modern acoustic door or window cannot perform beyond the perimeter support and seal.

Survey should include opening dimensions, joint depth, substrate condition and movement; a reversible subframe can create a controlled plane without cutting stone; sealants must be compatible with masonry and joinery; cover trims should not conceal unfilled cavities.

The complete opening should be tested after installation; a local high-frequency leak at one jamb may result from a deep void rather than the visible bead; temporary sealing and borescope inspection can distinguish the cause.

19.32 Material sampling, provenance and laboratory limits

Samples removed from historic fabric require authority, provenance and minimal intervention; a loose fragment may not represent intact wall stone;

mortar samples vary by campaign and depth; laboratory density, absorption and strength tests characterise the sample, not the complete composite wall.

The record should identify location, orientation, depth, condition and chain of custody; petrographic thin sections can reveal minerals and deterioration; results should be integrated with field survey; a precise laboratory value should not erase the uncertainty of hidden wall construction.

19.33 Emergency work and temporary security controls

Water entry, falling stone, fire damage or structural movement may require urgent work before a complete acoustic design is possible. The response should protect life and fabric first while maintaining proportionate information controls.

Temporary measures can include relocation of sensitive meetings, controlled access to adjoining spaces, portable inner enclosures, masking used within its limits, and increased operational discipline; these controls are documented as temporary and do not create a false claim of permanent room performance.

After stabilisation, the room is resurveyed. Repairs, drying and scaffolding can change acoustic paths. Baseline tests are repeated before ordinary secure use resumes.

19.34 Granite, limestone, marble, sandstone and slate as distinct acoustic materials

The principal stone families should not be compressed into one “massive wall” category; granite is commonly dense and stiff, with low open porosity, but jointing and microcracking govern installed performance; limestone ranges widely in pore structure and absorption; marble can be dense yet vulnerable to anisotropic thermal expansion and bowing; sandstone often follows bedding and cementation. Slate divides along foliation and can act as multiple thin plates when delaminated.

These distinctions influence investigation. Granite walls may justify attention to joints and concealed cores; porous limestone requires moisture and air-path analysis; thin marble cladding requires anchor and cavity review; sandstone repairs require compatible bedding orientation and mortar. Slate roofs or linings require inspection for delamination and discontinuous support.

Laboratory product tests establish sample properties. They do not establish a historic wall. The chapter source register should therefore separate dimension-stone standards from building-specific field evidence.

19.35 Engineered stone, resin composites and fire behaviour

Engineered stone can contain mineral aggregate in resin, cementitious binders, glass, metal or honeycomb backing; density and surface appearance do not reveal internal composition; resin content affects damping, temperature response, smoke and fire behaviour; thin composite panels may radiate more readily than solid blocks.

Product-specific declarations and test reports are necessary; cutting or drilling can expose fillers and create dust hazards; adhesives and anchors must be compatible; in a secure room, engineered stone is usually a finish over another boundary. The acoustic analysis should identify the substrate and cavity rather than attributing performance to the decorative surface.

19.36 Historic plasters, renders and decorative finishes

Lime plaster, gypsum plaster, stucco, scagliola and decorative panels can close pores and add damping; they can also detach and form local plates; cracks may follow masonry movement or exist only in the finish; conservation decisions should distinguish substrate and finish.

A detached plaster zone can rattle or radiate; tapping and thermography can identify suspect areas; injection grouts may reattach plaster but must be compatible and reversible where required; an inner acoustic lining should not conceal unstable decoration without conservation review.

19.37 Security operations when physical improvement is constrained

Some historic rooms cannot be brought to a desired physical performance without unacceptable loss of significance; the response may combine limited reversible work with operational controls; meetings can be relocated for the most sensitive topics; adjoining spaces can be cleared and controlled; source level and seating can be managed. Temporary internal enclosures may be used.

These measures must be documented as compensating controls, not as evidence that the room itself meets a higher acoustic class; their effectiveness depends upon procedure and supervision; formal authority decides whether the residual risk is acceptable.

19.38 Vaulted masonry and domed rooms

Vaults and domes carry load through membrane and arch action; their curvature creates complex acoustic fields and structural paths; cracks at ribs, haunches and supports can transmit air; tie rods and chains provide long mechanical connections.

A secure room beneath a vault should be tested with source positions that excite the curved surface; an inner ceiling may be required, but it must avoid loading fragile plaster or altering moisture; supports should be reversible and independently engineered.

19.39 Historic metal ties, cramps and anchors

Stone façades and multi-wythe walls may contain iron or steel cramps, ties and anchors. Corrosion expands and cracks stone. The metal also transfers vibration between wythes. Location and condition are often uncertain.

Radar, metal detection and archival records can assist; repairs may require stainless replacement or local stone repair; acoustic implications are secondary to safety but should be recorded where a tie network connects rooms or façades.

19.40 Lime plaster, lath and decorative cavities

Historic interiors can include timber or metal lath, lime plaster and decorative mouldings separated from stone. The cavity can redistribute sound. Lath and plaster can act as a lightweight leaf, producing mass-air-mass behaviour with the wall.

Repairs should preserve breathability and significance. Adding a dense board directly over decorative plaster can trap moisture and create damage. A freestanding inner lining may be preferable.

19.41 Roofs, parapets and attic paths in historic buildings

Stone walls often terminate beneath timber or metal roofs. Attics contain open air volumes, trusses, chimneys and services. A secure room on the top floor can be bypassed over the wall head.

The survey traces the boundary into the attic; fire compartments, insulation and ventilation are documented; acoustic barriers must preserve roof ventilation and moisture control; access hatches and eaves require attention.

19.42 Historic-room source control and reversible furnishing strategies

Where fabric limits physical work, furnishing can support privacy. Heavy curtains, absorptive panels on freestanding frames and controlled seating reduce room reverberation and incident level at weak façades. Their effect is measured, not assumed.

Furnishings are reversible but operationally variable. Removal or rearrangement changes performance. The authorised room configuration should therefore include a furniture plan and change-control requirement.

19.43 Granite and dense igneous stone

Granite and related dense igneous stones generally provide high mass and low open porosity; in a monolithic block wall, direct airborne transmission can be very low; installed walls, however, are assemblies of blocks, mortar, anchors, cores and openings. Joint and concealed-path evidence remains decisive.

Granite contains quartz, feldspar and mica in variable proportions; thermal expansion differs among minerals and can create microcracks; fire or rapid heating can damage the near surface; polished cladding may conceal anchor cavities. A laboratory density value should be attached to the quarry and sample.

Repairs require compatible stone and mortar. Hard resin fills may close a crack but alter appearance and moisture. In heritage work, limited reversible inner isolation may be preferable.

19.44 Limestone and porous carbonate stone

Limestone spans a wide range of pore structure; dense crystalline limestone behaves differently from soft oolitic or fossiliferous material; water absorption, salt movement and surface erosion can be significant; distributed porosity may contribute to air movement, but joints and core construction often dominate.

Cleaning and water-repellent treatments can change moisture behaviour. They should not be used as acoustic sealants without conservation evidence. A coating that reduces surface absorption may trap moisture behind it.

Field investigation includes moisture mapping, joint survey and material identification. An inner air-control layer can improve acoustic reliability without forcing the historic stone to act as a modern membrane.

19.45 Marble, veining and thermal bowing

Marble can be dense and massive, but veining and anisotropic thermal expansion create directional behaviour; thin exterior panels can bow, opening joints and changing anchor loads; interior marble slabs may be decorative facings over cavities.

The acoustic model should identify whether the marble is structural, veneer or panel; a bowed panel can radiate and leak at its perimeter; replacement must match structural and visual requirements; an inner boundary is often more predictable than relying on a weathered stone façade.

19.46 Sandstone bedding and differential weathering

Sandstone properties depend upon grain size, cement, bedding and porosity; stone laid on edge can weather differently from stone laid on its natural bed; differential erosion opens joints and surfaces; moisture and salts can create delamination.

Sonic and ultrasonic measurements are orientation-sensitive. Reference samples should match bedding. Repointing mortar should be compatible. A dense cement patch can transfer stress into softer stone.

19.47 Slate and foliated stone

Slate splits along foliation into thin sheets; roofing and cladding depend upon overlap and fasteners rather than monolithic mass; delamination or broken pieces create openings; interior slate panels can rattle or radiate.

Acoustic treatment should focus on the backing wall, joints and cavities. Anchors and nails are structural details. Replacing slate with a denser panel does not establish equivalent heritage or acoustic performance.

