RESILIENT CEILING CONSTRUCTION IN RESIDENTIAL BUILDINGS

PACS 43.55.Rg

Nash, Anthony
Charles M. Salter Associates; 130 Sutter St., Suite 500, San Francisco, California 94104, USA; anthony.nash@cmsalter.com

ABSTRACT
In order to satisfy modern building codes, the floor/ceiling assembly that separates multi-family living units needs to be sound-rated. Throughout North America, a common light-frame floor construction involves wood or cold-formed metal joists spaced at 400 mm. The typical practice is to attach a gypsum board ceiling to the underside of the floor framing using narrow strips of “Z”-shaped thin metal called “resilient channels”. If the resilient channels or the ceiling are installed incorrectly, the low-frequency sound insulation of the assembly can be seriously degraded.

Based on our experience with resilient ceiling construction, there are two significant factors that have not yet been documented in an acoustical laboratory. One factor is to maintain a small separation around the entire perimeter of the ceiling where it intersects vertical wall surfaces (this void is later sealed airtight with a flexible caulking material). A second is the particular design characteristic of the “Z”-shaped channel. The paper demonstrates that it is possible to attain laboratory-grade acoustical performance from a resilient ceiling installed in a light-frame multi-family building.

PART I — DESCRIPTION OF FLOOR/CEILING

Introduction
This paper discusses the field acoustical performance of residential floor/ceiling assemblies resulting from proper ceiling installation techniques. Specifically, the paper will focus on ceilings attached to the underside of a floor structure that is supported by an array of wood or steel beams called “joists”. For a framed floor/ceiling assembly, an incorrect ceiling installation is known to have a significant effect upon both its airborne as well as its impact sound insulation performance.

The impact insulation performance of a framed floor/ceiling also depends on the floor finish and other parameters that are not easily controlled under field conditions — for this reason, the current paper will discuss only the airborne component.

Overview of Residential Sound-Rated Floor/Ceiling
In North America, a common framed floor construction involves wood floor panels supported by wood or cold-formed metal joists spaced at 16 inches (400 mm) on center. A 25-mm thick layer of poured-in-place gypsum/cement material is often applied onto the top of the wood subfloor panel in order to improve the sound insulation of the floor/ceiling assembly.

Another common practice is to attach a gypsum board ceiling across the underside of the floor framing using narrow strips of “Z”-shaped thin metal called “resilient channels”. The intended function of the resilient channel is to acoustically “de-couple” (isolate) the gypsum board ceiling panel from the joist, thereby reducing the transmission of structure-borne vibration between the floor joists and the ceiling. An isometric view of such a floor/ceiling assembly is shown in Figure 1 (on the following page).
Figure 1: In this view of a floor/ceiling assembly, the resilient channels are shown installed across the underside of the wood joists. The channels help to “de-couple” the floor structure from the two-layer gypsum board ceiling (note that the joist attachment screw is centered on the slot punched in the web of the channel). For this assembly, an underlayment of one-inch (25 mm) thick gypsum board has been placed over the subfloor in order to increase both its surface mass and, possibly, its fire endurance (image from product literature issued by USG = United States Gypsum Company).

Sound Absorption in Floor Cavity
An important component of the floor/ceiling assembly is the sound-absorbing material that is distributed within the joist cavities. The principal functions of this material are to a) help suppress locally high sound pressures caused by low-frequency acoustical modes along the length of the joist cavity and, b) decrease the acoustical stiffness of the trapped air volume. A secondary function is to minimize the reverberant sound field within the joist cavity.

Surface Mass
In modern construction of framed floor/ceiling assemblies, the top surface of the subfloor is often covered with a gypsum board underlayment or a poured-in-place gypsum/cement topping in order to improve the surface mass of the entire assembly. This technique increases the total surface mass to approximately 16 pounds per square foot (78 kilograms per square meter).

Resilient Channel Characteristics
With respect to attaining the full acoustical performance from a sound-rated floor/ceiling, the most critical component has proved to be the ceiling. Not only do the installation techniques of the resilient channel and ceiling panels have an effect upon the performance of the assembly, the design of the channel itself may be important for attaining the optimum sound insulation. The original USG design was based on a “Z”-shaped steel strip having two parallel flanges separated by an angled web. The resilient material has a nominal sheet thickness of 25-gauge (0.0247 inches equal to 0.6274 mm). Channel samples from other manufacturers occasionally have measured sheet thicknesses closer to 26-gauge (0.0217-inch or 0.551 mm). An isometric view of a resilient channel is shown in Figure 2 (on the following page).

