Compilation of Acoustics Information for Concrete Construction and Other Materials

Prepared by Acentech Incorporated for

National Ready Mixed Concrete Association and the
Ready Mixed Concrete (RMC) Research & Education Foundation

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BUILD WITH STRENGTH

NRMCA
NATIONAL READY MIXED CONCRETE ASSOCIATION

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BACKGROUND

There is a significant amount of information about the acoustic performance of concrete assemblies that is publicly available. Unfortunately, until now this information has been spread across many different sources and media types, making it particularly difficult for the lay-person to find accurate information on the acoustic performance of concrete assemblies.

NRMCA and the RMCRF commissioned a project to gather the available concrete acoustic performance information into one document to make it easier to access and use in project design. Included in this database are both concrete floor-ceiling assemblies as well as concrete walls of varying construction types such as pan joist, flat slab, ICF, concrete metal deck, etc. The focus is primarily on these main types of ready mixed concrete assemblies, but also included is additional information on related structural systems, such as precast slab, wood joist, mass timber (CLT), etc. This report has also compiled the benefits of different types of available acoustical treatments for these systems, such as resilient flooring underlayment and acoustical ceiling treatments for comparison. Finally, resources for all associated acoustics topics have been compiled for users who would like further information about specific items.

THE ACOUSTICS OF CONCRETE

INTRODUCTION

Acoustics has become an integral factor in the construction of modern buildings. In the United States, nearly every market segment includes acoustical requirements from multi-family residences to medical facilities to schools and universities, and most everything in between. Primarily these requirements dictate the acoustics performance of the floor-ceiling and wall assemblies used throughout a project. Concrete has increasingly become preferred acoustically in the construction of floor-ceilings and walls in all building market segments, due to the high acoustics performance inherent to concrete assemblies.

Through the ever-evolving building environment, acoustics data for concrete assemblies has been made available in many publications and online sources. However, these sources are spread across many locations making it difficult to find accurate and comprehensive acoustics information.

The database assembled herein addresses this lack of unified information and represents a compilation of extensive publicly available acoustics test data, test reports collected from NRMCA partners, as well as additional external resources. Its goal is to inform users about the importance of acoustics in the built environment and how to use concrete assemblies to meet these acoustics goals and requirements.

ACOUSTICS BASICS

Sound is transmitted through buildings in two ways: through the air or through the structure of a building. Many sound sources, such as speakers placed on the floor, can generate both airborne and structure borne acoustic energy. When airborne noise is generated, it interacts with the surrounding walls, floors, and ceilings, with some sound energy being *transmitted* through these assemblies, some sound energy being *absorbed* by these assemblies, and some sound energy being *reflected* back from these assemblies. Construction details of building wall and floor-ceiling assemblies determine how much airborne noise will be transmitted / absorbed / reflected. Acoustic metrics sound transmission class (STC) and noise reduction class (NRC) (defined below) have been specifically developed to quantify these properties.

Structure borne noise is generated when a mechanical force is applied to a structural building element, such as through footfall noise, hammering a nail into wood studs, or mechanical equipment vibration (without isolation). Construction details of floor-ceiling assemblies determine how much impact noise will be transmitted from an upper floor to a lower floor, quantified by the IIC acoustical metric (also defined below).

Frequency of Sound

The pitch of a sound is measured in Hertz. Human hearing ranges from 20 Hz to 20,000 Hz. Low frequencies are typically defined below 250 Hz; high frequencies extend above 2000 Hz. Acoustics data for sound isolation and impact insulation is most commonly presented in 1-octave or ⅓-octave frequency bands between 100 Hz and 5000 Hz, which covers the primary speech range.

Pressure & Decibels

Sound is fundamentally a pressure wave that travels through a physical medium, such as air, water, wood, etc. These pressure waves are measured in Pascals (Pa), with human sensitivity to sound ranging between about 0.00002 – 630 Pa, which is more than 7 orders of magnitude. To condense this range based on human perception, sound pressure is converted from Pascals (Pa) to decibels (dB) using a logarithmic expression with a reference pressure value. As a result, most measured sound is between 0 dB (near the threshold of human audibility) and 150+ dB (for the loudest sounds, such as jet engines and explosions).

Frequency Weighting & Noise Criteria

Typically, sound levels are measured in A-weighted decibels (dBA), where an electrical filter is introduced to approximate the human response to sound of moderate levels.

Sound levels may also be presented using Noise Criteria (NC) ratings, which is single-number metric calculated using the sound level frequency spectra between 16 – 8,000 Hz. NC ratings are typically 5 points lower than dBA sound levels for the same noise event.

Sound Transmission Class

Sound Transmission Class (STC) is a single-number metric used to measure the sound isolation performance of walls and flooring-ceiling assemblies in a laboratory. ASTM Standards define the procedures and methodology for calculating STC (E90[1] for Laboratory Test Methods and E413[2] for Rating Classifications). STC values are calculated by measuring loud sound levels in one room (source room) and subsequently measuring the resulting sound levels in an adjacent room (receiving room). The sound level differences between source and receiving rooms are used to calculate the STC value for the wall or floor-ceiling assembly, known as Noise Reduction (NR) values or Transmission Loss (TL) values, depending on measurement conditions. Higher values of STC indicate that an assembly is more effective at reducing the sound transmitted to the receiving room.

The Apparent Sound Transmission Class (ASTC), Noise Isolation Class (NIC), and Normalized Noise Isolation Class (NNIC) are field-measured sound isolation metrics analogous to the laboratory-measured STC metric and are defined by ASTM Standard E336[3]. ASTC replaced the previous Field Sound Transmission Class (FSTC) rating, which can still be found in some published sound data. ASTC / NIC / NNIC values are typically 5 points or more lower than STC ratings for the same assembly, due to construction variations in the field.

Impact Insulation Class

Impact Insulation Class (IIC) is a single-number metric used to measure the impact insulation performance of a floor-ceiling assembly in a laboratory, primarily applicable to footfall noise in occupied spaces. ASTM Standards define the procedures and methodology for calculating IIC (E492[4] for Laboratory Test Methods and E989[5] for Rating Classifications). IIC values are calculated by measuring a calibrated tapping machine placed in an upper room (source room) and subsequently measuring the resulting sound levels in a lower room (receiving room). The sound levels measured in the receiving room are used to calculate the IIC value for the floor-ceiling assembly. Higher values of IIC indicate that the assembly is more effective at reducing the sound transmission due to impact between the two rooms.

