For many years now, design professionals have been using structural steel and cold-formed steel framing to develop buildings for a wide variety of uses, from a basic one-story storage building to a multi-story shopping center, from a basic schoolroom to the massive sports arena, from a simple one room church classroom to an expansive church sanctuary. In many cases, these facilities are required to accommodate a large number of occupants in a “quiet” environment, such as auditoriums, sanctuaries, libraries, dormitories, classrooms, and multi-purpose gymnasiums.

All of these projects have been very carefully designed, yet, sometimes upon completion, the interior environment is not as quiet as expected and the structure makes unexpected noises at various times. When these noises become loud or objectionable, the owner and occupants may become concerned and ask questions, such as what is making the noise and why?—should this have been expected?—is the building still safe?—what can be done to eliminate these noises?

Several years ago, an independent study was performed in an effort to answer these questions. This study uncovered several sources and reasons for these noises. It also created a better understanding for why some were louder and more objectionable than others, as well as some potential means of avoiding many of these noises.

The study was performed over several months and covered approximately eight projects that were experiencing various noises in the roof deck and structural framing. Several of the projects were experiencing objectionable noises and a few, of similar design, were not experiencing much, if any, objectionable noise. Although the report does not claim that all of the objectionable noises were addressed or resolved, it does provide guidance to the design professional and the owner of various things that should be considered in an effort to design quiet interior environments.

In this short article, it will be assumed that the design professionals have done their jobs properly and the structure was safely designed as required by the local building code, as is the case in all of the projects studied.

Some level of structural noise should be expected, and there are things that can be done to reduce these noises. First of all, we must understand that all buildings move almost imperceptibly. It does not matter if the building is constructed of concrete, structural steel, cold-formed steel, or wood-framed trusses; all buildings move. With every wind gust or temperature change, buildings move in response to these environmental conditions, while protecting the interior environment of the building. As the parts of the building move, they may make noises as these parts move over each other. Oftentimes the noises may be unnoticeable, but sometimes they may be very audible.

Very early in the case study, it became apparent that most of these projects had several common characteristics. The following is a list of the common characteristics that contributed in the presence of objectionable noises.
Common Features

1. Wide open interior spaces such as a gymnasium, sanctuary, meeting hall, or auditorium.

2. The roof structure was left exposed without finished ceilings.

3. The roof framing was a combination of structural steel trusses, beams and bar joists. The roof was supported by one or more main long span trusses or frames, long span being considered as 60 foot or more in length. Other smaller members such as beams, or bar joists, were supported by the main long span trusses or frames.

4. The roof covering was supported by a metal deck with the flutes of the metal deck running parallel to the main long span trusses or frames.

These four characteristic features appeared in each project. From these characteristics, the study revealed the following list of potential noise producers. We must point out that due to variations in design, these items do not occur in every steel frame building, or structure.

Potential Sources of Noises

1. Local buckling of the steel roof deck:

   When loaded in compression, the slender elements of the roof deck will locally buckle, producing waves in the flat portions of the deck. This is sometimes informally referred to as oil canning. This is an inherent structural performance property of steel deck within its design limitations to remain serviceable as required by IBC and SDI. This oil canning is normal and does not indicate any structural deficiency.

   Long span trusses, including beams and bar joists, are usually fabricated and erected with positive camber (an upward bow). As these members are set in place, some of the camber is removed by the dead weight of the members. As additional materials are installed, more of the camber disappears and the top chord of the truss goes into compression. When the metal deck is installed (welded, screwed, or pinned) to the top chord of the truss, the deck cannot move independently from the top chord of the truss. Consequently, the metal deck will also go into compression. As additional materials (including insulation, roof coverings, rooftop units, etc.) are installed, additional compression forces develop in the metal deck, leading to further oil canning.

   As testing revealed, the metal deck would begin to show signs of local buckling (oil canning) upon application of very little added load, (creating compression loads parallel to the flutes of the deck.) As the oil canning developed in the deck, the deck began to make rumbling or popping noises. As the load was removed, the oil canning disappeared, once again creating popping noises. These noises are similar in nature to what you hear when you compress the lid or walls of a soda can.
2. Temperature Changes and Wind:
   A slight change in temperature or a very light wind could cause a change in magnitude
   in the previously described compression loads. As the sun rises, the roof deck assembly
   begins to absorb heat and expand. With the deck attachments already in place, the
   roof deck assembly attempts to expand but is resisted by the attachments, and the
   compression loads in the deck increase, causing a series of popping or pinging noises.
   As the deck cools, or as a light wind blows by, these compression loads are decreased,
   gradually or only momentarily. Either way, the amount of oil canning changes, also
   causing a series of popping noises. Sometimes this change is gradual, but sometimes
   it builds up over several minutes and then suddenly releases a series of rumbling/
   popping noises. As these compression loads increase, the likelihood and volume of the
   noises also increases.

3. Building Perimeter Framing:
   Many times a structure will require the use of continuous steel angles or bent plates
   around the perimeter of the structure to transfer forces out of the roof. These angles or
   plates may be welded continuously end-to-end, preventing any release of compression
   loads across or parallel to the deck flutes. Similar structures with non-continuous
   perimeter angles or plates did not experience the same amount of perimeter noises.