19.48 Stone stairs, columns and balustrades as structure-borne paths

Massive stone stairs and columns can transmit vibration into a room. Treads may be monolithic or supported on steel. Balustrades and handrails introduce connections. Footfall on a public stair can excite a party wall.

Measurements should include operational footsteps and controlled impact. Receiver treatment or operational control may be more practical than altering historic stone. The path is reported separately from airborne leakage.

19.49 Historic glazing and shutters

Historic windows may include single glass, leaded lights, timber shutters and deep reveals. Closed shutters add mass and cavity separation but have joints. Secondary glazing can provide a controlled inner layer.

The cavity depth, pane asymmetry and frame seals are designed deliberately. Ventilation and condensation are assessed. Original windows remain operable and inspectable where required; commissioning tests each configuration, including shutters open and closed if both states are authorised.

19.50 Conservation-compatible service routing

New electrical, data, fire and audiovisual services should avoid chasing historic masonry. Surface routes can be placed within reversible furniture, raised platforms or inner linings. Penetrations are concentrated in controlled zones.

Existing chases are investigated before reuse; they may connect rooms or contain hazardous materials; fire and acoustic closure are restored at boundaries; the as-built record distinguishes historic and new work.

19.51 Heritage-room operational baseline

The authorised configuration includes furniture, curtains, secondary glazing, doors, flue closures and service states; removing a curtain or opening a shutter can change incident level and leakage; operational staff should understand which elements are performance dependencies.

Baseline photographs and field curves support later comparison. Changes in conservation treatment or exhibition use trigger review. The room is managed as a configured asset rather than a static stone shell.

19.52 Historic-stone peer review and residual uncertainty

A peer review should include conservation, structural, building-physics, fire, acoustic and security perspectives. It should identify hidden-construction uncertainty, material compatibility, reversible options and residual paths.

The final report does not claim certainty where the wall core is unknown; it states what was observed, measured and inferred; where destructive verification is prohibited, uncertainty may be managed through an independent boundary and operational controls.

19.53 Historic masonry chronology as an engineering variable

A historic wall is the accumulated result of construction campaigns, repairs, openings, closures and service installations; a visible stone face may conceal brick backing, timber framing, rubble hearting, concrete infill or later plasterboard; documentary chronology is therefore part of the engineering model; drawings, photographs, maintenance records, paint stratigraphy and local openings can identify phases that correspond with different acoustic paths. [184]

The record should distinguish original fabric from later work without assigning automatic value to either; a twentieth-century conduit chase may be the dominant leak, while an eighteenth-century rubble core remains massive and benign; conservation significance and acoustic consequence are separate attributes that must be considered together.

184 MB-1062. National Park Service, Preservation Brief 1: Assessing Cleaning and Water-Repellent Treatments for Historic Masonry Buildings.

19.54 Irregular wall thickness and uncertainty mapping

Rubble and early ashlar walls can vary substantially in thickness; niches, flues, former openings and pockets create local minima; a single thickness measurement at a window reveal can misrepresent the broader wall; non-invasive methods, measured drawings and limited borescope access can be combined into a thickness-confidence map.

The acoustic model should represent uncertainty spatially; regions with high confidence can support quantitative estimates; regions containing suspected voids or undocumented alterations may require bounded scenarios; the report should not convert an uncertain historic wall into a uniform slab merely because a calculation needs one number.

Integrated worked example 19.22. Effect of a thin local zone

A 30 m^2 stone wall is represented by 28 m^2 of 600 mm construction with an idealised transmission coefficient of 10^-6 and 2 m^2 of a former opening infilled to a coefficient of 10^-4; area-weighted transmission is [(28)(10^-6) + (2)(10^-4)]/30 = 7.6 x 10^-6, corresponding to 51.2 dB. The larger wall region alone would screen at 60 dB, but the two-square-metre infill lowers the combined result by nearly 9 dB; the calculation assumes equal receiving normalisation and power addition; it demonstrates why chronology and local thickness matter more than average wall mass.

19.55 Rubble hearting, settlement and connected air routes

Rubble hearting contains stones, mortar fragments and voids of irregular size; settlement can open continuous routes at wall heads, around beams or beside flues; fine debris can block one section while leaving another connected; injecting grout without understanding moisture and structural behaviour can displace water, load fragile fabric or make future conservation impossible.

A connected route is investigated through safe tracer tests, pressure response, local listening, borescope observations and reversible closures. Total porosity alone is not decisive. A wall with many isolated pores can perform well, whereas one narrow connected channel can dominate. [185]

19.56 Stone-mortar interface and compatible repointing

Mortar joints accommodate movement, transmit load and influence moisture evaporation. Hard, dense replacement mortar can concentrate stress in softer stone and trap moisture; a weak or eroded joint can create air leakage; repointing must therefore be based on material character, joint profile, exposure and conservation significance, not solely on compressive strength; National Park Service guidance and ICOMOS principles emphasise compatibility and minimum intervention. [186]

For acoustic purposes, continuity is important, but continuity must be achieved with an appropriate mortar and joint preparation; a thin surface smear over loose material may look closed while concealing a deep void; trial panels and cured inspection should precede broad work.

19.57 Moisture transport, seasonal state and acoustic stability

Moisture changes density, stiffness and damping, but the larger security concern is often the deterioration it drives; salt crystallisation, freeze-thaw cycles, corrosion of embedded iron and timber decay can open joints or

185 MB-1065. National Park Service, ASTM E90-23, ASTM E336-25a.
186 MB-1064. National Park Service, Preservation Brief 2: Repointing Mortar Joints in Historic Masonry Buildings.

detach finishes; a room tested during one dry season may change after prolonged wetting or heating-system alteration.

Environmental monitoring should accompany crack maps and acoustic baselines where moisture risk is material. Correlation is not causation. A humidity change that coincides with a two-decibel spectral change requires repeated observation and physical inspection before attribution. [187]

19.58 Timber beams, joist pockets and hybrid wall behaviour

Historic floors often bear into wall pockets; the pocket can connect rooms, cavities and floor voids; timber transmits vibration differently from stone and can shrink away from mortar; fire-stopping or later packing may be incomplete. A suspended ceiling can conceal the route.

Inspection should identify pocket geometry, timber condition, fire treatment and air closure without trapping moisture against the beam end; a reversible inner floor edge or independent lining can control the room-side path while preserving the structural pocket. Structural and conservation advice remains essential.

19.59 Chimneys, flues and former fireplaces

A disused chimney may connect several floors and roof spaces; closing only the visible fireplace leaves the shaft active; dampers, rubble, liners and later service routes create uncertain impedance; smoke or pressure testing may be restricted by condition and legal controls. Safe inspection begins with documentary review, visual access and competent chimney assessment.

Where closure is permitted, dual barriers separated along the shaft can reduce transmission and provide inspection; ventilation and moisture

187 MB-0113. ASTM International, ASTM C119-24, ASTM C97.

requirements must be preserved; a flue should remain on the configuration register even after treatment because later maintenance can reopen it.

Integrated worked example 19.23. Two-stage flue closure

A single closure provides 30 dB attenuation in a selected band; a second independent closure is expected to provide 25 dB, but the connecting shaft and side leakage limit independence; a naive sum gives 55 dB. If a parallel side route has 42 dB attenuation, the combined linear coefficient is $10^{-5.5} + 10^{-4.2} = 6.63 \times 10^{-5}$, or 41.8 dB. The side route controls. The calculation shows why two barriers are not automatically additive and why the shaft perimeter must be inspected.

19.60 Stone façades, anchors and rainscreen cavities

Modern stone cladding is usually a thin anchored veneer rather than a massive wall. Panel bending, open joints, anchor stiffness, insulation and the backing wall determine acoustic behaviour; the cavity can connect bays or floors; drainage and ventilation must not be blocked by an acoustic repair that creates moisture problems; ASTM C1242 addresses selection and installation of dimension-stone attachment systems, but it does not certify room sound isolation. [188]

The secure-room boundary should ordinarily be formed by an independent interior construction rather than relying on an exterior veneer. The façade remains relevant as an external listener path and as a structural flank.

19.61 Engineered stone and resin-bound composites

Engineered stone products combine mineral aggregate with resin or cementitious binders; their density, damping, fire response and dimensional

188 MB-0122. ASTM International, ASTM C1242-26, ASTM E90-23.

behaviour differ from natural stone; product slabs are often thin and attached as finishes; they should not be credited with massive-wall performance without assembly data.

