STRUCTURAL PRACTICES

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Long-Span, Open-Web Trusses

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In the engineering and construction industry, any truss spanning more than 60 feet is considered to be "long span", thus requiring engineering consideration (per *International Building Code* (IBC) 2015 Section 2303.4, "Trusses" [for design of]). The purpose of this article is first to explore and explain various aspects of building with long-span, open-web trusses, including manufacturing, architectural design options, engineering considerations, and installation practices and, second to provide examples of structures where long-span, open-web trusses are featured (*Figure 1*).

Two types of wood trusses are found in today's market:

- **Metal-plate-connected wood trusses** are typically manufactured with chords and webs of solid-sawn wood fastened together with metal plates. These types of trusses are typically used in roof applications, yet are sometimes used in floor systems.
- **Open-web pin-connected trusses** have chords made of either solid-sawn or engineered wood, and tubular steel webs attached using pinned connections. These trusses are suitable for either roof or floor systems.

With their open-web construction, both truss styles allow for easy installation of plumbing, electrical lines, and HVAC ductwork. The trusses are custom designed and manufactured for each job, yet pin-connected trusses offer designers and builders the advantages of both wood and steel that generally allow for a shallower truss. They can also be attached to a variety of wall types, and their high strength-to-weight ratio and long-span capabilities give architects more design freedom with large open spaces. Although much of the following design and installation information could be applied to either style of truss, the balance of this article will focus on pin-connected trusses.

Profile Options

Pin-connected open-web trusses come in a variety of profiles and chord configurations allowing for unique designs. Although the trusses are industrial grade and come with cosmetic imperfections, some designers elect to leave them exposed for visual effect. Following is a list of the various open-web truss profiles (*Figure 2*).

Parallel Chord: An economical workhorse ideal for flat roofs and floors.

Tapered: Allows for built-in roof drainage and a dramatic look when designed with a more extreme depth differential.

Pitched and Radius Pitched: Provides varying slopes to create different looks for roofs and ceilings.

Bow String: Offers a radius pitch continuous arc across the top chord while creating a flat interior ceiling at the bottom chord.

Barrel and Compound Barrel: Both the top and bottom chords have radii to provide curved ceilings.

Pitched Top Chord/Radius Bottom Chord: An unusual chord combination that allows curved ceilings with a pitched roofline.

Figure 1. Exposed trusses create visual appeal for the Taylor Middle School cafeteria and public meeting space.

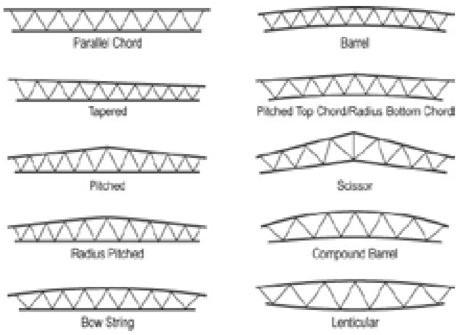

Figure 2. Open-web truss profiles.

Scissor: Ideal for shallow depth trusses with vaulted interiors.

Lenticular: A lens-shaped truss (curved top and bottom).

Design and Engineering Considerations

IBC 2015 Section 2303.4.1.3, "Trusses spanning 60 feet or greater," requires that a registered professional be responsible for the design of both temporary and permanent bracing. Temporary bracing is any non-permanent element used to stabilize the trusses during the construction process. The primary component of permanent bracing is typically the plywood or oriented strand board (OSB) roof diaphragm that laterally braces the top chords of the trusses. Other permanent bracing elements are used for conditions in which the bottom chord is in compression, such as wind uplift or cantilever conditions. Even without compressive forces, the bottom chord should be braced to hold the truss in proper alignment, which is usually perpendicular to the roof deck. Providing adequate temporary bracing enhances safety and prevents truss damage during installation. Permanent bracing helps ensure the truss will support the intended design loads.

Structural Roof Panels

Top chords in compression can buckle laterally if not properly braced. It is recommended that plywood or OSB-rated panels that form the roof diaphragm be fastened directly to the tops of the trusses to provide permanent lateral stability. If the truss top chord is a double-chord member, both top chord members should be independently fastened to the roof diaphragm to prevent lateral buckling. Alternate decking materials may lack adequate top chord buckling restraint. For example, structural insulated panels have large, single fasteners that may fall between truss chords or split the truss chords. Cementitious fiber panels not only use large fasteners but may require structural adhesive to create a bond to brace the truss top chord adequately. Wood tongue-and-groove decking may not provide a diaphragm to brace the trusses unless the boards are fastened together or have structural panels installed over them to create the diaphragm. Metal decking may also lack diaphragm action if not properly designed. A wood cap attached directly to the top chords of the trusses may help address issues of oversized or closely spaced fasteners.

