

SHEAR WALL AND DIAPHRAGM TRUSSES

In the field of engineering, a truss is a structural assembly formed by connecting individual framing members together such that the entire assembly is a series of connected triangles.

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When connected into such triangular configurations, the forces induced in the individual framing members (when the truss is loaded) are largely aligned along the member axes. This results in principle stresses within each truss member that are relatively uniform in direction and magnitude at every location within the member. Such uniformity is highly desirable as it translates into an efficient use of framing material. By sizing each truss member so that it is stressed near its maximum allowable limit when the truss is under a design load, the overall truss becomes an extremely efficient structural assembly from a material usage perspective, and thus the economical choice for many applications.

Virtually all wood trusses are planar (2-D) assemblies (as opposed to 3-dimensional space frames) whose individual members are joined with metal connector plates. Within the post-frame building industry, planar trusses are commonly used as roof trusses, girder trusses and mezzanine floor supports. In each of these three cases, the trusses are largely used to transfer vertical components of building loads to posts and other vertical supports.

Another use for planar trusses in post-frame buildings is for transfer of horizontal components of building loads. Two trusses that can serve this purpose are herein referred to as shear wall trusses and diaphragm trusses. Because

of their limited use, and hence unfamiliarity among many practitioners, these two truss applications are the focus of this article.

Shear Wall Trusses

A shear wall is a wall that is designed and constructed to transfer in-plane horizontal forces from one elevation to another. This transfer of lateral force is commonly referred to as shear force transfer or simply as shear transfer, and hence the name shear wall. Wood-framed shear walls are generally formed via the proper attachment of structural sheathing (e.g. wood panels, corrugated steel sheathing) or diagonal bracing to a wood frame. Alternatively, a wood-framed shear wall can be formed by properly attaching a planar truss to wall framing. Any truss used in such a manner is herein defined as a shear wall truss.

Figure 1 shows a shear wall truss in the sidewall of a post-frame dairy freestall barn. As with most shear wall trusses used in post-frame buildings, the truss in figure 1 is a parallel chord truss (a.k.a. flat truss) placed against the inside of exterior girts with its chords attached to adjacent posts. Note that the bottom truss web member has been preservative-treated because of its location near grade. In this case, the shear wall truss was used in place of corrugated steel sheathing so as to enable greater natural airflow through the wall.



Figure 1. Shear wall truss in the end bay of a dairy freestall barn.

The purpose of the shear wall truss in figure 1 is to help transfer lateral forces from the roof diaphragm into the ground. In other words, it keeps the roof diaphragm from shifting parallel-to-the-ridge when wind forces act on endwalls. Because it is used in most buildings to help transfer wind forces, some designers refer to trusses like that in figure 1 as “wind trusses”. However, use of the term “wind truss” does not recognize the fact that the truss helps resist earthquake-induced and other forces that would rack the wall.

Although there are different ways to use diagonal bracing to achieve the same effect as the shear wall truss in figure 1, adequately connecting the diagonal bracing is generally more difficult. Also, unlike most diagonal bracing, a shear wall truss can

be used to quickly lock in post plumb and spacing.

Diaphragm Trusses

A diaphragm truss is herein defined as a parallel chord truss located in the plane of a roof between adjacent rafters or truss top chords (figure 2), or located in the plane of the ceiling between adjacent ceiling joists or truss bottom chords. As its name implies, a diaphragm truss is a truss that functions as a diaphragm, which is to say that it functions as a structural element in the transfer of lateral loads to shear walls. When placed between roof rafters and/or truss top chords in a post-frame building, a diaphragm truss transfers components of wind load (acting normal to the endwall of the building) from the endwall to the sidewalls of the building.

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Figure 2. Portion of a diaphragm truss in an end bay

Figure 3 graphically illustrates the transfer of endwall applied forces by two diaphragm trusses (one on each side of the ridge). Each of these trusses is attached to a rake rafter, to the top chord of the first interior truss, and to the underside of purlins. Use of diaphragm trusses for the transfer of endwall forces is generally only required when (1) a floating roof system is used and attached directly to purlins (i.e. there is no wood panel substrate), and (2) no other diagonal bracing or cabling exists to transfer endwall loads to the sidewalls. Given that a floating roof system (i.e., roof cladding attached directly to purlins with sliding clips) is relatively uncommon on post-frame buildings, the need for diaphragm trusses as permanent structural elements in post-frame buildings is rare.