The Apparent Impact Insulation Class (AIIC), Impact Sound Rating (ISR), and Normalized Impact Sound Rating (NISR) are field-measured impact insulation metrics analogous to the laboratory-measured IIC metric and are defined by ASTM Standard E1007[6]. AIIC replaced the previous Field Impact Insulation Class (FIIC) rating. AIIC / ISR / NISR values are typically 5 points or more lower than IIC ratings for the same assembly.

Acoustical Absorption & Noise Reduction Coefficient

When sound reflects off of a surface, a portion of the sound energy will be absorbed by the surface and not allowed to transmit through the surface or be reflected back into the room. This is known as acoustical absorption, and is rated using acoustical absorption coefficients, referred to as Alpha values (α). These values typically range from 0.0 to 1.0, with 0.0 representing complete reflection and 1.0 representing full absorption. Absorption coefficients differ across frequency, quite dramatically for some materials. Smooth surfaces typically have low absorption properties (such as polished concrete) while rough or textured surfaces typically have high absorption values (such as plush curtains).

The Noise Reduction Coefficient (NRC) is a single-number metric used to represent the average absorption of a surface across the central range of speech (250 – 2,000 Hz).

Reverberation Time

Reverberation Time (RT, RT_{60}, T_{60}) is the time it takes for sound to decay within a closed room. The reverberation of a space is a function of its volume and the acoustical absorption of interior room surfaces. For instance, a large room with very reflective surfaces would have a longer reverberation time than a small room with very absorptive interior surfaces.

ACOUSTIC REQUIREMENTS

Acoustics requirements are applicable to most building market segments throughout the United States, though the applicable governing body(s) depend on the type of project, as well as the state and even locality in which a building is being constructed.

IBC Code Requirements

Acoustics requirements for multi-family residential buildings are presented in the International Building Code[7] (IBC), which has been adopted throughout most of the United States as well as several jurisdictions outside of the United States. The IBC contains requirements for sound isolation, defining minimum ratings of STC 50 between residences and adjacent residences / public spaces. Impact insulation is also required to be a minimum of IIC 50 between vertical residence adjacencies.

It should be noted that the IBC criteria of STC 50 & IIC 50 represent 'minimum' requirements: multi-family residences are typically designed to exceed these to provide higher sound isolation and impact insulation between residences. For example, the International Code Council (ICC) G2 – 2010 Guideline for Acoustics[8] recommends field-rated sound and impact isolation of NNIC / NISR 52 for 'Acceptable Performance' and NNIC / NISR 57 for 'Preferred Performance'.

Other Acoustics Requirements

Depending on the building type and the certifications that may be pursued, requirements from other governing agencies may be applicable beyond Code.

- LEED: Many new buildings of all types apply for LEED[9] Certification, which contains criteria for sound isolation, reverberation time, and mechanical noise control, by interior space type. Acoustics requirements are determined by building type and interior fit out.
- WELL: Another certification applicable to many new building types is WELL[10], which includes acoustics criteria for interior and exterior sound isolation, speech privacy, reverberation time, mechanical noise control, and impact noise management, by interior space type.
- FGI: The Facility Guidelines Institute[11] (FGI) provides guidelines for hospitals, outpatient healthcare facilities, and long-term support facilities, which contain criteria for interior and exterior sound isolation, speech privacy, reverberation time, mechanical noise control, and footfall vibration velocities, by interior space type.
- ASHRAE: ASHRAE[12] acoustics criteria for mechanical noise and vibration control is referred to in LEED and FGI requirements.
- ANSI: ANSI[13] acoustics criteria are referred to in LEED and FGI requirements. S12.60 is a widely used standard for the acoustics design of K-12 schools.

Acoustics Sources & Receivers

When designing a building, acoustics must be considered from all physical directions to appropriately address potential noise issues down the road.

Source – Path – Receiver

Acoustical analysis can be simplified using the source – path – receiver model, where there is source of noise (inside or outside of a building), a receiver of this noise (usually an occupant inside a room), and the path between the two is determined by the building construction.

In a large building, this can become quite complicated, as acoustical adjacencies can occur horizontally on the same floor or vertically above or below. It is possible for airborne sound to be transmitted to multiple rooms or that structure borne noise can be transmitted to nearby spaces (or sometimes not so nearby) through the building structure in the form of vibrations.

Example Diagram

FIGURE 1 shows a graphical representation of the potential adjacencies that can occur in a new building, and the applicable acoustical requirements. It is important to identify loud noise sources (such as MEP spaces, event rooms, etc.) as well as noise-sensitive receivers. After that, building wall and floor-ceiling assemblies can be evaluated for acoustical performance, and potential acoustical requirements. Please note, this is only an example and does not represent all applicable acoustics criteria or potential concerns but highlights the variety of acoustical adjacencies that are common in buildings.

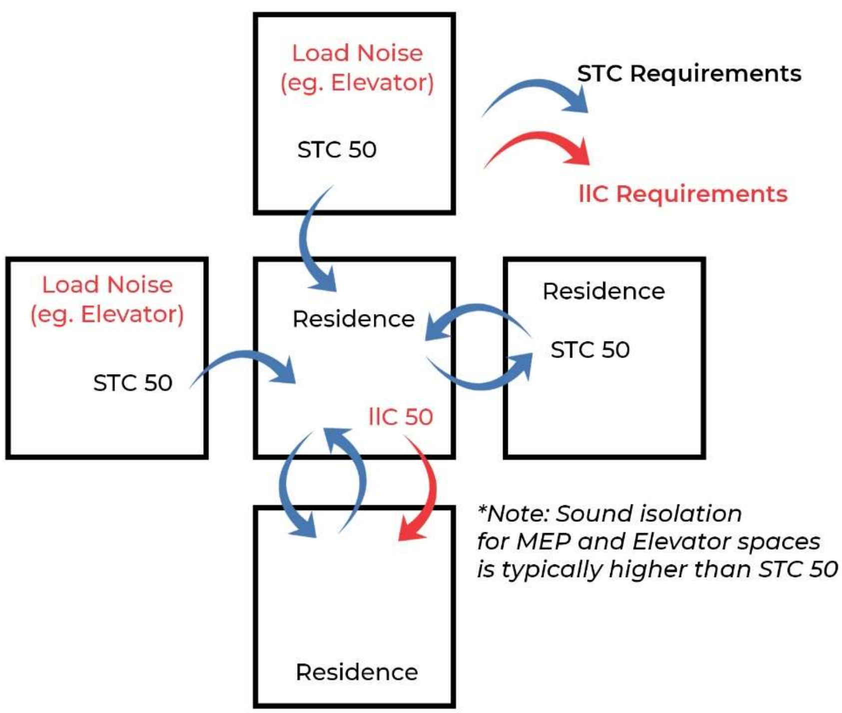


FIGURE 1. Potential Adjacencies in a Residential Building – STC & IIC Requirements