4. Metal Deck-to-Structure at Deck Fasteners:
   If the metal deck is not firmly seated against the structural framing with the fastener,
   it can create a location where the deck can slip, resulting in a pinging noise. The
   deck connection is structurally sound, however, if the deck is not firmly seated on
   the support structure, these noises may occur as the building moves in reaction to
   environmental conditions.

5. Metal Deck-to-Structure Without Fasteners:
   This condition exists when structural load requirements do not require the use of deck
   fasteners in every flute across every structural support member. It also tends to occur
   in conditions where the metal deck is running perpendicular to the long span support
   truss. In this case, the metal deck receives a compression load perpendicular to the
   flutes, and seeks to relieve this load. In most cases, the metal deck bows ever so slightly
   upward above the structure. As the compression load is released, the metal deck will
   return to its original position and may bang against the structure.

6. Metal Deck-to-Metal Deck Connection:
   This condition is very similar to the perimeter framing condition. As the compression
   loads travel within a sheet of deck, with proper placement and seating of deck flutes, it
   is very likely the noises will travel from deck panel-to-deck panel and potentially across
   the length and width of the building.

7. Insulation-to-Metal Deck Attachment:
   In structures requiring the use of rigid board insulation above the metal roof deck,
   this is potentially a source of some noise. These roof deck assemblies are constructed
in layers and mechanically fastened together with screws and/or adhesives. Once again, as the roof deck assembly goes through its normal environmental adjustments, the individual components will expand or contract, and attempt to move in opposing directions, or at different rates. As the insulation “moves across” the surface of the metal deck, it creates a small popping noise. Several of these pops in unison can be objectionable.

8. Structural Steel Bolted Connections:
In almost every structural steel frame, there are some bolted connections. In accordance with AISC, the connection design permits the use of bolt holes larger than the diameter of the bolt, thus, creating some fabrication/erection tolerance. Depending upon the location and structural requirements of the connection, some of these bolt holes may actually be slotted as much as 50% larger than the bolt diameter. During the erection process, the bolts are installed in every bolt hole and the nuts are tightened. The bolts may be located in the middle portion of the holes. As the structure is loaded, the bolt may slip in the hole until it comes to bear against the edge of the hole. When the bolt impacts the edge of the bolt hole, a loud bang, or series of bangs, may result. This condition usually occurs during the construction phase as bolted connections become fully engaged. However, depending upon the location of the bolts and the structural design, this can occur after the building is occupied, and may coincide with heavy winds or severe temperature changes. This is a normal, fairly common occurrence and does not indicate any structural problems.

9. Purlin-to-Structure Connection:
This condition usually occurs in pre-engineered steel structures and cold-formed framing projects. In this case, the metal deck is supported by steel purlins (small roof beams) that are running continuous across the top flange of the main building frames. These purlins can be of various shapes and sizes. The bottom flange of the purlin is attached to the support framing, and the top flange of the purlin supports the metal deck. Noises may occur when the metal deck moves through expansion, contraction, or wind uplift. The top flange of the purlin moves with the metal deck while the bottom flange is attached to the structural framing. Simply put, the purlin rocks back and forth on the structural framing. If there are any small gaps between the purlin and the structural framing, these components may create noise with each movement cycle. The potential condition increases with depth of the purlin, because the larger depth makes the purlin more flexible perpendicular to its length.

Recommendations
The following list of recommendations may reduce, but not completely eliminate, the potential for objectionable noises.

1. Adjust the structural framing to allow the metal deck flutes to run perpendicular to the main long span support truss or frame. This reduces the chance of axial compression loads developing in the steel deck, leading to oil canning.
2. Review the performance requirements of the metal deck, including the slenderness ratio of the desired metal deck section. Per AISI, the slenderness ratio is the width of the steel deck flange divided by the thickness of the steel used to make the deck. The lower the slenderness ratio, the lesser the potential for noise. By simply increasing the gage, or thickness, of the metal deck, the chances of objectionable noises are reduced.

3. Avoid butt-welded connections of perimeter angles or bent plates. Design all end connections of perimeter angles, or bent plates, to be over steel beams. The bearing leg of the angle can be welded to the beam, yet, leave a slight gap between ends of perimeter angles, thereby avoid welding the vertical leg of the angles together. This will allow expansion and contraction to occur, and will release compression loads within the deck and the structure, thus avoiding a large build up of loads and the potential for objectionable noises.

4. During the steel erection process, pre-load long span trusses whenever possible. Install all of the structural framing in the area and remove any temporary shoring prior to installation of the metal deck. This will dramatically reduce the compression loads in the metal deck.

5. The use of acoustical ceilings, fireproofing, or various other means of interior sound absorption can be effective in dampening any potential noises.

It should be noted that all of these recommendations require early design consideration, simply because it is much easier and less costly. Trying to make these changes after the project is complete can be very expensive.

Also make note that several of the noise producers were not addressed in the recommendations. As stated earlier, all buildings inherently move, and all buildings make noises. Some noises can be avoided, some can be dampened, but not all noises can be eliminated. However, by following these recommendations during the design and construction stages, many of objectionable noises can be reduced or avoided. For further technical information, contact the Steel Deck Institute (SDI) for a copy of Dr. Luttrell’s report or for additional resources that have been developed which address reducing objectionable noises.

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