Resin content can increase damping but also introduces temperature and fire considerations; joints and fasteners remain dominant at many frequencies; the source register should identify exact product formulation and supporting test evidence where the material contributes to the boundary.

19.62 Historic plaster, lath and detached finishes

Plaster on masonry can close distributed pores and add a stiff surface; plaster on lath forms a separate lightweight leaf with a cavity; detached plaster can rattle or radiate strongly while remaining visually intact; conservation treatment may require retention, consolidation or local repair rather than removal.

Tap surveys, thermography, endoscopy and vibration measurements can help map detached regions, but each has limitations; an observed anomaly is not an instruction to open historic fabric; the investigation plan should identify consequence, authority and the least destructive discriminating method.

19.63 Floors, vaults and domes

Vaulted masonry and domes distribute force through curvature and supports; they can carry vibration to remote walls and create focusing or long reverberation inside the room; floor construction above a vault may contain fill, timber, screed and voids. A local intervention on the visible soffit can therefore miss the dominant path.

Models should preserve geometry and boundary conditions; simple flat-plate assumptions may be unsuitable; measurements at springing lines, crowns and adjoining walls can reveal modal patterns; any attachment to the historic surface requires conservation approval.

19.64 Historic windows, shutters and secondary glazing

Windows often govern historic-room isolation. Sash boxes, pulley pockets, shutters and uneven reveals form multiple paths. Replacing original windows may be unacceptable or unnecessary. Secondary glazing can create a deeper, better-sealed cavity while preserving the primary window, provided condensation, access and emergency use are addressed. [189]

The secondary frame should be independent where practicable and sealed to a verified inner air plane. Cavity symmetry and pane selection influence resonance. Commissioning includes operation, contact, perimeter inspection and room-level testing.

19.65 Door openings in historic stone

Historic doors may be part of significant joinery and cannot simply be replaced by a heavy acoustic assembly; the opening may include deep reveals, panelling, transoms and concealed voids; a secondary internal door or compact sound lock can improve performance while preserving the original leaf. The intervention should remain reversible and should not overload fragile masonry or floors.

The design record identifies which door is the environmental, fire, security and acoustic boundary. Operational sequences must remain practical. A beautiful but rarely closed secondary leaf provides no reliable control.

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189 MB-1060. National Park Service, ASTM E90-23, ASTM E336-25a.

19.66 Reversible service routes

New power, data, ventilation and monitoring systems should avoid chasing historic masonry where possible; surface routes, floor zones or reversible service spines can reduce fabric loss and maintain inspection; penetrations should be grouped, documented and sealed with compatible, removable systems where authorised.

The route must also avoid creating a continuous duct around the inner shell; cables should not hold seals open; service supports should not bridge independent linings; future capacity is planned so that later work does not proliferate uncontrolled holes.

19.67 Conservation-compatible inner-room construction

An inner room can separate the acoustic boundary from uncertain historic fabric; its floor, walls and ceiling require their own structural support, fire strategy, ventilation and access; clearances should permit inspection and avoid moisture traps; the system must not transfer loads to decorative plaster, fragile stone or historic joinery without approval.

The inner shell is not automatically superior; limited room dimensions can raise cavity resonances and reduce usable space; its doors, services and junctions can become the weak paths; the design should be modelled and tested as a complete enclosure.

19.68 Forensic opening and evidence preservation in heritage fabric

Where a controlled opening is necessary, its location, authority, dimensions and sequence are documented before disturbance; photographs, samples and orientation records preserve provenance; removed material is assessed for significance and retained where required; the opening should answer a defined question, not become an exploratory demolition campaign.

Closure uses compatible materials and is recorded in the as-built model. If the opening reveals unexpected construction, the evidence map and risk assessment are updated before further work.

19.69 Historic-room acceptance and residual uncertainty

Acceptance of a historic secure room should state what is known, measured and controlled; concealed construction may remain partly uncertain even after proportionate investigation; the competent authority can consider field isolation, occupied speech tests, access control and operational measures together. A fabricated laboratory rating for the historic wall is neither necessary nor defensible.

Residual uncertainty is managed through monitoring, controlled use, adjoining-space restrictions and change control. The report should identify which future observations would require reassessment.

19.70 Chapter synthesis. Historic mass without false certainty

Natural stone and historic masonry can provide substantial direct isolation, yet age, voids, pockets, flues, hybrid floors, windows and later services often govern the room result; conservation-compatible engineering begins with chronology and minimum intervention, then uses reversible systems and measured evidence. The visible weight of stone is not proof of speech security; the final claim belongs to the configured room, tested state and authorised use.

19.71 Stone density, porosity and wave-speed distributions

Dimension-stone standards provide bounded tests for density, absorption, compressive strength, flexural strength and petrography; historic walls, however, contain variable stone, mortar, voids and weathered zones; a laboratory specimen can characterise the sampled material but cannot represent the wall's complete composite path; sampling location, orientation and moisture state must accompany every numerical property. [190]

Wave speed can help identify gross changes but is affected by mineral orientation, cracks, contact and path length; a high velocity through one ashlar block does not prove continuity through the rubble core; the investigation should use property distributions and structural context rather than a single catalogue value.

Integrated worked example 19.24. Uncertainty in stone-derived surface mass

A wall is estimated at 0.55 m thickness; representative bulk density is 2,450 kg/m^3 with standard uncertainty 120 kg/m^3, and thickness uncertainty is 0.04 m; surface mass is m' = rho h = 1,348 kg/m^2. First-order standard uncertainty is sqrt[(h u_rho)^2 + (rho u_h)^2] = sqrt[(0.55 x 120)^2 + (2,450 x 0.04)^2] = 118 kg/m^2; the relative standard uncertainty is about 8.8 per cent; the calculation assumes independent density and thickness uncertainty and a uniform wall. It demonstrates that even mass is not precisely known; it does not predict transmission loss through voids, joints or openings.

19.72 Anisotropy, bedding and orientation of stone

Slate, sandstone and some metamorphic stones possess pronounced directional fabric; flexural strength and wave speed can differ with

190 MB-0111. ASTM International, ASTM C119-24, ASTM C97.

orientation; weathering often follows bedding or foliation; in a wall, blocks may be laid with mixed orientations, and replacement stone may not match the original quarry or bed.

The survey should note bedding, delamination and thermal bowing where visible. Petrographic examination can support material classification, but the acoustic model must still account for joints and composite construction. Anisotropy is particularly relevant to thin panels, lintels and stairs that can vibrate as discrete elements. [191]

19.73 Seismic strengthening and acoustic consequences

Historic buildings may contain ties, anchors, diaphragms, shotcrete, grout or steel frames added for seismic resistance; these interventions can improve structural integrity while creating new force paths; a steel collector or diaphragm anchor can couple a formerly flexible wall to floors and roofs. Conversely, a continuous structural repair may close cracks and improve airborne isolation.

Acoustic work must not compromise strengthening. The engineer should obtain structural records and map connections before proposing isolation. Where an inner shell is used, its restraints must accommodate seismic demands without becoming unintended rigid bridges. [192]

19.74 Historic wall paintings, panelling and tapestries

Decorative surfaces can be significant fabric and can also alter acoustics; timber panelling creates cavities, joints and removable access; wall paintings constrain drilling and opening; tapestries and soft hangings add absorption

191 MB-0183. ASTM International, ASTM C880, ASTM C1721-22.
192 MB-0787. ICOMOS, Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage.

within the room but do not form an air barrier. They may reduce reverberant source level while leaving direct leakage unchanged.

Investigation methods should be selected with conservators; remote vibration measurements, environmental observation and temporary source control can provide information without contact; a conclusion should state whether a decorative layer affects room acoustics, boundary transmission or both.

19.75 Historic ventilation grilles and passive shafts

Older buildings may use wall grilles, floor ducts, chimneys and ceiling voids for natural ventilation; these paths can connect multiple rooms without mechanical plant; closing them can create moisture, air-quality or heritage problems; the first task is to map the network and identify whether it remains active.

Where continued ventilation is necessary, an acoustically treated route can be inserted reversibly; bends, lined sections or attenuators may be placed in accessible service zones rather than cutting historic masonry; airflow and pressure must remain adequate; the treatment should be inspected after seasonal changes.