CONCRETE ACOUSTICS DATA

The following sound isolation (STC) and impact insulation (IIC) data has been compiled for floor-ceiling and wall assemblies from numerous laboratory-certified acoustical test reports (see bibliography), including publicly available information as well as additional information provided by NRMCA partners.

FLOOR-CEILING ASSEMBLIES

Floor-Ceiling Acoustical Performance

TABLE 1 presents the potential range of sound isolation and impact insulation performance for typical concrete floor-ceiling assembly types compiled from laboratory test data. FIGURE 2 shows the acoustical performance of these assemblies across the frequency spectrum.

TABLE 1. Concrete Floor-Ceiling Assemblies – Sound Isolation & Impact Insulation Performance

Assembly Type	Assembly Thickness	STC Ratings	IIC Ratings
Concrete Slab – Normal Weight Concrete	4"	STC 44 – 47	IIC 20 – 25
	6"	STC 50 – 55	IIC 26 – 30
	8"	STC 57 – 58	IIC 28 – 32
Concrete Metal Deck – Normal Weight Concrete	4" Total	STC 45 – 49	IIC 18 – 21
	5.5" – 6" Total	STC 52 – 57	IIC 21 – 26

Floor-Ceiling Assembly Graph

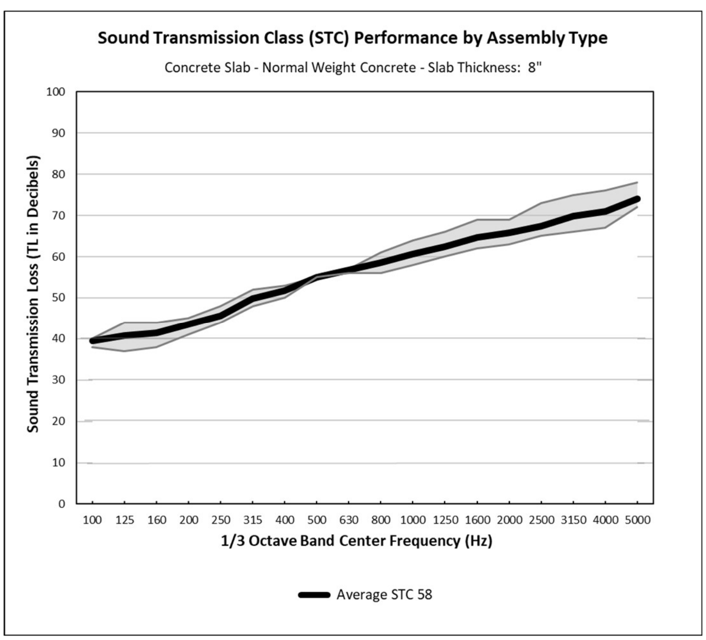


FIGURE 2. Concrete Floor-Ceiling Assemblies – Acoustics Performance Interactive Graph

Concrete Slab

Acoustical data for concrete slabs presented in TABLE 1 represents all cast-in-place structural types with exposed concrete undersides, including flat slab, pan joist, no beam, concrete beams, with or without post-tensioning rods. For this structural type, the thickness of the concrete slab is by far the most important acoustical element: beams, columns, and other structural elements play a much lesser role. Data has been provided for normal weight concrete (typically around 140 – 150 pcf).

Concrete Metal Deck

Acoustical data for concrete metal deck in TABLE 1 represents cast-in-place concrete atop a metal deck of varying depth. For this structural type, the thickness of the concrete topping is the most important acoustical element, though the specifications of the metal deck do play a role in the overall acoustical performance of the assembly.

CONCRETE SLAB STC ESTIMATOR

The concrete slab STC estimator below calculates the sound isolation performance of concrete slab thicknesses not listed in the laboratory test data above. The STC estimator uses acoustic mass law to estimate the sound isolation performance of the slab, based on the selected concrete density and thickness.

WALL ASSEMBLIES

Wall Acoustical Performance

TABLE 2 presents the potential range of sound isolation performance for typical concrete wall assemblies compiled from laboratory test data. FIGURE 3 shows the acoustical performance of these assemblies across the frequency spectrum.

TABLE 2. Concrete Wall Assemblies – Sound Isolation Performance

Assembly Type	Wall Thickness	Drywall	STC Ratings
ICF Walls	4” Core	-	STC 41 – 46
	4” Core	1 Layer – 1 Side Only	STC 42 – 46
	4” Core	1 Layer – Both Sides	STC 48 – 51
	6” Core	-	STC 46 – 50
	6” Core	1 Layer – 1 Side Only	STC 48 – 51
	6” Core	1 Layer – Both Sides	STC 54 – 56
	8” Core	-	STC 48 – 52
	8” Core	1 Layer – 1 Side Only	STC 50 – 53
	8” Core	1 Layer – Both Sides	STC 56 – 60