Diaphragm Design with Modular Erection

Modular erection involves a group of trusses that are assembled on the ground with most of the permanent plywood or OSB panels fastened in place to the truss top chords. Also, 2x4 top and bottom chord bridging with cross bracing is installed – typically ten foot on center – to brace the bottom chords. This entire assembled unit, which is very stable relative to a single truss, is referred to as a "truss module".

When trusses are erected in modules, the permanent roof diaphragm will have a continuous edge at eight-foot-on-center (based on standard panel dimensions). The engineer must take this panel layup into account when designing the diaphragm. Most long-span open-web trusses have double chords, meaning the top chord consists of two separate members (usually 2x6 members), connected with pins and lock washers at truss panel points. It is common for the manufacturer to factory install a plywood cap on the trusses to transfer shear across the joint. Diaphragm nails should be long enough to penetrate through the plywood cap and into the truss chord. IBC 2015 section 2306.2 on wood-frame diaphragms references the American Wood Council's *Special Design Provisions for Wind and Seismic* (AWC SDPWS). The AWC SDPWS provides diaphragm assembly Tables 4.2A, 4.2B, and 4.2C, in which nailed diaphragms can be used to determine allowable diaphragm shear. When using these tables and designing with double-chord open-web trusses, a nominal framing width of three inches should be employed when determining allowable shear. The engineer should review the truss manufacturer's allowable nail spacing into the truss chord to verify the closest allowable on-center spacing is not exceeded.

Loading

The structural engineer's drawings should provide all design loads, along with load duration factors and/or required load combinations. Following are some examples:

- Snow loads, including any snow drifting or non-snow live loads
- Uniform design dead loads for top and bottom chords
- Any wind or seismic lateral loads
- Wind uplift loads
- Other loads, including those for mechanical units or loads suspended from the trusses

Engineers must also address other loads, such as sprinkler mains, which often are not known until after contract drawings are completed.

Connections

Open-web trusses typically include factory-installed bearing hardware. The engineer should work with the manufacturer to verify gravity, uplift and lateral capacities during the design process and confirm if the engineer or the manufacturer is responsible for the design of any given connection. Usually, if the hardware is factory-installed on the truss, the truss manufacturer assumes design responsibility for the connection, but only if the engineer specifies the design loads. Be aware some truss hardware may only be designed for gravity or uplift load conditions. Additional hardware from another manufacturer may be required to resist lateral loads. Wall anchors and straps specifically designed for use with open-web trusses are available. It is important to choose an anchor or strap that has fasteners compatible with the truss chords and bearing hardware. It is up to the engineer to specify the correct model.

Bearings

Specifications for truss bearing hardware required bearing lengths, allowable field tolerance, slope bearing requirements, and minimum chord cut-off lengths all vary based on the truss series and the specific design application. The engineer should address all of these requirements during the design process to ensure that there are no installation issues related to the bearing details.

Deflection

Long-span trusses can experience significant vertical deflection when loaded. It is advisable for the engineer of record to review the design deflections and specify the truss camber for long spans. The following situations are examples of when camber and deflection should be evaluated:

- Trusses located next to fixed elements such as walls
- Deflection limits related to suspended/movable partition walls
- Gap requirements over non-bearing partition walls
- Top-of-wall bracing details

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- Long-term creep and short-term creep that can vary depending on truss chord moisture content and construction loads
- Roof designs with potential for ponding

With scissor profile trusses, limiting horizontal deflection should also be considered.

Truss Length

Truss design length may exceed what the manufacturer can build or ship to a given area. Trusses can sometimes be manufactured in two sections and assembled in the field using special connections where the sections meet.

Although they are designed much the same way as any standard length open-web truss, long-span trusses present some additional considerations. It is recommended that the engineer works in close collaboration with the manufacturer during the design process, thus avoiding potential design and installation issues.

Figure 3. Workers are guiding a module of pitched trusses into place.

Open-Web Truss Installation Methods

Due to their long length and narrow chords, steps must be taken during installation to prevent buckling or rolling of the trusses. Open-web trusses less than 70 feet in length are usually installed one truss at a time with the use of strut bracing. Strut bracing is manufactured using light gage steel tubing with flattened ends that include punched nail holes positioned over the truss chords. They are designed to fit common truss spacing such as 16 inches, 24 inches, 32 inches, or 48 inches on-center. The bracing is temporary in that the struts can be removed once the trusses are permanently braced with the diaphragm.

Instability of the truss chords due to the truss self-weight, as well as temporary construction loads, is amplified as the span increases. For spans over 70 feet, modular erection is recommended to avoid material damage, or worse yet, a work-site injury. Some manufacturers contractually require modular erection when spans exceed 70 feet. In addition to improving safety, modular erection can speed up the installation process (*Figure 3*).