Most diaphragm trusses are used during construction to establish and maintain a straight endwall, and to keep purlins and trusses from shifting before and during roof panel application

(a practice I first observed in use by Leo Souder of M.P.B. Builders Inc. in Ripon, WI). Using diaphragm trusses to prevent lateral movement of trusses during construction is extremely effective. When installed in the first erected bay of the building, **diaphragm trusses often eliminate the need to add temporary diagonal bracing to purlin rows as remaining trusses and purlins are installed.**

In cases where a roof is clad with wood or metal panels that are through-fastened to purlins (and thus provide significant diaphragm action), diaphragm trusses essentially become redundant structural elements. That said, there are some designers that are not comfortable relying solely on through-fastened panels for diaphragm action, and there are buildings and building environments that can preclude reliance on metal-clad wood

frame diaphragms. In such cases, the inclusion of diaphragm trusses in post-frame building design is an attractive option, especially in wider and taller buildings where (1) the total wind force acting on an endwall can be large, (2) maintaining a straight endwall becomes more difficult, and (3) the need for substantial lateral truss bracing during erection becomes increasingly critical.

A diaphragm truss located in the plane of a ceiling can be more effective, and is often less expensive in endwall-to-sidewall load transfer than diaphragm trusses located in a roof plane. Another structural reason for locating a diaphragm truss in a ceiling plane is to resist forces induced by installation of flexible/fabric ceilings that are held in place by tensioning polyester strapping between endwalls (e.g. polyethylene Tri-Ply ceilings).

Finally, while it is common to place diaphragm trusses in both end bays of a building to maintain straight endwalls, there may be applications where locating diaphragm trusses in one or

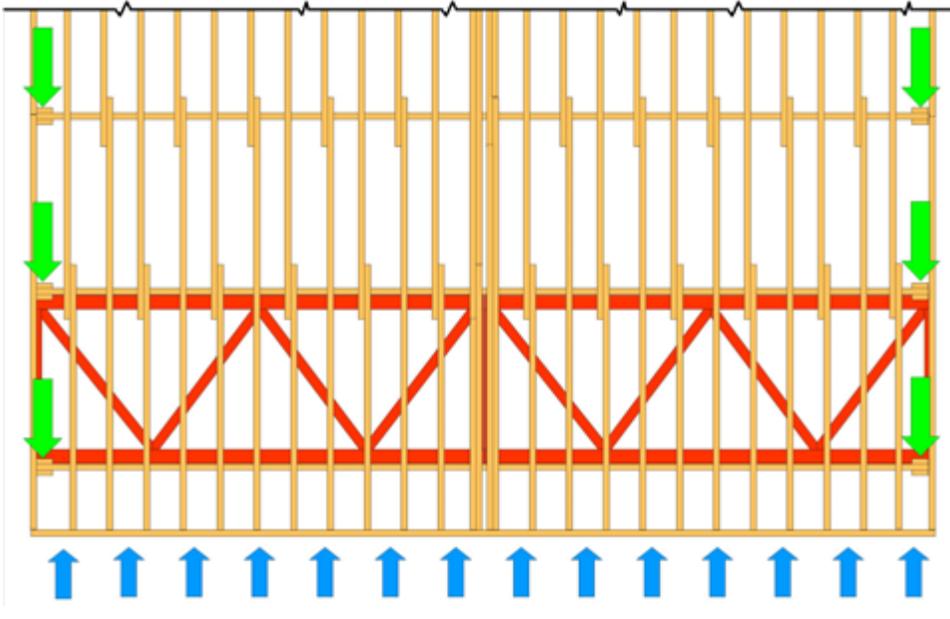


Figure 3. Diaphragm action provided by diaphragm trusses (in red) located between roof rafters/truss top chords but in contact with purlins-on-edge. Wind forces (blue arrows) are transferred to sidewalls by the diaphragm trusses, where they are ultimately resisted by post anchors and/or soil pushing against embedded posts (green arrows).

more interior bays may be needed or desirable (1) from a permanent bracing perspective, and (2) when using diaphragm trusses to replace temporary diagonal bracing during roof truss erection. Some factors affecting this need include overall building length, overall building width, bay width, magnitude of design loads, location of shear walls that can transfer load from diaphragm trusses, connections between purlins and roof trusses, diaphragm truss connections, and diaphragm truss characteristics.

Structural Engineering Criteria

At present, there are no specific engineering standard(s) or other documents covering the incorporation of shear wall trusses and diaphragm trusses into post-frame buildings. This leaves structural modeling and other major design-related decisions to the engineer-of-record.