19.76 Timber-stone composite floors and ceilings

Many historic rooms combine massive walls with timber joists, boards, plaster ceilings and fill; the floor can be much weaker acoustically than the stone enclosure; joists entering wall pockets transmit vibration and create air paths; floor voids can bypass partitions and doors.

A complete room assessment therefore includes the horizontal boundaries; reversible floating floor zones, independent ceilings and controlled pocket closures may be more effective than work on the stone walls; fire, moisture and structural limits govern the detail.

Integrated worked example 19.25. Horizontal boundary governs a massive room

A stone wall path screens at 62 dB in a selected band, while a timber floor path screens at 43 dB and a door at 46 dB; linear addition gives 10^-6.2 + 10^-4.3 + 10^-4.6 = 7.57 x 10^-5, or 41.2 dB. Improving the stone wall by a further 8 dB changes the combined result by less than 0.1 dB; the calculation assumes comparable reference conditions and uncorrelated power addition; it demonstrates why historic-room remediation must rank the entire envelope.

19.77 Moisture-safe inner lining cavities

An independent lining against historic masonry creates a new cavity; if the cavity is sealed without hygrothermal analysis, moisture can accumulate on cold stone or timber; venting the cavity can create an acoustic path; materials, vapour control, drainage and inspection must therefore be coordinated with climate and wall construction.

The preferred design often keeps the acoustic air barrier on the room side while allowing the historic wall to dry through controlled pathways outside the protected boundary; sensors can monitor temperature and humidity in high-risk cavities; alarm thresholds should be based on conservation advice, not arbitrary comfort limits.

19.78 Conservation decision matrix for acoustic interventions

A decision matrix can compare technical gain, reversibility, fabric loss, moisture risk, fire implications, access and maintenance; the matrix does not replace statutory consent or professional judgement; it makes trade-offs visible and helps reject interventions whose marginal acoustic gain is disproportionate to heritage harm.

For example, deep grout injection into rubble may be irreversible and uncertain, while a freestanding inner lining may offer greater measurable control with less fabric alteration; a secondary door may preserve original joinery better than leaf modification. The selected measure should be tied to the demonstrated path.

19.79 Non-destructive methods and false certainty

Ground-penetrating radar, ultrasonic pulse velocity, thermography, endoscopy and impact sounding can reveal anomalies; their response depends on moisture, geometry, material contrast, access and calibration; an anomaly may represent a void, crack, metal, thickness change or surface condition. No single method proves the acoustic consequence.

A robust investigation combines methods and uses controlled openings sparingly to validate interpretation. Negative results also have limits. An instrument that cannot resolve a small connected channel should not be reported as proving solid construction.

19.80 Historic-room speech testing and occupant protection

Operational speech tests should be designed to avoid exposing real sensitive content. Standardised or controlled speech material can represent vocal effort and spectral content; listener positions, languages and access are defined; testing during maximum vocal effort should remain authorised and safe for occupants; public guidance on secure speech environments can inform the functional objective, while controlled governmental thresholds must not be invented. [193]

The report separates measured field isolation from occupied speech performance and formal approval. A historic room may rely on a combination of physical improvement, adjoining-space control, masking and operational limits.

19.81 Integrated case. Stone council chamber with ceiling and chimney paths

A council chamber has 700 mm rubble walls, historic sash windows, a timber floor and an ornate plaster ceiling; baseline tests show weak bands near a disused chimney and above a doorway; vibration measurements indicate floor coupling, while temporary chimney closures produce a clear upper-band improvement. The walls themselves are not the governing path.

The project installs reversible secondary glazing, a secondary inner door, inspectable dual chimney closures and an isolated ceiling above selected service zones; floor pockets are closed locally with compatible materials; the original stone and decorative plaster remain substantially untouched. Post-work field tests and controlled speech trials show that gains correspond to the treated routes; residual uncertainty at one concealed pocket is managed through adjoining-space control and monitoring.

The case demonstrates the central historic-fabric doctrine: diagnose first, intervene at the demonstrated path, and retain evidence of every reversible change.

193 MB-0331. ASTM International, ASTM E90-23, ASTM E336-25a.

19.82 Historic-stone final evidence package

The final package contains chronology, measured drawings, material descriptions, conservation assessments, environmental data, photographs, path tests, intervention records and post-work results; it distinguishes sampled facts from inferred construction and records areas that remain inaccessible; future maintenance restrictions and retest triggers are included.

The resulting conclusion is necessarily bounded. It states the performance of the configured room under tested conditions and the operational controls needed for use; it does not convert a heterogeneous historic wall into a fictitious laboratory-rated product.

19.83 Lime mortars, hydraulic binders and repair compatibility

Historic masonry commonly relies on lime-rich mortar whose strength, permeability and movement differ from modern dense cement mortar; repair selection should consider original binder, aggregate, joint width, exposure and stone durability; a harder mortar can shift weathering into the stone; a weak or poorly cured mortar can erode and reopen the air path. National Park Service and ICOMOS guidance support compatible, minimum-intervention repair rather than strength maximisation. [194]

For acoustic purposes, a properly filled compatible joint can close leakage without turning the wall into a rigid monolith; trial panels should be allowed to cure and weather before broad application where practicable; surface colour is not evidence of internal joint depth.

194 MB-1064. National Park Service, Preservation Brief 2: Repointing Mortar Joints in Historic Masonry Buildings.

19.84 Corroding ties, cramps and embedded iron

Iron cramps, anchors and ties can corrode, expand and fracture adjacent stone; they also provide structure-borne connections between wythes, floors or façades; rust staining and cracking may indicate distress, but concealed metal can remain undetected; magnetic or radar surveys can help locate metal, subject to geometry and material limitations.

Acoustic remediation should not remove or isolate structural ties without engineering approval; where replacement or strengthening is required, the new connection becomes part of the vibration model; conservation records should identify material, location and reversibility.

19.85 Seismic restraints for reversible inner shells

A freestanding inner shell still needs stability under seismic and accidental loads; restraints should limit displacement without creating stiff everyday bridges; gapped snubbers, low-stiffness restraints or carefully located connections may be used according to structural design; their clearances and condition require inspection.

The design should model both service and event states; a restraint that is inactive during normal operation may engage during an earthquake; post-event inspection is required before sensitive use resumes; the inner shell must not damage historic finishes when movement occurs. [195]

19.86 Historic roofs, attics and parapet paths

Roof structures can connect rooms through timber trusses, masonry parapets, gutters, ventilation openings and attic voids; a secure room beneath an attic may be bypassed over the wall head; birds, wind and rain

195 MB-0787. ICOMOS, Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage.

can complicate measurements, but the path remains relevant during quiet conditions.

Inspection should include wall termination, roof decking, eaves, dormers and service routes. A ceiling alone may not close the attic. Reversible barriers and independent ceilings can control the inner boundary while preserving roof ventilation.

19.87 Cellars, crypts and subterranean passages

Historic buildings may contain cellars, undercrofts, drains and sealed passages not shown on current plans; these spaces can connect floors and provide listener access; moisture and structural stability often limit investigation; documentary research and careful survey are therefore essential.

Controls may include access restrictions, reversible closures and inner floor construction. Permanent filling can damage archaeology, drainage or fabric and should not be undertaken merely for acoustic convenience.

19.88 Measuring irregular wall thickness

Methods include measured reveals, endoscopy, radar, ultrasonic travel time and limited drilling where authorised; each method samples different geometry and carries uncertainty; radar velocity depends on moisture and material; ultrasonic paths may follow dense stones rather than voided hearting. A borehole proves only its line.

The final thickness model should show confidence and data source. Areas of uncertainty can be treated through conservative scenarios or independent inner construction rather than through invented precision.

Integrated worked example 19.26. Combining thickness observations

Three authorised measurements at a wall zone are 0.62 m, 0.55 m and 0.68 m; their mean is 0.617 m, but the range is 0.13 m; using the sample standard deviation gives approximately 0.065 m. The variability is much greater than normal instrument resolution and probably reflects real geometry; a model using 0.617 m everywhere would suppress the local minimum; the appropriate representation may include separate zones rather than a single mean.

19.89 Laser vibrometry and non-contact observation

Laser Doppler vibrometry can measure surface velocity without attaching a sensor, which is valuable for fragile plaster, glazing or carved stone; reflectivity, beam angle, access and environmental motion influence data quality; a reflective target may be prohibited or may alter appearance. Natural surface texture can reduce signal.