When using the modular erection method of stabilizing long-span trusses during installation, the structural engineer should include appropriate information in the contract drawings to let the contractor know modular erection is required. Following is an example of appropriate verbiage: "*The trusses shall be installed in rigid modules at least 8 feet in width, accurately assembled in a jig with final sheathing permanently attached while on the ground. Specified bridging and bracing shall be installed in each module as detailed in the manufacturer's drawings*."

Trusses typically arrive at the job site on a flatbed trailer in banded bundles. When banded, the bundles are relatively stable, but it is still important to have the pick points spaced far enough apart to provide stability (*Figure 4*). Using a single forklift to move long span trusses should be avoided. The truss bundle should be placed on dunnage and all trusses braced in preparation for removing the banding. Once the bands are removed, the trusses can be moved one truss at a time into a prebuilt jig to assemble the truss modules. A crane with nylon rigging straps long enough to widely space the pick points is typically sufficient to move the single trusses into the jig. Jigs should be located on level ground, be designed to support the trusses in multiple locations, and take the truss camber into consideration. The purpose of the jig is to provide a safe way to space and align trusses squarely for attachment

Figure 4. Proper forklift spacing and fork locations ensure trusses are not damaged during handling.

Figure 5. Spreader bar with proper pick locations lifted by a crane. Notice the second module in assembly jig on the ground.

Figure 6. Delivered segments before assembly. Once assembled, they will form a 75-foot-long scissor pitched truss. Note the required steel-tube cross-bracing in the foreground.

Figure 7. The multi-purpose building for Lighthouse Baptist Church includes a second story basketball gymnasium.

of bracing and sheathing while still on the ground. Once the modules are constructed, they will be ready to lift into place in a safe and efficient manner (*Figure 5*).

As with truss design, the design professional can receive assistance from the manufacturer regarding bracing methods.

Examples and Applications

Some common applications for long-span open-web roof trusses are school gymnasiums, church gathering rooms, and light commercial construction – anywhere a big, open room is desired. Trusses can be installed in buildings with wood, concrete or masonry walls, including those located in high seismic zones. While spans can extend over 100 feet, the most common long-span applications range between 60 and 100 feet.

Taylor Middle School

Located in Millbrae, California, the 15,694 square-foot cafeteria of Taylor Middle School not only serves school lunches but is also a venue for graduations, board meetings, community meetings and even basketball and volleyball games. The design team selected a scissor truss system that spans the width of the cafeteria and then left it exposed to create an open feel. The 75-foot-long double-scissor trusses are eight-foot-on-center and meet seismic and other loading requirements (*Figure 6*).

Lighthouse Baptist Church Multi-Purpose Building

While it is typical for a gymnasium to be located on the ground-floor level, not so for Lighthouse Baptist Church, where their only option was to go up. The design and construction team created a first-floor with offices, classrooms, and a sanctuary, and a second-floor that hosts a basketball gymnasium with roll-out bleachers (*Figure 7*), to develop this unique multi-purpose building. The two-story, wood-framed building is 45 feet high and 22,464 square feet in size. Its 89-foot-long, pin-connected open-web trusses are spaced at 48 inches on-center and span the entire gymnasium. Left exposed, they create an attractive, clean-looking roof structure. The team built the entire roof in modules on the ground and then lifted them into place by crane to keep construction simple (*Figure 8*).

Morrell's Electro Plating

Located in Compton, California, Morrell's is a metal finishing provider for the aerospace and military defense industries. Their 80,000-square-foot structure features 62 trusses, each 73 feet long. The clear span of the trusses allows an obstruction-free interior to the warehouse. The truss depths of just 36 inches were required to accommodate building height restrictions of the city. The building includes concrete block walls with wood ledgers that support the trusses. Two hold-downs per truss end were used to anchor the walls laterally to the trusses (*Figure 9*).

Long-span, open-web trusses provide architects with design freedom and engineers with a choice in material selection. The trusses are custom designed, detailed, and manufactured to meet the structural needs and design intent for the specific application. They are economical and provide the added benefit of building with wood, which is considered a green alternative to steel or concrete.▪

References

2015 *International Building Code*. International Code Council (2015). Country Club Hills, Ill: ICC.

Special Design Provisions for Wind and Seismic (2015 Edition). American Wood Council. Leesburg, VA.

Figure 8. Modules of 89-foot-long pitched profile trusses for multi-purpose building hoisted into place by crane.

Figure 9. These single-piece 73-foot-long, top-chord- bearing parallel profile trusses will be installed onto wood-ledgers-connected concrete block walls.