Wall Assembly Graph

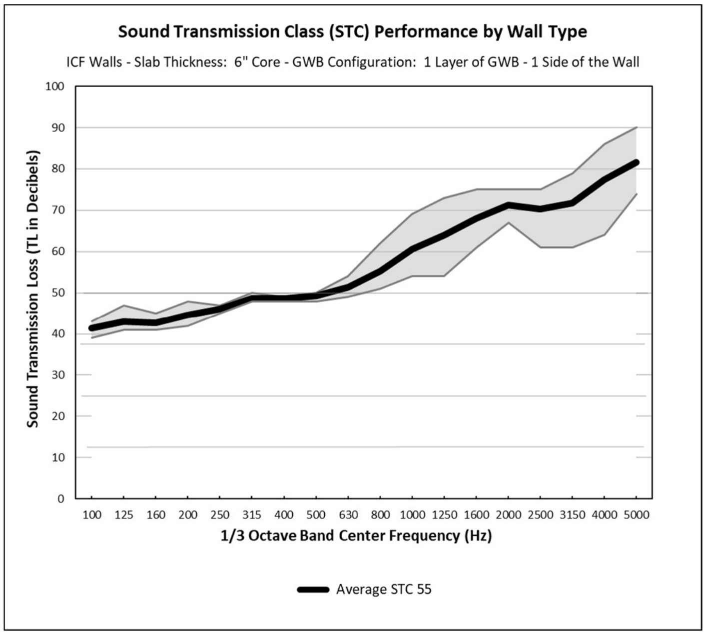


FIGURE 3. Concrete Wall Assemblies – Acoustics Performance Interactive Graph

Concrete Walls

The sound isolation performance of cast concrete walls is determined by the concrete density and thickness, just as for floor-ceiling slabs. Please refer to the STC data provided for concrete floor-ceiling assemblies in the previous section.

ICF Walls

Acoustical data for insulated concrete form (ICF) walls presented in TABLE 2 includes three concrete core thickness (4”, 6”, & 8”). Data for each core thickness was provided for three finish wall configurations: no drywall on either side of the wall, one layer of drywall on only one side of the wall, and one layer of drywall on both sides of the wall. Many other ICF wall configurations are possible, but these nine wall thickness / finish walls represent the most typical ICF constructions. We thank the Insulating Concrete Forms Manufacturers Association (ICFMA) and their participating members for their contributions to the data for ICF walls.

CONCRETE ACOUSTICAL UPGRADE OPTIONS

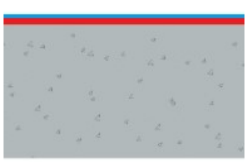
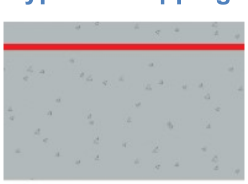
Depending on the project construction type, there may be sound isolation or impact insulation code requirements or other acoustics criteria that must be achieved. The STC & IIC data provided for floor-ceiling and wall assemblies in the previous sections are for base assemblies only, without finish ceilings, finish flooring, or any acoustical upgrades. Depending on the selection of floor, ceiling, and wall finish treatments, overall acoustical performance of assemblies can change dramatically. The following sections describe the general types of acoustical treatments that are available for concrete assemblies.

It should be noted that the sound isolation performance of concrete floor-ceiling and wall assemblies is inherently quite good, and these assemblies often achieve STC requirements without acoustical upgrades. Most acoustical upgrades for concrete floor-ceiling assemblies are needed to achieve impact insulation (IIC) requirements, or if a project is looking to achieve acoustics performance well above code requirements. It should also be noted that it is common to see acoustical flooring products rated using the delta impact insulation class (ΔIIC) metric to demonstrate the expected improvement to impact noise over a base 6” concrete slab assembly.

FLOORING TREATMENTS

For concrete floor-ceiling assemblies, the most common acoustical treatment option is at the floor. This can include installation of carpet, selection of hard-surface flooring with an acoustical underlayment, selection of specialty acoustics flooring, or construction of higher performing acoustical floated floors.

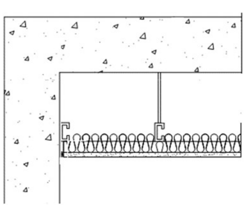
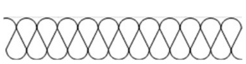
Installation of most finish flooring (e.g. carpet, hard-surface flooring, or sports flooring), however, will not improve floor-ceiling STC ratings, though all will improve IIC ratings to some degree. Of the flooring upgrade options below, only the floated floor option described below will improve STC ratings.

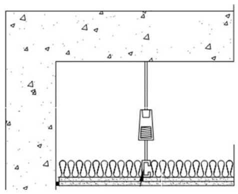
Flooring Treatment	Acoustical Considerations
Carpet	Carpet remains one of the best acoustical options to dramatically improve IIC ratings for floor-ceiling assemblies. Thicker padded carpets perform even better at mitigating impact noise (e.g. footfalls) than thinner carpet.
Acoustical Underlayment 	For standard hard-surface finish flooring (e.g., luxury vinyl tile (LVT), porcelain tile, hardwood flooring, engineered wood, linoleum, or similar), only marginal improvements to IIC performance can be expected when installed directly atop the base floor-ceiling assembly. To achieve higher IIC performance, an acoustical underlayment is needed. This may be installed as a separate layer, typically recycled rubber in thickness of 2 mm – 10 mm, available from several manfacturers[14,15,16,17,18,19,20,21]. Thicker acoustical underlayments generally provide higher impact insulation performance. LVT and engineered wood products are also available with integrated acoustical underlayment backing layers, which achieve similar acoustical performance as the dedicated underlayments above at comparable thicknesses. Acoustical LVT options are available from a variety of manufacturers[22,23,24,25].
Gypcrete Toppings 	Another method to improve IIC performance is through the installation of a gypcrete topping above the structural flooring assembly, with an acoustical entangled mesh underlayment beneath the gypcrete[19,20,26]. This mitigation method may be an option to improve acoustics performance when exposed ceilings are considered. Gypcrete toppings with entangled mesh underlayments are much more commonly found in hollow-core concrete and wood-frame constructions.

Specialty Flooring 	In fitness center, gymnasiums, and other specialty use areas (particularly activity related), there may be a need for dedicated acoustics flooring. Depending on the activity, this could be a modest rubberized fitness floor (such as for a yoga room) or much thicker specialized fitness flooring for heavy-weight lifting areas. Products are available from a variety of manufacturers[14,16,17,18,27,28]
Floated Floors 	If very high sound isolation or impact insulation is required, an acoustical floated floor could be installed. In these systems, a concrete topping (typically 2” – 6” thick) is poured atop a vibration isolation layer (using spring isolators, fiberglass, or rubber elements) which is installed atop the concrete structural slab. Floated floors are commonly found in mechanical penthouses, where sound isolation upgrades need to be installed by the base building, within the mechanical rooms. Floated floors are available from a number of manufacturers[16,29,30].