Non-contact measurement does not eliminate the need for provenance and coordinates. The beam location, angle, focus, range and reference should be recorded. Motion indicates structural response, not information recovery. [196]

19.90 Model uncertainty in heterogeneous historic walls

Models of historic walls can range from homogeneous mass screens to detailed discrete-element or finite-element representations; greater geometric detail does not guarantee accuracy when material contacts, voids and damping remain unknown; the model should be selected to answer a bounded question and validated against field data.

196 MB-0409. Carl Hopkins, Sound Insulation.

Scenario analysis is often more honest than one deterministic prediction; a low-connectivity and high-connectivity void case can bound airborne routes; alternative pocket or flue states can be compared; the decision should remain robust across credible scenarios where possible.

19.91 Conservation mock-ups and trial interventions

A small trial can test mortar, sealant, reversible frame attachment, lining clearance or secondary glazing; the mock-up should be located and sized to represent the intended condition without damaging significant fabric; it can be evaluated for appearance, moisture, movement, fire and acoustic effect.

Trial results should include cure time and environmental state. A successful dry-season mock-up may need observation through a wet cycle. The approved detail becomes a reference but does not replace field inspection.

19.92 Operational controls when physical intervention is limited

Some rooms cannot be altered sufficiently because of heritage significance, structural risk or cost; operational controls can include adjoining-space exclusion, meeting scheduling, controlled vocal effort, temporary masking, reduced amplification and selection of another room for the most sensitive subjects. These measures should be explicit and tested where possible.

Operational controls are not a hidden substitute for formal approval. The competent authority must understand the physical limitations and conditions of use. Controls should be simple enough to follow and auditable over time.

19.93 Integrated case. Historic archive room with underfloor route

A thick-stone archive room is proposed for privileged discussions; wall and window improvements perform well, but receiving sound persists in an adjoining office; inspection reveals a timber floor void crossing beneath both rooms and a former heating trench opening into the office skirting.

The design creates a reversible sealed floor-edge barrier at the room perimeter, closes the trench with an inspectable fire-compatible system and adds a secondary inner door; the stone walls are not altered; field spectra improve in the bands predicted by the path model. The case shows why horizontal routes can govern a massive historic enclosure.

19.94 Historic-room final review questions

The review should ask: What is original, altered and unknown? Which elements are significant? Where are voids, pockets, flues, floors, roofs and services? Which interventions are reversible? What moisture and fire consequences follow? Which field tests support the path model? What residual uncertainty remains? Which operational controls and retest triggers are required?

A historic room can achieve useful acoustic security without pretending that its walls are uniform or laboratory-rated. Credibility comes from disciplined uncertainty, compatible intervention and measured system performance.

19.95 Historic fabric significance and acoustic intervention hierarchy

The significance of historic fabric can vary by room, surface and element; a plain later partition may be altered more readily than carved stone, original joinery or wall painting; the intervention hierarchy should therefore rank source control, operational control, reversible secondary construction, local compatible repair and irreversible alteration. The sequence is guided by demonstrated acoustic path and conservation significance. [197]

A high acoustic gain does not automatically justify severe fabric loss. Equally, significance does not require accepting an uncontrolled path without considering reversible alternatives. The decision record should show the technical and heritage reasoning.

19.96 Quarry source, replacement stone and property mismatch

Replacement stone of similar colour can differ in porosity, strength, thermal movement and bedding. Quarry source and orientation matter. A dense patch beside porous limestone can alter moisture and stress. Product standards help classify new stone but do not guarantee compatibility with historic fabric. [198]

Trial pieces and petrographic comparison can reduce risk. The acoustic significance is usually secondary to durability, yet cracking or debonding from incompatibility can reopen paths. Replacement records should be retained for future monitoring.

19.97 Stone panel resonance and anchor stiffness

Thin stone panels can vibrate as plates; panel dimensions, thickness, support spacing, anchor stiffness and cavity damping determine modes; a heavy mineral appearance can obscure the fact that a 30 mm panel is

197 MB-1062. National Park Service, Preservation Brief 1: Assessing Cleaning and Water-Repellent Treatments for Historic Masonry Buildings.
198 MB-0121. ASTM International, ASTM C1242-26, ASTM C615.

mechanically lightweight compared with a massive wall. Open joints and ventilated cavities further limit direct isolation.

Where a secure room lies behind a stone rainscreen, the inner wall should form the controlled boundary; panel vibration remains relevant to exterior radiation and façade flanking; laser vibrometry or accelerometers on accessible backing can support diagnosis.

Integrated worked example 19.27. Thin panel surface mass

A granite panel is 30 mm thick with density 2,700 kg/m^3; surface mass is 0.030(2,700) = 81 kg/m^2; a 600 mm rubble wall at 2,200 kg/m^3 has nominal surface mass 1,320 kg/m^2 before voids. The panel is visually stone but has only about 6.1 per cent of the massive wall's nominal surface mass; the comparison does not predict transmission loss because supports, joints and cavities differ. It prevents material name from substituting for assembly description.

19.98 Historic metal ceilings and decorative screens

Pressed-metal ceilings, grilles and decorative screens can create lightweight resonant layers below massive structure; they may conceal ducts, wiring or damaged plaster; their vibration can increase receiving sound even when the stone walls are strong.

Inspection should record support, cavity and services. Non-contact measurement may be preferable. Removal may damage significant fabric, so an independent ceiling or service treatment may provide the safer control.

19.99 Subfloor fills, pugging and historic acoustic treatments

Historic floors sometimes contain sand, ash, lime, clay or other pugging between joists; these fills add mass and damping but can settle, become wet or be removed during renovation; their presence should be documented rather than assumed from building age.

A renovation that removes fill for services can reduce isolation; replacement must consider structure, moisture, fire and conservation; the configuration register should treat concealed floor fill as a functional element where evidence supports its role.

19.100 Arches, lintels and concentrated load paths

Stone arches and lintels concentrate force around openings; cracks at springing points or bearings can create air paths, while the structural element can transmit vibration to adjacent walls; door and window upgrades should not alter thrust or overload the opening.

The acoustic detail should work within structural geometry. Secondary frames may be supported independently. Monitoring of existing cracks can show whether intervention changes movement.

19.101 Historic mechanical systems and abandoned ducts

Buildings often retain disused radiator pipes, speaking tubes, bell pulls, pneumatic tubes or ventilation ducts. These routes may be concealed behind panelling and connect remote spaces. Abandonment does not guarantee closure.

The survey should combine archives, physical tracing and controlled testing. Closures remain inspectable where possible. Removing a heritage system may be unnecessary if two independent barriers and access control can manage the path.

19.102 Environmental control and preservation of acoustic repairs

Temperature and humidity control can protect both fabric and repairs; rapid changes can move timber, sealants and stone joints; HVAC modifications intended to improve conservation can alter room pressure and acoustic background; the design should assess these interactions before commissioning.

Monitoring should include the relevant cavity or joint, not only room air. Alarm and maintenance responses should avoid emergency penetrations through the protected boundary.

19.103 Independent peer review of heritage acoustic work

Complex historic projects benefit from review by conservation, structural, fire, mechanical and acoustic specialists; the review tests assumptions, reversibility, moisture, source control and evidence; it should occur before irreversible work and again after field results.

An internal multidisciplinary review is not equivalent to statutory consent or formal government approval. The final report should identify the actual reviewers and limits of their remit.

19.104 Historic-stone chapter final statement

Historic stone rooms require greater, not lesser, evidentiary discipline; material properties, chronology, voids, hybrid floors, windows, flues and later services must be mapped; compatible repair and reversible inner systems can achieve meaningful improvement without inventing laboratory ratings or damaging significant fabric. Acceptance remains bounded to the configured room and authorised use.

19.105 Vault acoustics, curvature and coupled structural response

Masonry vaults and domes carry load through curvature, thrust and supports; their acoustic behaviour differs from a flat ceiling; curved surfaces can focus sound within the room, while the shell can transmit vibration to springing walls and buttresses. A lightweight decorative lining below the vault can form a second leaf with an irregular cavity.

Measurement should include several source positions because focusing and modes vary spatially; structural sensors at crown and springing points can reveal coupled response; a flat-plate mass-law calculation is inadequate; models should preserve curvature and support conditions where the result matters.