In the absence of standard procedures, engineers typically err on the conservative side of design. With respect to a shear wall truss, a conservative design begins with the assumption that the truss alone transfers (from eave to grade) the entire shear load to which that portion of the wall is subjected. In other words, when sizing shear wall truss components,

it is assumed that the posts (to which the truss will be attached) do not transfer shear, but do help prevent truss chord buckling. To determine shear wall truss component forces, model the truss as an independent component, with the shear force applied along the top of the truss, and the bottom/base of each chord pinned to a support. Each resulting support reaction is equivalent to the minimum total force that must be transferred from the truss chord into the

post. Continual transfer of this total force is obtained by evenly spacing chord-to-post connections along the entire post-chord interface. In the end, this continual load transfer results in forces in truss components that are less than those used to size the truss components – hence a conservative design.

Diaphragm truss design varies slightly depending on whether a single diaphragm truss or multiple diaphragm trusses are located in the same bay between sidewalls. Multiple trusses require engineering of the on-site connections used to join the chords of adjacent trusses. Multiple trusses are required when there is an abrupt change in roof slope (as shown in figure 3) or ceiling slope, or when the distance to be spanned between sidewalls is sufficiently large to necessitate the on-site connection of a series of individual trusses to form a single assembly.

For a conservative design, model diaphragm trusses as if they alone transfer all endwall loads to the sidewalls, and then size individual truss components accordingly.

The most efficient way to transfer load from a diaphragm truss into a sidewall is to connect the entire edge of the diaphragm truss

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directly to (1) the framing member to which the top edge of structural wall sheathing is fastened, or if used, (2) the top of a shear wall truss.

Clearly specify (on contract documents) structural connection details between (1) diaphragm trusses and shear walls, (2) multiple diaphragm trusses in the same building bay, (3) shear wall trusses and posts, and (4) shear wall trusses and roof framing. Engineering details of other connections may also be required. This would include connections between diaphragm truss chords and the ledgers, rafters, joists and/or trusses that are

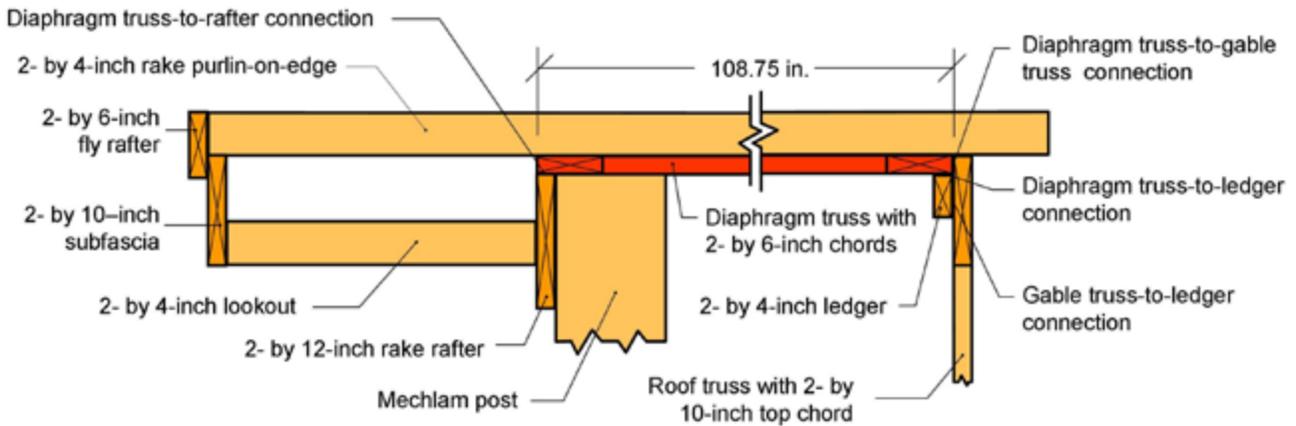
used to reduce the buckling potential of the chords.

Web members in shear wall and diaphragm trusses are relatively long, and when fabricated from 2-by lumber, will generally require out-of-truss-plane support to prevent buckling. Depending upon their orientation and spacing, purlins and girts can provide some of this support. Alternatively, thicker lumber can be used in truss fabrication, webs can be L- or T-braced, or 2-ply trusses could be used.