Ceiling Treatments

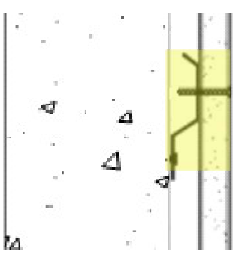
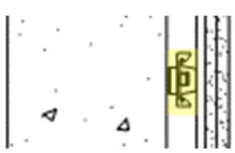
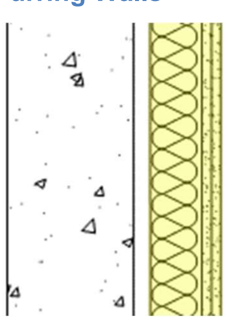
For concrete floor-ceiling assemblies, the underside of the structural slab or deck can represent the ceiling of the lower floor. These assemblies may also be provided with finish ceilings, such as drywall, acoustical ceiling tile (ACT), wood ceilings, etc. The ceiling type affects not only aesthetics but can determine the sound isolation and impact insulation performance of the overall floor-ceiling assembly.

Ceiling Treatment	Acoustical Considerations
Effects of No Ceilings	If the underside of the structural slab or concrete metal deck is left exposed with no finish ceilings installed below, then the acoustics performance of the overall assembly will be dictated by the concrete structure and flooring treatments alone. Therefore, if acoustical requirements are applicable to a project, exposed ceilings may require extensive acoustical treatments on the top side of the assembly to meet these goals, such as thicker acoustical underlayments or additional gypcrete or floated floor mitigation options.
Standard Ceilings 	When finish ceilings such as drywall or ACT are installed for concrete floor ceiling assemblies, they are typically hung using conventional methods, such as light-gauge metal framing or metal hanging wire. Installation of continuous ceilings can dramatically improve the sound isolation performance of a floor-ceiling assembly, particularly when using multiple layers of drywall, even with standard framing methods. Impact insulation performance is also improved through the installation of continuous ceilings on standard framing, though not as much as compared to the improvements to sound isolation. Note, if ceilings are not continuous, such as for wood-slat or blade-style ceilings, then no improvement in acoustics performance can be expected above the base assembly performance. Also, if selecting ACT, mineral fiber ACT products provide modest sound isolation performance (depending on Ceiling Attenuation Class ratings), while glass fiber ACT products provide only a small benefit to sound isolation performance.
Batt Insulation 	If finish ceilings are installed, typically the easiest and most cost effective way to improve the acoustics performance of the overall floor-ceiling assembly is to include batt insulation in the ceiling cavity. Installation of batt insulation in a ceiling cavity can typically improve sound isolation performance by 4 – 7 STC points and impact insulation performance by 2 – 5 IIC points, sometimes more. Batt insulation thickness is recommended to be 2 – 4” for acoustical purposes, as there are diminishing returns beyond 4” thick. The insulation does not need to form a continuous layer: coverage around 70% of the plenum plan area is generally sufficient.

Sound Barrier Ceilings 	If high sound isolation performance is desired for a concrete floor-ceiling assembly, installation of a sound barrier ceiling is one of the most common approaches. A sound barrier ceiling includes at least two layers of drywall, resiliently suspended from the slab / deck using resilient ceiling hangers, with batt insulation installed in the ceiling cavity, and all ceiling perimeters and penetrations sealed with non-hardening acoustical caulk. The improvement to sound isolation and impact insulation performance for a sound barrier ceiling depends on the component selection, including the layers of drywall and the ceiling hanger selection. For the highest acoustical performance, spring isolation hangers significantly outperform neoprene isolation hangers. It is possible to install sound barrier ceilings below structural beams (usually creating a ceiling cavity of 18" or more): in this configuration MEP systems would likely need to be coordinated above the sound barrier ceilings. Alternatively, it is possible to install sound barrier ceilings between structural beams, spaced off of the slab or deck by approximately 6": this configuration would put the sound barrier ceilings close to the structure, with all MEP systems hung below from the exposed undersides of the beams. Cavity depths of less than 4" should be avoided.

WALL TREATMENTS

For concrete wall assemblies, improving acoustical performance requires installation of additional construction layers, typically drywall. The methods used to attach the additional drywall will help to determine the acoustical performance of the upgraded wall assemblies.

Wall Treatment	Acoustical Considerations
Furring & Resilient Channels 	The most direct method of attaching drywall layers to a concrete wall is by using furring channels or resilient channels, which are thin light gauge metal framing elements that space drywall off the concrete parent wall by approximately 3/4". Channels are available in 2-leg versions (furring / hat channel) or 1-leg versions (resilient channel). 1-leg resilient channels perform noticeably better acoustically than standard furring channels. Directly attaching drywall layers to a concrete parent wall provides the least improvement to sound isolation performance of the wall upgrade options listed here, primarily due to the very small air cavity created behind the drywall, with no possibility to install batt insulation in the cavity. This condition should be avoided for acoustical performance.
Resilient Clips 	To further improve the acoustical performance of concrete walls, neoprene resilient clips may be used to affix the drywall in lieu of direct attachment to the walls. Neoprene clips further decouple the drywall layers from the concrete parent wall, improving the sound isolation performance of the wall assembly. When using resilient clips, it is possible to install batt insulation (1 – 2 " thickness) in the wall cavity as well. Resilient clips are available in a variety of form factors from multiple manufacturers[14,15,16].
Furring Walls 	The highest performing acoustical upgrade that can be provided for concrete walls is the installation of free-standing furring walls on separate framing, with a 1" airspace (minimum) between the furring wall stud rows and the concrete parent wall. By spacing the furring wall off of the parent wall, no physical connection is made along the stud rows, greatly improving the sound isolation performance of the overall wall assembly. Similar to ceiling cavities, inclusion of batt insulation in furring wall stud cavities can improve the sound isolation performance of the overall wall assembly, by up to 5 STC points in most cases. Inclusion of batt insulation is recommended for any furring wall installed between noise-generating and noise-sensitive spaces, as often found between elevator / stairwell core walls and residential units or occupied office areas.