Integrated worked example 19.28. Focusing and source-position sensitivity

Two source positions in a vaulted room produce receiving levels differing by 7 dB at the same exterior location; measurement repeatability is 1.0 dB; the difference is much larger than repeatability and indicates a strong geometry or path effect. It does not by itself identify focusing, a flue route or structural coupling; the correct response is to map the field and test the competing mechanisms rather than select the louder position as the only room condition.

19.106 Ventilated wall cores and moisture management

Some historic walls contain cavities that assist drainage or drying; sealing them indiscriminately can trap moisture; a cavity may also connect rooms or façades acoustically; the design should identify whether ventilation is intentional, accidental or no longer functional.

An inner acoustic boundary can often be established without filling the historic core. Controlled vents can terminate outside the protected envelope. Environmental monitoring helps verify that the intervention has not created harmful moisture conditions. [199]

19.107 Fire stopping in historic assemblies

Historic floors and walls may not contain modern fire compartmentation; acoustic upgrades that open cavities can reveal or worsen fire paths; new fire stopping must be compatible with irregular masonry, timber and movement, and it may require listed systems or project-specific engineering.

Acoustic sealants should not be substituted for fire systems; conversely, loosely packed fire material may remain air-permeable; the detail should identify both functions and preserve access for inspection; building-control and conservation approvals remain separate from acoustic acceptance. [200]

19.108 Biological damage, pests and concealed void development

Insects, rodents, birds and vegetation can disturb mortar, insulation and timber, enlarge openings or carry debris into cavities; the resulting path

199 MB-1061. National Park Service, Preservation Brief 1: Assessing Cleaning and Water-Repellent Treatments for Historic Masonry Buildings.
200 MB-0791. International Code Council, 2024 International Building Code.

may be seasonal and inaccessible; pest control and conservation staff can provide evidence about routes that architectural drawings omit.

Treatment should not introduce toxic or corrosive materials into occupied secure rooms without appropriate review. After control, cavities and openings are inspected and repaired compatibly. The incident remains in the lifecycle record.

19.109 Archaeology and below-ground heritage constraints

Cellars, foundations and buried passages may have archaeological significance; drilling, trenching or grouting can require consent and documentation; acoustic work should begin with existing surveys and non-invasive methods; operational controls or above-ground inner construction may be preferable to irreversible below-ground intervention.

Where excavation is authorised, findings can materially change the path model. A newly discovered void or passage should be secured and documented before design proceeds.

19.110 Measurement background in historic urban buildings

Historic government and diplomatic buildings often occupy dense urban sites with traffic, bells, plant and public activity; background varies by time and season; high wall mass can place receiving levels near the measurement floor; testing may require night work, plant coordination or longer averaging, but those conditions must still represent the operational room where appropriate.

A result obtained with heating or ventilation disabled should not be applied silently to occupied conditions. Background-limited bands are reported as bounds. [201]

19.111 Speech-source representation in large historic rooms

Large chambers can encourage increased vocal effort; long reverberation reinforces some bands and reduces clarity inside, while directional talkers and sound systems produce local high levels; a small loudspeaker at one location may not represent debate, presentation and conferencing states.

Source protocols should include authorised vocal effort and any installed reinforcement. Microphone and loudspeaker settings are recorded. Testing uses non-sensitive speech material. The objective is to model exposure, not to recreate classified content.

19.112 Security operations during conservation work

Conservation work can require scaffolds, open windows, removed panelling and access by specialist contractors; the room may be unsuitable for sensitive use throughout the work; tools, samples and waste are controlled under the facility's security arrangements; acoustic engineers should not invent or publish restricted procedures, but they should identify when the physical boundary is open.

A pre-return inspection confirms closure, services and configuration. Acoustic retesting is proportional to the altered paths. Conservation completion alone does not restore the previous secure-room status.

201 MB-0330. ASTM International, ASTM E90-23, ASTM E336-25a.

19.113 Integrated case. Porous limestone meeting room

A limestone meeting room shows high direct-wall mass but weak upper-band isolation along one exterior wall; inspection finds weathered joints, a ventilated service chase and an unsealed secondary-window perimeter; parging the stone is rejected because it would alter significant fabric and moisture behaviour.

The project repoints selected joints with compatible mortar, creates an independent interior air barrier at the service chase and rebuilds the secondary-glazing seal; temporary tests before permanent work predict the staged gains; post-work field measurements confirm that the wall stone itself was not the controlling weakness.

19.114 Integrated case. Fortified room with stair and roof flank

A massive room in a former defensive structure has thick stone walls and a vaulted ceiling; receiving sound is detected in a stair tower; vibration measurements show coupling through a stone stair and parapet, while an attic route bypasses the wall head.

The solution uses a reversible inner ceiling, controlled attic barrier and local receiver treatment at the stair-side wall; the stair is not cut or isolated; the result improves without altering the primary masonry; the case demonstrates that historic structural continuity can govern even where direct walls are exceptionally massive.

19.115 Model specification for historic acoustic work

A specification should identify protected fabric, approved access, reversible methods, environmental controls, documentation, trial areas, inspection points and acoustic acceptance; it should prohibit undocumented drilling, foams, hard mortars and permanent adhesives where incompatible; materials should be selected with conservation specialists.

The specification also defines the measured quantities and reporting limits. It should not demand an invented STC for an irregular historic wall. Field performance and operational criteria are usually more appropriate.

19.116 Maintenance and housekeeping effects

Carpets, tapestries, curtains and furniture affect room absorption and source behaviour; cleaning can dislodge seals or remove temporary closures; window operation and seasonal shutters change paths; the operational baseline should identify significant movable elements.

Maintenance instructions should distinguish decorative conditions from the actual air barrier. Replacing a curtain does not necessarily require retesting, while removing secondary glazing or opening a chimney closure does.

19.117 Multidisciplinary review record

The review record should capture conservation, structural, fire, mechanical, acoustic and security comments, their resolution and remaining disagreement; it should distinguish actual external peer review from internal project review; unresolved matters are not hidden by consensus language.

This record is particularly important where no intervention is ideal. The competent authority can then understand the technical gain, heritage cost and residual uncertainty.

19.118 Historic-stone chapter closure

Historic stone demands a room-specific evidence model; material tests, chronology, voids, hybrid floors, roofs, windows, shafts and later alterations all matter; compatible repair and reversible inner systems can control demonstrated paths while preserving fabric; the final conclusion should remain measured, source-grounded and explicit about uncertainty.

19.119 Comparative heavy-boundary doctrine

Masonry, cast concrete and historic stone are often grouped as massive construction, yet their acoustic behaviour and evidentiary burdens differ; concrete can be relatively homogeneous but contains joints, ties, sleeves and reinforcement; concrete masonry is explicitly cellular and jointed; historic stone is heterogeneous, altered and often partly undocumented. A secure-room design should therefore begin with the actual construction topology rather than a generic "heavy wall" category. [202]

The common advantage is high surface mass and potential durability. The common danger is overconfidence. Direct transmission through the nominal wall can be so low that openings, wall heads, slabs, frames and services control the result; the evidence strategy should shift from material selection to path verification as direct performance increases.

19.120 Comparing CMU, concrete and stone by uncertainty class

CMU usually offers good product and construction standards, but grout state, joint fill and cell connectivity require records; cast concrete offers defined mixture and placement controls, but concealed honeycombing, form ties and construction joints remain; historic stone may lack reliable

202 MB-0407. Carl Hopkins, Sound Insulation.

drawings, uniform materials or accessible cavities. These differences justify different uncertainty models.

A new CMU wall can be documented through unit lot, mortar, grout and surveillance; a concrete wall can be tied to pour records and testing; a historic wall may require bounded scenarios and field measurement; applying the same confidence level to all three would be analytically false.

19.121 Mass law as a preliminary screen, not a final answer

Ideal mass law can help compare gross trends where barriers are limp, homogeneous and nonporous. Massive real walls violate several assumptions through stiffness, coincidence, finite size, joints and flanking. The calculation is most useful for showing that small increases in already large mass offer diminishing system benefit when another path governs. [203]

Integrated worked example 19.29. Diminishing value of additional heavy-wall mass

An ideal mass-law screen predicts that doubling surface mass increases transmission loss by about 6 dB at fixed frequency; suppose a direct wall path is 58 dB and a door path is 42 dB; combined result is approximately -10 log10(10^-5.8 + 10^-4.2) = 41.9 dB. Increasing the wall by 6 dB changes the combined result to -10 log10(10^-6.4 + 10^-4.2) = 42.0 dB, a gain of only about 0.1 dB; the arithmetic assumes comparable reference conditions and uncorrelated power. It demonstrates why weakest-path control precedes further mass.