1 These [nominal] sheet thickness data are based on ASTM A924, Standard Specification for General Requirements for Sheet Steel, Metallic-Coated by the Hot-Dip Process and ASTM A653, Standard Specification for Sheet Steel, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvanized) by the Hot-Dip Process.
Figure 2: USG RC-1 resilient channel (circa 1986). By design, the framing attachment points (pre-punched holes) are aligned with the center of the punched slots in the web.

In the USG design, the central web is punched every four inches (100 mm) to create a series of three-inch-long (75 mm) slots. Only a one-inch long (25 mm) bridge of solid material remains between the ends of adjacent slots. Screw holes are pre-punched into the framing-mounting flange at four inches (100 mm) on center; these screw holes are aligned with the slot centers.

The intent of the pre-punched holes is for screws to be inserted at these locations as the channel is being attached to the underside of the joist; thus, the joist attachment point would always be aligned with the center of the slot in the central web. The manufacturer assumed that the spacing of floor joists would be uniformly distributed at some integer multiple of four inches (100 mm). That is, the slots in the central web could always be properly aligned with any joist spacing dimension commonly used in North America (i.e., 12, 16, or 24 inches on center).

Resilient Channel Installation
The channels are attached perpendicular to the underside of the joists with a nominal spacing between adjacent rows of resilient channel (e.g., 24 inches or 600 mm). The grid-like array of channels and joists is shown as a reflected ceiling plan in Figure 3 (on the following page).

In Figure 3, it is evident that the sole mechanical coupling between the floor structure and the ceiling panel is a series of low-stiffness point connections occurring at every joist-channel intersection.

---

2 A special case of a joist spacing dimension was developed by the wood industry for the "I"-shaped engineered wood joist. It was agreed to establish a spacing of 19.2 inches (488 mm) so five evenly-spaced joists could support a standard 96-inch (2440 mm) length of plywood floor sheathing. Clearly, a 19.2-inch joist spacing is not commensurate with an integer multiple of the four-inch (100 mm) slot spacing found in the USG RC-1 resilient channel.

3 For extended fire endurance ratings, USG specifies that the spacing between rows of resilient channels be reduced to 16 inches (400 mm) on center, thereby creating a 16 x 16-inch square grid of point contacts. The increased number of point contacts between the floor structure and the ceiling panel leads to a slight reduction in the assembly's sound insulation performance.

4 USG performed static load tests on a ceiling supported by RC-1 channels attached at 24 inches (600 mm) on center across wood joists at 16 inches (400 mm) on center. A vacuum was applied to the room below and the resulting force caused the entire ceiling to deflect downward. The measured static stiffness of the resilient channel system was 78 pounds per square foot per inch of deflection (147 pascals per millimeter) — equivalent to a stiffness of 208 pounds per inch (36.4 newtons per millimeter) concentrated at each RC-1-to-joist intersection. At a differential pressure of 40 pounds per square foot (1930 pascals), the 0.5-inch (12.5 mm) thick gypsum board ceiling panel was finally wrenched from its own attachment screws. This limit represents a point force of 107 pounds (475 newtons) applied to each RC-1-to-joist intersection. Expressed in terms of a uniform gravitational load, the total force developed by the vacuum and ceiling panel is equivalent to 8.5 inches (240 mm) of solid gypsum board. The static load test demonstrated that an array of resilient channels could safely support any feasible gypsum board ceiling.
Figure 3: Reflected ceiling plan of floor joists with resilient channels. The gypsum board ceiling (partly shown in the lower left corner) is attached only to the resilient channels. A grid of point contacts is created by the “columns” of floor joists at 16 inches (400 mm) on center intersecting the “rows” of resilient channels at 24 inches (600 mm) on center. The last row of resilient channels is located within six inches (150 mm) of the ceiling boundary so the edge of the gypsum panel is supported without excessive bending stress. At the other two ceiling boundaries, the channel ends are held back approximately 0.5 inches (12.5 mm) from the intersecting sidewalls to help avoid mechanical interference between the light-frame wall structure and the ceiling panel. The finite number of connections significantly reduces the transmission of vibration between the floor structure and the ceiling panel, especially in the frequency range above 100 hertz.5