Construction Details

Grouting / Seams

It must be noted that construction precision can play a large role in the overall sound isolation performance of a floor-ceiling or wall assembly, particularly at seams and edges between structural elements. Sound is very good at finding the 'weak spot' in these assemblies, and as such all intersections between concrete, drywall, framing, etc. must be appropriately sealed to achieve expected acoustics performance.

Acoustics Performance Estimator

TABLE 3 presents possible acoustics mitigation options for concrete floor-ceiling assemblies used in three typical building types:

- Commercial, with no code requirements for acoustic performance
- Residential, targeting code minimum performance
- Residential, targeting higher than code minimum acoustical performance.

Mitigation options are provided for both normal and lightweight concrete as well as for exposed slab / deck and finished ceiling configurations.

TABLE 3. Concrete Floor-Ceiling Assemblies – STC / IIC Goals and Needed Acoustic Mitigation

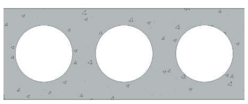
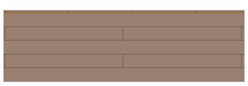
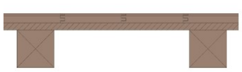
STC / IIC Goals	Structural Type	Ceiling Type	Acoustic Mitigation
Commercial Buildings: No Code Requirements Typical Goals: STC 50+	Normal-Weight Concrete Slab Or Composite Metal Deck	Exposed Slab / Deck	None Required
		Finish Ceilings Installed	None Required
	Lightweight Concrete Slab Or Composite Metal Deck	Exposed Slab / Deck	**a)** Increase Slab Thickness **b)** Add a 2 – 3” Gypcrete Topping
		Finish Ceilings Installed	None Required
Residential Buildings: Code Requirements: STC 50 IIC 50	Normal-Weight Concrete Slab Or Composite Metal Deck	Exposed Slab / Deck	**a)** Install Acoustical Underlayment Beneath Finish Flooring
		Finish Ceilings Installed	**a)** Install Acoustical Underlayment Beneath Finish Flooring w/ Standard Ceilings **b)** Install Drywall Ceilings w/ Neoprene Ceiling Hangers
	Lightweight Concrete Slab Or Composite Metal Deck	Exposed Slab / Deck	**a)** Install Acoustical Underlayment Beneath Finish Flooring **AND** Add Gypcrete Topping w/ Entangled Mesh Underlayment **b)** Add a 2 – 3” Gypcrete Topping w/ 3/4” Entangled Mesh Underlayment
		Finish Ceilings Installed	**a)** Install Acoustical Underlayment Beneath Finish Flooring **AND** Install Drywall Ceilings w/ Neoprene Ceiling Hangers **b)** Add Gypcrete Topping w/ Entangled Mesh Underlayment w/ Standard Ceilings
Residential Buildings: Higher Performance: STC 55 – 60 IIC 55 – 60	Normal-Weight Concrete Slab Or Composite Metal Deck	Exposed Slab / Deck	**a)** Add a > 1” Gypcrete Topping w/ Entangled Mesh Underlayment
		Finish Ceilings Installed	**a)** Install Thicker (≥ 5 mm) Acoustical Underlayment Beneath Finish Flooring w/ Standard Ceilings **b)** Install Acoustical Underlayment Beneath Finish Flooring **AND** Drywall Finish Ceilings w/ Neoprene Ceiling Hangers **c)** Install Drywall Finish Ceilings w/ Spring Isolation Hangers
	Lightweight Concrete Slab Or Composite Metal Deck	Exposed Slab / Deck	**a)** Install Acoustical Underlayment Beneath Finish Flooring **AND** Add > 3” Gypcrete Topping w/ 3/4” Entangled Mesh Underlayment
		Finish Ceilings Installed	**a)** Install Acoustical Underlayment Beneath Finish Flooring **AND** (2) Layer Drywall Ceilings w/ Neoprene Ceiling Hangers **b)** Install Drywall Finish Ceilings w/ Spring Isolation Hangers **c)** Add Gypcrete Topping w/ Entangled Mesh **AND** (2) Layer Drywall Ceilings

OTHER ASSEMBLIES

In addition to concrete floor-ceiling and wall assemblies, many other structural types are typical, each with their own benefits and design challenges inherent to the type of construction. The following sections describe these alternative floor-ceiling and wall assemblies, along with the acoustical concerns associated with each structural type.

FLOOR-CEILING ASSEMBLIES WITHOUT CEILINGS

The assemblies below are structural systems that do not require the inclusion of a finish ceiling. These systems may be provided with finish ceilings (as described in the acoustical upgrade section for concrete assemblies), but it is common to see these assembly types constructed with the undersides of the structure exposed.

Floor-Ceiling Type	Acoustical Concerns
Hollow Core Concrete 	Hollow core concrete floor-ceiling assemblies include precast concrete planks, typically 6" – 10" in thickness, which have tubular hollow cavities cast at the core of the planks. Hollow core concrete assemblies are most commonly found in multi-story residential and commercial buildings, where structural loads are relatively low. Similar to concrete slab construction, finish ceilings may or may not be installed for hollow core concrete assemblies, depending on the aesthetic design. On the topside of the assembly, seams are created between the planks when installed in the field. To solve this, a thin layer (~1") of gypcrete is typically required to be poured directly onto the hollow core concrete planks, with finish flooring then installed atop the gypcrete.
Mass Timber (CLT) 	Mass timber (also known as cross laminated timber or CLT) is an engineered wood product made up of multiple layers of wood, laminated together to create a structural system. CLT structural floor-ceiling assemblies are typically formed with 3-ply (~5" thick) or 5-ply (~7" thick) laminates. Similar to hollow core concrete, CLT is typically found in multi-story residential and commercial buildings. CLT constructions benefit aesthetically from inherent wood ceiling finishes. However, CLT constructions can be very challenging acoustically, based on the low mass of the systems (in comparison to concrete) as well as the preference to expose the underside of the wood structures. Typically, this results in the need for thick concrete flooring toppings and acoustical underlayments atop the CLT in residential applications.
Existing / Heavy Timber 	Heavy timber floor-ceiling assemblies can be found in existing buildings constructed using wood joist / subfloor systems. These are typically old mill buildings or other industrial / manufacturing facilities from the turn of the 20th century. Existing wood floor buildups are commonly 3 – 6" in thickness, with wood beams below. Heavy timber construction presents many of the same benefits and challenges described for CLT assemblies, including possible exposed wood ceiling structures as well as challenging acoustics performance.