203 MB-0408. Carl Hopkins, Sound Insulation.

19.122 Junctions as the unifying heavy-construction problem

The transition between wall and slab, wall and façade, wall and roof, or wall and opening often controls performance; in CMU, bond beams and grouted cells change stiffness; in concrete, monolithic continuity and precast connections transmit force. In stone, pockets, arches and later inserts create irregular routes; the junction should be described through force, air closure and movement, not solely through material names.

ISO 10848 and ISO 12354 concepts can organise flanking analysis, but their inputs must represent the actual junction. Field mobility, vibration reduction and receiving radiation can refine the model. [204]

19.123 Openings and penetrations in heavy walls

A heavy wall invites later coring because it appears robust; each opening can create an air route, intersect reinforcement or voids, and introduce a service force path; frames may be grout-filled or anchored rigidly. Sleeves can connect cavities. The penetration process should therefore be designed before construction and controlled throughout the room's life.

For new work, service zones and spare controlled sleeves reduce later drilling. For historic work, reversible surface routes may be preferable. Every penetration receives an identifier, closure detail, inspection and change history.

19.124 Independent linings as a cross-material remediation tool

Independent linings can improve CMU, concrete and stone without relying upon uncertain surface repair; their benefit comes from added leaf mass,

204 MB-0826. International Organization for Standardization, ISO 10848-2:2017, ISO 12354-1:2017.

cavity depth and reduced mechanical coupling; their risks are bridges, mass-air-mass resonance, service penetrations, fire interactions and loss of inspection access.

The support strategy differs by substrate. CMU may permit selected anchors in grouted cells; concrete offers strong anchorage but can create stiff bridges; historic stone may prohibit attachment, favouring freestanding support; the lining should be modelled and inspected as its own assembly.

19.125 Surface closure versus structural modification

Parging, plaster, coatings and compatible repointing can close distributed air paths; structural modification changes stiffness, load and force transmission; the two should not be conflated; a surface closure can improve upper bands without altering the structural system. Grouting, reinforcement or concrete repair can change both.

The least invasive measure that changes the demonstrated mechanism is preferred. Before-and-after spectral evidence helps distinguish air closure from structural effect. A visible improvement in finish is not itself proof.

19.126 Heavy-construction forensic sequence

The forensic sequence begins with records and geometry, then room-level spectra, spatial scans and path-specific measurements. Reversible sealing tests airborne discontinuities. Vibration and intensity measurements examine structural routes; borescopes, cores or controlled openings follow only where the result will discriminate among remaining hypotheses and where authority permits.

The sequence protects evidence and avoids destructive search based on intuition. Each intervention is documented and the room restored. The final report retains alternative explanations that were not resolved.

19.127 Comparative remediation case. Mixed masonry and concrete suite

A secure suite contains CMU internal walls, a cast concrete structural core and a historic stone exterior wall; initial tests show strong direct walls but weak low-frequency response near the core and high-frequency leakage at a CMU wall head. The stone façade is not controlling.

The project closes deck flutes and head joints at the CMU wall, isolates a receiver-side lining from the concrete core and rebuilds a service penetration; no work is undertaken on the historic stone; staged tests show separate spectral gains. The case demonstrates the value of assigning each band and location to a mechanism rather than applying one heavy-wall remedy everywhere.

19.128 Heavy-boundary construction surveillance

Surveillance priorities differ by system. CMU requires joint, cell, grout and parging records; concrete requires placement, consolidation, tie-hole, joint and sleeve records; stone work requires chronology, compatible mortar, minimum intervention and documentation of hidden fabric; all require wall-head, opening and service inspection before closure.

A common surveillance register can identify location, mechanism, evidence and disposition while preserving system-specific details. Photographs should show scale, orientation and adjacent work. The record supports both acceptance and later forensic review.

19.129 Comparative acceptance language

Acceptance language should avoid declaring any wall material secure; it should identify the construction, tested method, bands, source state, receiving environment, uncertainty and residual paths; laboratory assembly evidence, field room performance, occupied speech testing and formal approval remain separate.

Where a historic wall cannot be fully characterised, the statement can rely on measured room performance and operational controls; where new concrete or masonry is documented, the record can more confidently link performance to configuration; in neither case should an unverified catalogue value replace field evidence.

19.130 Part V synthesis. Mass, continuity and evidence

Part V establishes that mass is valuable but never sufficient; CMU, concrete and stone acquire acoustic reliability through continuity, controlled joints, documented openings, compatible repairs and an evidence chain from design to lifecycle; their differences matter: cells and grout in masonry, placements and connections in concrete, chronology and conservation in stone. Their common lesson is the same. The secure room is a complete path network, and the conclusion belongs to the installed, tested and authorised system.

19.131 Selecting a heavy-boundary system for new secure construction

Selection among grouted CMU, cast concrete, precast concrete and other heavy systems should begin with site, structural, programme and service constraints; direct airborne isolation is one criterion; construction access, structural load, joint count, future penetrations, fire resistance, moisture, schedule and inspectability can be equally decisive. A heavier option is not automatically the most reliable if its joints and services cannot be controlled.

The basis of design should compare complete systems at the frequency bands and operational states that matter. It should identify laboratory evidence, expected field loss, flanking, openings and construction surveillance. The final choice should be traceable to the path model rather than to tradition or catalogue prominence. [205]

19.132 Heavy construction in retrofit projects

Retrofit begins with the host structure. Adding masonry or concrete can exceed floor capacity, obstruct services and create new rigid connections; historic stone may already provide more direct mass than the room needs; an independent lightweight or medium-weight inner shell can sometimes achieve greater system benefit with less load and better service control.

The retrofit study should compare floor loading, cavity depth, door and ceiling interfaces, construction access and reversibility; a local heavy infill may still be appropriate at an opening or shaft; the chosen solution should address demonstrated weak paths and preserve future inspection.

19.133 Construction sequencing and enclosure integrity

Heavy walls are often built early, while doors, façades, roofs and services follow later; the acoustic boundary therefore becomes complete in stages; temporary openings and unfinished wall heads can expose the room or contaminate joints; the construction plan should identify when the enclosure first becomes controlled and what inspections occur before each closure.

205 MB-0326. ASTM International, ASTM E90-23, ASTM E413-22.

A wall that passed a first-of-type test can be damaged by later trades; penetrations, anchors and chases should require permits and updated records; final testing should occur after representative finishes and services, not immediately after masonry or concrete work alone.

19.134 Procurement evidence for heavy assemblies

Submittals should include product standards, complete laboratory reports, specimen dimensions, material state, joints, finishes, penetrations and mounting; a summary certificate or STC number is insufficient where the proposed configuration differs; for historic work, the equivalent evidence is a condition survey, material analysis, intervention detail and field-performance plan.

The reviewer should separate what the source proves from what remains project design; an ASTM unit specification proves bounded product characteristics; a structural code proves design compliance under its scope. Neither establishes occupied speech security.

19.135 Field testing strategy for massive boundaries

High-performing walls can exceed laboratory or field dynamic range in some bands; background, flanking and chamber limits should be recorded; a lower-bound result may be more honest than an inflated precise number; field tests should include enough source and microphone positions to identify spatial variation and weak interfaces. [206]

Where direct wall transmission is below the measurement floor, diagnostic attention shifts to doors, services, slabs and façades. The objective is system performance, not proving an ever-higher wall rating.

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206 MB-0325. ASTM International, ASTM E90-23, ASTM E336-25a.

Integrated worked example 19.30. Dynamic-range limited wall result

A source-room level is 96 dB in a band; receiving background is 28 dB, and the test method requires a correction limit that prevents reliable reporting when the test level is too close to background; the measured receiving level is 29 dB. Apparent level difference is 67 dB, but the signal is only 1 dB above background; the defensible report is a lower bound governed by the method, not a precise 67 dB claim; the result also indicates that another path or a quieter test environment may be needed to characterise the wall further.

19.136 Heavy-wall interfaces with doors and glazing

Frames often govern how a massive wall meets an operable or transparent opening; grout, anchors, lintels, sealants and reveals affect both structure and air closure; a strong wall can be bypassed through a hollow frame, unfilled cell or façade cavity. The detail should identify the primary air seal and how movement is accommodated.