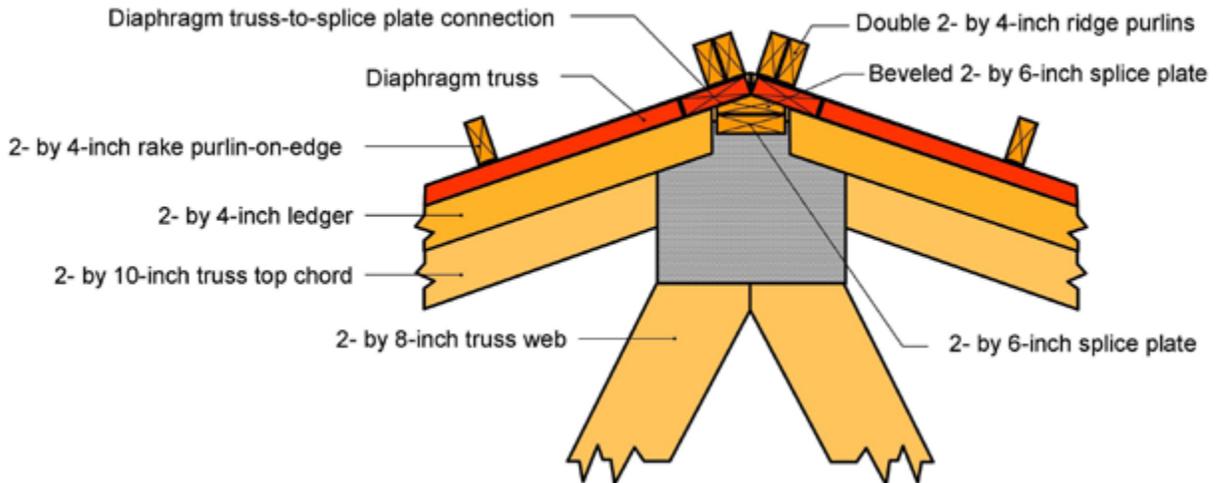
Installation

One of the major benefits of shear wall trusses

Parallel-to-Ridge Cross-Section Thru Diaphragm Truss



Perpendicular-to-Ridge Cross-Section Thru Diaphragm Trusses



Cross-sections through diaphragm trusses (red elements) shown in figures 2, 5 and 6. Lumber sizes are nominal.

and diaphragm trusses is the structural stability, and ease of component plumbing and alignment they provide prior to cladding attachment. For this reason, it's generally beneficial to install them as early as possible in the framing process, as they can speed and improve the quality of overall construction.

Installation of shear wall trusses is a fairly quick process since they are relatively short (truss length does not exceed wall height) and they can generally be positioned from the ground without powered lifting equipment. They are typically positioned between posts and in contact with exterior girts.

Diaphragm trusses are commonly placed in contact with the underside of purlins as shown in figure 4 – a position that enables on-edge purlins to provide critical buckling support for diaphragm truss web members. In this case, the diaphragm truss is attached to the top of the rake rafter and to a nominal 2-by-4-inch ledger attached to the side of the interior truss.

Like regular roof trusses, the length and out-of-plane flexibility of diaphragm trusses requires special handling during installation to prevent damage to plated joints. Because they must be oriented horizontally, it is imperative that diaphragm trusses be strapped at multiple locations to a stiffback, spreader bar, or strongback prior to being lifted for placement.

The simplest, and most direct method for diaphragm truss installation is to (1) complete endwall framing, (2) set the first interior truss and then temporarily brace it to the endwall, (3) use a telehandler to set the diaphragm truss into its final position, and then (4) complete all connections between the diaphragm truss and the endwall and interior truss.

When roof framing for an individual bay is assembled on the ground and lifted into place (figure 5) a diaphragm truss makes it easy to square the assembly and also provides tremendous rigidity to the overall assembly. This construction option generally requires an on-site crane.

A third diaphragm truss installation option (and one I have used and prefer) is to attach purlins along with as much rake overhang structure as



Figure 5. Ground assembly of a bay of roof framing that includes two diaphragm trusses (one on each side of the ridge).

possible to the diaphragm truss prior to lifting it in place (figure 6). This approach significantly reduces working at height, and placement of the assembly can generally be managed with a telehandler.



Figure 6. Diaphragm truss with attached purlins and rake overhang framing. Shown in an up-side-down position just prior placement.

Summary

Shear wall and diaphragm trusses provide a very efficient means for transferring horizontal components of building forces from their point of application to the building's foundation. In addition to this horizontal load-transfer role, diaphragm trusses also serve to maintain a straight eave line during construction, and reduce the amount of temporary diagonal bracing required in the roof plane during truss placement. Engineering of both shear wall trusses and diaphragm trusses is relatively straight forward, with proper use highly dependent on properly engineered and installed connections.

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