Typical Acoustical Performance

TABLE 4 presents the range of sound isolation and impact insulation performance for hollow core concrete, CLT, and heavy timber floor-ceiling assemblies without finish ceilings. STC and IIC ratings were collected from multiple laboratory-certified acoustical test reports for each assembly type.

Sound isolation performance data has been divided into 6" and 8" thick slabs for hollow core concrete as well as 3-ply and 5-ply CLT assemblies, as the added thickness improves STC performance. Impact insulation performance for hollow core concrete and CLT assemblies does not change significantly with added structural thickness, so only one IIC range is given for each assembly type. For heavy timber floor-ceiling assemblies, the thickness and construction details (flooring & ceiling conditions, etc.) of the existing structure dictate the acoustical performance of the assembly. Data presented in TABLE 4 for heavy timber structures represent a range of assembly thicknesses, between 3" – 6".

TABLE 4. Floor-Ceiling Assemblies Without Ceilings – Sound Isolation & Impact Insulation Performance

Assembly Type	Floor/Ceiling	Assembly Description	STC Ratings	IIC Ratings
Hollow Core Concrete	None	6" Thick	STC 46 – 48	IIC 23 – 28
	None	8" Thick	STC 49 – 54	
Mass Timber / CLT	None	3-Ply – 5" Thick	STC 32 – 38	IIC 22 – 26
	None	5-Ply – 7" Thick	STC 39 – 42	
Old / Heavy Timber	None	Typically 3" – 6" of Existing Floor Structure	STC 29 – 39 [1]	IIC 23 – 33 [1]

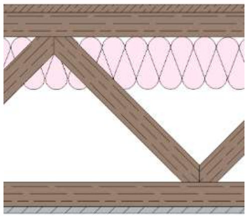
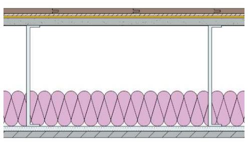
Notes: [1] STC & IIC ratings for old / heavy timber floor-ceiling assemblies are highly dependent on the existing construction details of the assembly (floor thickness, flooring selection, ceiling details, etc.)

Acoustical Upgrade Options for Assemblies Without Ceilings

Hollow core concrete floor-ceiling assemblies are most similar to concrete slab assemblies, and as such can be acoustically treated using comparable mitigation strategies. The main difference for hollow core concrete assemblies is the necessity of a gypcrete topping, and given this, installation of acoustical entangled mesh underlayments beneath the gypcrete is common for hollow core concrete floor-ceiling assemblies. Other acoustical flooring and ceiling mitigation options are still viable for hollow core concrete assemblies, as listed for normal-weight concrete slab assemblies in TABLE 3.

CLT floor-ceiling assemblies have two main acoustical challenges: low mass and the typical desire to expose the underside of structure for aesthetic reasons. As such, CLT assemblies typically include all acoustical treatment on the topside of structure, through the use of acoustical underlayments and gypcrete toppings. 5-ply CLT assemblies are similar in mass to 4" lightweight concrete slabs, and as such acoustical mitigation options listed in TABLE 3 for lightweight concrete would be appropriate for CLT (most likely for exposed ceilings, though some CLT projects include finished ceilings).

Heavy timber floor-ceiling assemblies face the same acoustical challenges as CLT, though typically with even less mass in the wood structure. As such, mitigation options listed for lightweight concrete slabs in TABLE 3 are an appropriate start for heavy timber assemblies.

Floor-Ceiling Type	Acoustical Concerns
Wood Joist / Beam 	Probably the most common floor-ceiling assemblies in modern construction use wood frame joists or beams, with drywall ceilings, and finish flooring. It is typically for these assemblies to include gypcrete toppings installed atop acoustical entangled mesh underlayments, along with ceilings supported by resilient channels, and batt insulation in the ceiling cavity. Wood joist assemblies (parallel cord truss or I-joist) provide slightly higher acoustical performance in comparison to wood beam assemblies. Wood-frame assemblies benefit from the requirement of finish ceilings, along with relatively thick flooring underlayment (particularly with the installation of a gypcrete topping). As such, sound isolation ratings for wood-frame assemblies are typically quite high. Mitigation of impact noise, however, requires dedicated acoustical treatment, as provided by acoustical underlayments or resilient ceiling hangers. Joist and beam structures also introduce complexity when extending gypsum wallboard on demising walls to deck, potentially introducing leakage paths between adjacent spaces.
LGMF 	Light gauge metal framing (LGMF) floor-ceiling assemblies share many similarities to wood-frame assemblies, while using metal structural framing in lieu of wood frame joists or beams. LGMF assemblies include drywall ceilings, finish flooring, batt insulation in the ceiling cavity, and typically are provided with gypcrete toppings. LGMF systems are also very similar to wood-frame assemblies acoustically, with comparable sound isolation performance, impact insulation performance, and potential upgrade options applicable to both structural types.

FLOOR-CEILING ASSEMBLIES WITH CEILINGS

Wood joist / beam and light gauge metal framing assemblies require the inclusion of a finish ceiling as part of the structural system, and as such face different acoustical concerns as compared to the previous assemblies.

Typical Acoustical Performance

TABLE 5 presents the range of sound isolation and impact insulation performance for wood joist / beam and LGMF floor-ceiling assemblies with finish ceilings. STC and IIC ratings were collected from multiple laboratory-certified acoustical test reports for each assembly type, and do not include neoprene / spring ceiling hangers or acoustical underlayments.

Please note, the resulting acoustical performance for wood frame or LGMF assemblies are highly dependent on all structural components, construction details, finish flooring, and ceiling selections, and as such these assemblies should be evaluated acoustically on a case-by-case basis.