Door and glazing test reports should match the proposed surrounding construction where possible. Field commissioning should examine the interface, not only the centre of the opening.

19.137 Service zoning and future capacity

Heavy walls are difficult and risky to modify after completion; service zoning can concentrate penetrations in controlled panels, sleeves or vestibules; spare capacity should be sealed and documented; cable trays and pipes should not cross the boundary through open wall heads or cavities.

The zoning plan should include future maintenance access. A removable tested panel can be more reliable than repeated coring. Every unused route remains closed at both ends and appears in the penetration register.

19.138 Part V forensic reporting standard

A forensic report for heavy construction should identify the nominal system, observed state, records, test methods, interventions and limitations; it should distinguish vulnerability, installation defect, damage, confirmed transmission path and actual information disclosure; the conclusion should not exceed the evidence.

Photographs, drawings, spectra, vibration data and samples should be cross-referenced. Alternative hypotheses and negative tests remain visible. This structure supports technical review and litigation without dramatic but unsupported labels.

19.139 Lifecycle governance across masonry, concrete and stone

Lifecycle triggers include new penetrations, repairs, water intrusion, cracking, equipment changes, façade work, door replacement and structural modification; the responsible organisation should know which change requires local inspection, partial retest or full recommissioning; the threshold follows mechanism and consequence.

Baseline records are preserved across staff and contractor changes. The wall is not assumed unchanged because it appears solid. Configuration control turns a one-time construction achievement into an enduring boundary.

19.140 Final Part V synthesis

Heavy construction earns its value through mass, continuity and robust evidence; CMU requires control of cells, joints and grout; concrete requires control of placements, ties, joints, repairs and structural flanking; historic stone requires chronology, compatibility, reversibility and explicit uncertainty. All three systems are vulnerable at openings, services and junctions.

The Part V conclusion is therefore system-level; material and code compliance establish necessary but limited propositions; laboratory tests establish specimen performance; field testing establishes the configured room pair under measured conditions; speech tests address information exposure; formal approval belongs to the competent authority; this hierarchy prevents mass from becoming a false synonym for security.

Table 19-R1. Historic feature, conservation risk, acoustic path and reversible intervention.

Historic feature	Conservation risk	Acoustic path	Reversible intervention
Rubble core and flue	Irreversible filling and trapped moisture	Connected void network	Inspectable dual closure or independent lining
Sash window	Damage to joinery and altered appearance	Frame and pocket leakage	Secondary glazing in reversible frame
Timber floor pocket	Decay and structural disturbance	Air and structure-borne coupling	Local inner floor zone and pocket closure
Decorative plaster	Loss of fabric or concealed instability	Detached lightweight leaf	Freestanding inner shell with monitoring
Stone façade panel	Anchor and drainage disruption	Panel radiation and cavity flank	Independent interior boundary

19.141 Historic-stone technical schedules

Table 19-1. Stone family, property uncertainty and acoustic implication

Stone family	Characteristic variability	Acoustic implication	Evidence priority
Granite	Mineralogy, microcracks, jointing and finish	High density supports mass, but joints and anchors usually govern	Petrographic identity, density, joint map and support system
Limestone	Wide porosity and absorption range, bedding and fossils	Moisture and connected pores can change leakage and durability	C568 classification, absorption, bedding orientation and moisture survey
Marble	Veining, anisotropy and possible panel bowing	Thin panels can develop joint changes and local resonances	C503 product data, flatness survey, anchor and temperature history
Sandstone	Strong bedding, porosity and weathering	Delamination can create shallow radiating plates; joints erode	C616 classification, bedding direction, moisture and sounding controls
Slate	Cleavage and directional strength	Thin panels and fastener holes behave unlike massive wall	C629 product data, foliation orientation and fixing detail
Engineered stone	Resin, aggregate, backing and adhesive system	Composite modes and fire/ageing properties are product-specific	Exact construction, laboratory report, support and substitution control

Table 19-2. Historic-wall evidence classes

Evidence class	Example	Strength	Limitation
Archival	Original drawings, surveys, repair records and photographs	Reveals intended construction and change chronology	May be incomplete, idealised or inconsistent with as-built work
Surface survey	Joint, crack, moisture, patch and material mapping	Comprehensive visible-condition record	Cannot prove core geometry or depth
Non-invasive indication	Infrared, radar, acoustic response or moisture mapping	Locates anomalies and guides openings	Requires calibration and often yields non-unique interpretation
Controlled opening	Borescope hole, lifted trim or local exposed core	Direct observation of concealed condition	Local, potentially destructive and subject to access bias
Material test	Density, absorption, petrography, mortar analysis	Quantifies sampled material properties	Sample may not represent whole wall
Field acoustic test	Room-to-room spectrum and local path mapping	Establishes configured performance	Does not identify one element without discriminating tests
Operational assessment	Representative speech and accessible listener positions	Links physical isolation to use state	Does not confer formal approval

Table 19-3. Conservation-compatible intervention hierarchy

Intervention	Reversibility	Principal benefit	Principal risk
Operational control and masking	High	Reduces exposure without fabric alteration	Dependent on operation, power and listener conditions
Secondary glazing	Generally high	Improves weak historic window while retaining exterior fabric	Condensation, frame leakage and visual impact
Internal secondary door	High to moderate	Creates sound lock and preserves original door	Space, egress, hardware and architectural impact
Independent inner lining	Moderate to high	Creates measured continuous boundary over irregular wall	Moisture trapping, service coordination and loss of room area
Compatible repointing	Moderate	Restores joint closure and durability	Damage from excessive removal or incompatible mortar
Flue closure with access	Moderate	Controls major vertical air path	Ventilation, fire, soot and future inspection requirements
Grout or resin injection	Low	May fill voids or bond cracks	Irreversible moisture redistribution, stiffness change and uncertain spread

Table 19-4. Historic-room hold points

Stage	Hold point	Required participants	Record
Investigation	Before any opening or sample	Conservation authority, structural engineer and acoustic investigator	Location justification, method, photographs and restoration plan
Mortar work	After rake-out and before repointing	Conservator and mason	Joint depth, substrate condition, mortar batch and test panel
Independent lining	Before cavity closure	Architect, conservation and acoustics	Clearance, moisture, supports, services, insulation and perimeter
Secondary glazing	Before trim completion	Architect and acoustics	Pane identity, frame seals, cavity and reversible fixings
Flue or fireplace treatment	Before permanent closure	Fire, conservation and acoustics	Flue status, access, noncombustible construction and acoustic detail
Commissioning	After all furnishings and services	Owner, acoustics and competent authority representative	Field spectra, operational states, limitations and lifecycle baseline

19.142 Conclusions

Natural stone and historic massive construction demand humility; density and thickness support strong direct isolation, but voids, flues, joints, floor pockets, joinery and later alterations often govern; product standards for new dimension stone do not certify historic composite walls. Conservation-compatible work preserves fabric, moisture behaviour and reversibility while creating a measured inner boundary.

The correct conclusion is bounded by the surveyed and tested configuration. A visible wall is not a homogeneous specimen, and a heritage room is not accredited by architectural grandeur.

Chapter 19 Glossary

Ashlar. Dressed stone masonry laid in regular courses or patterns.

Conservation-compatible isolation. Acoustic intervention designed to preserve significant historic fabric, reversibility, moisture behaviour and statutory obligations.

Dimension stone. Natural stone selected and fabricated to specified dimensions and properties for construction.

Floor pocket. Recess in masonry receiving the end of a timber or structural floor member.

Pointing. Exposed mortar finish within masonry joints; repointing removes deteriorated mortar and installs compatible replacement mortar.

Rubble core. Irregular internal masonry composed of smaller stones, mortar and possible voids between outer wythes.

Secondary glazing. Additional interior glazing installed separately from an existing window to improve environmental or acoustic performance.

Through-stone. Stone extending through much or all of a wall thickness and tying wythes together.

Foliation. Planar mineral fabric along which slate or other metamorphic stone may split or respond anisotropically.

Hearting. Irregular inner rubble and mortar between the outer faces of a multi-wythe historic masonry wall.

Petrographic fabric. Mineral, grain, pore and crack arrangement observed through petrographic examination.

Reversible inner shell. Independent acoustic enclosure designed to be removed with minimal irreversible effect on historic fabric.

Salt crystallisation. Growth of salts within pores during drying, capable of producing stress, scaling and joint deterioration.

Void connectivity. Degree to which separate cavities or pores form a continuous route between source and receiver.