5 Brunskog measured the mechanical impedance for a small sample of resilient channel loaded in tension. When the channel was loaded by a mass representing a typical section of a gypsum board ceiling, he found that its dynamic stiffness was approximately 50 newtons per millimeter (285 pounds per inch) in the frequency range between 100 and 400 hertz. Above 400 Hz, the experimental system exhibited several resonances, the frequency of which depended on the mass used to load the channel. Some of these resonances may have involved rotation or bending. The test length of the channel used by Brunskog was relatively short (~ four inches or 100 mm). Assuming the ceiling panel load were 11.2 pounds (50 newtons) at each channel-to-joist intersection, then the dynamic deflection for a short length of channel would be on the order of 0.04 inches (1.0 mm). This point stiffness value is similar to that obtained from the USG static load test (i.e., 208 pounds per inch or 36.4 newtons per millimeter). It is not clear from the Brunskog and Hammer papers whether quantifying a one-dimensional spring constant is adequate to describe the dynamic function of the channel in a ceiling system — i.e., minimizing the mechanical power flow between the framing structure and the ceiling panel. It would seem intuitive that the distributed rotational and bending stiffness of the channel should also be analyzed. [refer to papers by J. Brunskog & P. Hammer in TVBA 3105, Lund University, 1999]
Ceiling Perimeter
In framed construction involving resilient channels, the perimeter of the gypsum board ceiling is another potential path of vibration between the building structure and the ceiling panel. For this reason, the perimeter of the ceiling panel should not come into mechanical contact with the intersecting sidewalls. This is easily accomplished by leaving a small air gap between the building structure and the ceiling perimeter. In order to prevent sound leaking in or out of the joist cavities, it is necessary to seal this perimeter gap using a flexible material as shown below in Figure 4.

Figure 4: In this section view, the resilient channel is shown installed between the underside of the wood joist and the two-layer gypsum board ceiling. The ends of the channel are held away from the sidewall by a nominal dimension to help avoid mechanical interference. The perimeter gap around the ceiling panel itself is held away from the intersecting sidewall by 0.25 inches (6 mm) and the gap is sealed airtight with a flexible material (i.e., acoustical sealant). For structural reasons, the resilient channel does not extend more than six inches (150 mm) from its closest support.

PART II — ACOUSTICAL PERFORMANCE UNDER FIELD CONDITIONS
Paradigm Floor/Ceiling
The sound insulation performance of the floor/ceiling described in this section will serve as a paradigm (or benchmark) of the principles discussed in this paper. The paradigm wood-frame floor/ceiling assembly involved a retrofit of a joist floor with a two-layer gypsum board ceiling installed on USG RC-1. A contractor installed both the resilient channels and the ceiling panels under the close supervision of an acoustical consultant. The floor/ceiling was then field-tested to determine its sound transmission loss values at each of 16 frequency bands.

6 Construction details of the paradigm floor/ceiling assembly are available from the author.
7 In accordance with ASTM E336, the measured noise reduction data were corrected (or “normalized”) to account for the volume and reverberation characteristics of the receiving space (the corrected noise reduction value is called the sound transmission loss). A standard contour was then fitted to the 16 discrete values of sound transmission loss to calculate the sound transmission class or “STC” (see definition of STC in footnote 8). The source and receiving rooms were unfurnished during the test; hence, there was little sound absorption. The volume of the receiving room was 1570 cubic feet (44.5 cubic meters).
In Figure 5 below, the sound transmission loss data are plotted along with the appropriate STC contour. This figure also includes data from a laboratory test of a nearly identical floor/ceiling assembly. Presumably, the laboratory test data are unaffected by “flanking” sound paths.

![Sound Transmission Loss Graph](image)

**Figure 5:** Test of a sound-rated floor/ceiling assembly constructed in the field under the close supervision of an acoustical consultant. The STC 58 contour is shown as a dashed line on the plot. The second data set is shown as a chained line and represents a laboratory test (RAL-TL89-145) of the USG floor/ceiling assembly shown earlier in Figure 1. The “valley” seen in the 2 kHz band of the laboratory test is probably due to “coincidence” effects in the two-layer gypsum board ceiling panel. Such “coincidence” behavior only appears when the laboratory sound field includes extremely high (grazing) angles of incidence.

For the paradigm floor/ceiling assembly, the measured field sound insulation was STC 58 — a value comparable to the STC 58 obtained from the acoustical laboratory measurement of the USG floor/ceiling assembly shown earlier in Figure 1. The floor/ceiling specimens for both the field and laboratory assemblies had similar surface masses — 16 pounds per square foot (78 kilograms per square meter).

**CONCLUSIONS**

The field test discussed in this paper demonstrates that it is possible to duplicate laboratory performance in light-frame wood buildings, assuming a) one takes care during the installation of the resiliently-supported gypsum board ceiling and, b) little or no “flanking” sound transmission is present.

---

8 **Sound Transmission Class (STC)** — A single-number rating derived from the sound insulation properties of a partition when measured under controlled laboratory conditions. Numerically, STC approximates the number of decibels of speech sound reduction from one side of a partition to the other. STC is calculated in accordance with ASTM E413 and is comparable to the weighted sound reduction index (Rw) value as defined in ISO 717-1.