TABLE 5. Floor-Ceiling Assemblies With Ceilings – Sound Isolation & Impact Insulation Performance

Assembly Type	Ceiling	Topping	STC Ratings [1]	IIC Ratings [1]
Wood Joist / Beam	1 Layer Drywall w/ Resilient Channels – No 'Acoustical' Ceiling Hangers	With ~1" Gypcrete Topping – No Acoustical Underlayment	STC 54 – 62	IIC 29 – 35
LGMF	1 Layer Drywall w/ Resilient Channels – No 'Acoustical' Ceiling Hangers	With ~1" Gypcrete Topping – No Acoustical Underlayment	STC 55 – 62	IIC 35 – 42

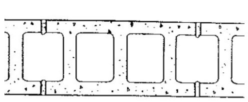
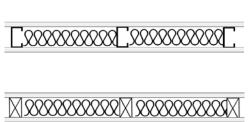
Notes: [1] STC & IIC ratings for wood joist / beam and LGMF floor-ceiling assemblies are highly dependent on the construction details of the assembly (flooring selection, ceiling details, inclusion of insulation, etc.)

Acoustical Upgrade Options for Assemblies With Ceilings

Wood framed and LGMF floor-ceiling assemblies have many potential options to improve sound isolation and impact insulation performance. All flooring upgrades discussed above for concrete assemblies are possible, including installation of carpet, selection of hard-surface flooring with an acoustical underlayment, selection of specialty acoustics flooring, or construction of higher performing acoustical floated floors. These assemblies may be provided with standard ceiling framing or higher performing sound barrier ceilings.

Acoustical treatment is often provided on both the topside and underside of wood frame or LGMF floor-ceiling assembly, such as installation of an acoustical underlayment beneath the finish flooring combined with resilient ceiling hangers. In other situations, it may be possible to meet project goals by providing higher performing acoustical treatment on only one side of the assembly (topside or underside), such as installation of acoustical floated floors or alternatively, installation of sound barrier ceilings.

WALL ASSEMBLIES

Wall Type	Acoustical Concerns
CMU 	Concrete masonry unit (CMU) walls are comprised of many stacked precast concrete blocks, typically 6" – 10" in thickness. The cavities of the CMU blocks may be left empty, filled solid with grout, or filled with insulation. The faces of CMU walls are commonly painted (such as for mechanical equipment rooms) or if higher acoustical performance is called for, interior furring walls are typical, as described above for concrete walls.
Steel & Wood Stud 	Steel and wood stud framed walls are comprised of a stud wall, along with drywall on both sides of the studs, creating an air cavity within the wall that is typically filled with batt insulation. Stud wall details significantly affect the potential sound isolation performance of a wall assembly, including stud thickness, depth, spacing, & assembly type. In general, the less connection a framed wall can have between the two visible layers of drywall, the better the acoustical performance will be. For example, a double-stud wall assembly (with two separate stud rows installed with a 1" airspace between) performs better than a staggered-stud wall assembly (with two stud rows installed on the same top and bottom stud row tracks), which in turn performs better than a single-stud wall assembly.

Typical Acoustical Performance

TABLE 6 presents the range of sound isolation performance for a small selection of CMU, wood-stud, and steel stud wall assemblies. STC ratings were collected from multiple laboratory-certified acoustical test reports for each assembly type. Wall thickness, stud configurations, and drywall conditions have been noted for each entry.

Please note, the resulting acoustical performance of CMU and framed wall assemblies is highly dependent on all structural components, construction details, and wall selections, and as such these assemblies should be evaluated acoustically on a case-by-case basis.

TABLE 6. Other Wall Assemblies – Sound Isolation Performance

Assembly Type	Wall Thickness	Drywall	STC Ratings [1]
CMU	6” Core	–	STC 43 – 51
	8” Core	–	STC 45 – 56
	10” Core	–	STC 46 – 60
Wood Stud	Single-Stud Walls 3-5/8” or 6” Stud Rows	1 Layer – Both Sides	STC 32 – 42
		2 Layers – Both Sides	STC 38 – 46
	Staggered Stud Walls 3-5/8” or 6” Studs in the Same Stud Track	1 Layer – Both Sides	STC 42 – 49
		2 Layers – Both Sides	STC 53 – 57
	Double-Stud Walls (2) 3-5/8” or 6” Stud Rows Separated by a 1” Airspace	1 Layer – Both Sides	STC 51 – 59
		2 Layers – Both Sides	STC 64 – 69
Steel Stud	Single-Stud Walls 3-5/8” or 6” Stud Rows	1 Layer – Both Sides	STC 33 – 48
		2 Layers – Both Sides	STC 44 – 57
	Double-Stud Walls (2) 3-5/8” or 6” Stud Rows Separated by a 1” Airspace	1 Layer – Both Sides	STC 53 – 59
		2 Layers – Both Sides	STC 62 – 65

Notes: [1] STC ratings for wall assemblies are highly dependent on the construction details of the assembly (number of drywall layers, inclusion of insulation or resilient channel, etc.)

Acoustical Upgrade Options

CMU walls share many similarities with cast concrete walls regarding acoustical upgrade options. As such, mitigation options listed above for concrete walls are applicable to CMU walls as well.

Steel and wood stud framed walls have a number of acoustical upgrade options that can improve the sound isolation performance of the assembly. Beginning with the stud selection, lighter-weight studs perform better acoustically (e.g. 25 GA vs 20 GA) and when spaced at larger intervals (e.g. 24” O.C. vs 16” O.C.) sound isolation performance can improve even further. It is also possible to upgrade single-stud walls to staggered or double stud wall configurations, if space is available. In steel framed buildings, it is common to use 2-1/2” studs in double-stud walls to decrease wall width.

It is also possible to add multiple layers of drywall to framed walls, which will provide incremental improvements to sound isolation with each additional layer. The methods used to attach the drywall will also contribute to the acoustical performance of a framed wall, with the installation of neoprene clips as the highest performing option, followed by the installation of resilient channels, and then rigid installation as the lowest performing option. As with floor-ceiling assemblies, inclusion of batt insulation within the cavity of a wall assembly can improve the sound isolation performance of a framed wall by 5 STC points or more. Separate furring walls may also be installed to improve the acoustics performance of the overall assembly. These furring walls perform best when the stud rows are spaced at least 1” off the parent wall, and batt insulation is provided in the furring wall cavity, as described above for concrete walls.

PROJECT CONTRIBUTORS

We would like to thank the many contributors that made this compilation of data possible, including Roger Sculthorpe on behalf of the ICFMA[31]. In addition, we would like to thank individual contributing manufacturers Fox Blocks[32], Nudura[33], BuildBlock[34], and Logix[35] as well as Riverbank Laboratories for providing laboratory test report data for concrete floor-ceiling and wall assemblies.

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