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Knowledge is Power

"Commentary for Our TTB 'Always Diagonally Brace for Safety'" by Kirk Grundahl

As with any problem, there are usually two ways of looking at it:

Positively. This approach manifests itself in seeing the wide array of opportunities that present themselves with respect to existing problems. The positive approach allows one to seek and find industry-wide benefits that may exist because one was willing to part with "tradition."

Negatively. This approach manifests itself by bringing to the surface all of the things that are bad about both the problem and the possible solution(s). The normal outcome of this approach is intended to maintain the status quo, resist any change and to stop any progress dead in its tracks.

WTCA's Truss Technology in Building (TTB) series of publications are produced out of a recognition of a need for change. The purpose of these documents it to wrap technical solutions around market needs. One example of the technical work done at WTCA is the new TTB on temporary bracing that emphasizes the need to Always Diagonally Brace for Safety.

This TTB was created with the following in mind:

- The goal of the title of the document, "Always Diagonally Brace for Safety," is to place an emphasis on diagonal bracing so that framers understand the importance of this concept.
- This TTB takes what framers are actually doing in the field and provides them with a way to properly brace the trusses so that the jobsite remains as safe as possible until sheathing is applied to the top chord.

We believe that this TTB utilizes a conservative approach to bracing, especially in light of the fact that there is not a good bracing model available that is calibrated to full scale testing. There will certainly be other methods used in the field that are as safe, if not safer, based on the real life bracing experience of the framer. We also believe that knowledgeable professional framers will do this in the safest and most efficient manner possible. We need to listen to them closely as we make advancements in bracing and bracing technology.

- It is obvious that the key element that absolutely needs to be properly braced is the top chord, since it is the member under the most significant compression stresses during installation loading, and as it is the top chord that generally precipitates a buckling collapse due to insufficient bracing. Hence the emphasis within this TTB is on top chord bracing.

Finally, we show that the use of short pieces for spacing require more diagonal bracing to be safe. A possible outcome is for the reader to conclude that using short pieces is more work and that they instead use longer pieces of lateral bracing (see Option 1 found on page 2 of the Always Diagonally

Brace for Safety document) or sheath with plywood/OSB immediately after four to five trusses are erected. This will obviously be done in increments of four, six and eight feet to accommodate offsetting the sheathing end joints.

The following discussion should be helpful given the bracing methods this TTB embraces:

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- Short piece spacing is shown on this document as this method is frequently used in the field. We understand the risks associated with this, but the point of this TTB is to identify this as a risk that could lead to collapse and minimize it. We differentiate between “lateral braces” and these short pieces by referring to the short pieces as “spacers.”
- There is some question about the use of 26" spacers and their propensity to split. We assume that the 2x4 spacers used in the field are about this long or (hopefully) longer. We further assume that the spacers are marked to facilitate truss spacing, and that the nails may be preset into the spacers at the proper distance and then driven in when the trusses are set in place. This TTB warns of the splitting issue by explicitly stating NOT to use a spacer with splits caused by nailing. The truss manufacturers who distribute this TTB can only warn framers of the danger, they can't require framers to do anything about it. (See INSET #1 below.)

INSET #1 *Out of curiosity, and to provide a small degree of comfort, I drove two 16-d nails into a 2x4 with ½" nail spacing (nails side by side) and ½" edge and end distances, without splitting of the face of the 2x4. This suggests that a 25-½" spacer piece could be used if placed over the trusses so that at least a ½" end and edge distance was provided. Given the assumption of fairly proper placement, it is conceivable that a ¾" to 1" end and edge distance is fairly easy to provide, even with a 25-½" spacer. Provided that a 26" piece is going to be placed roughly symmetrically on the top of the trusses, the minimum end distance one should be able to expect is ¾" and if perfectly symmetrically placed is 1-3/8", so the end distance range is probably ¾" to 1-1/2". It seems reasonable to assume that the prudent use of a 26" spacer can be done without splitting the wood.*

We have also added language that suggests that a 26" piece is the minimum that should be used and that using longer spacers will reduce the potential of splitting.

- Some have said that the 22-1/2" spacer blocks placed between the trusses are not used in the field and therefore, should be removed from this TTB. In response to this comment, please review Photo #2. I have also seen this method promoted in recognized industry periodicals as a good way of bracing and spacing trusses at the same time. The advantage of this method is that you can accurately space trusses and more easily nail through the flat face of the truss into the spacer (usually with a nail gun, today). While this practice has risks, we believe that it would be irresponsible to ignore that fact that this practice is currently used in the field, and, therefore, we believe this method needs to be addressed in our educational publications.

PHOTO #2
CLICK ON IMAGE FOR LARGER VIEW

PHOTO #3
CLICK ON IMAGE FOR LARGER VIEW

The issue here revolves around the fact that nails applied into this type of spacer are in lumber end-grain, and the **NDS** states that end-grain nailing has a design value of zero pounds. (See INSET #2.)

> **INSET #2** *Again, out of curiosity, I applied two 16-d nails through the face of a 2x4 into the end-grain of a perpendicular 2x4. No splitting occurred. I then tried to pull the assembly apart by hand and couldn't do it. Assuming that I can easily apply 75 to 80 pounds of force, the load capacity of this assembly is quite a bit greater than that. So this brings us to the question: Why doesn't NDS allow design values to exist for nails in end-grain when they have value as proven in my simple experiment, by field use and experience?*
>
> *I was not sure of the precise reasons for this, but it can be surmised that the purpose of NDS is not for the design of short-term construction loading conditions that exist during installation processes. Rather, it is for the design of wood members that are going to be involved in carrying loads over a building's lifetime. Given this, there will be creep, shrinkage, loading and unloading, etc., which over time may reduce the value of an end-grain nail to zero.*

To test the hypothesis, I contacted Forest Products Laboratory (FPL) for information on end-grain tests that have been done to have backup for the use of nails in these types of spacers. All evidence suggested that end-grain nailing had strengths much greater than zero. Here is what FPL provided:

The NDS commentary states the following:

"Reduction of withdrawal design values up to 50 percent have been reported for nails driven in end-grain surfaces as compared to side-grain surfaces. When coupled with the effect of seasoning in service after fabrication, such reductions are considered too great for reliable design. It is considered to be on this basis that loading of nails and spikes in withdrawal from end-grain has been prohibited in the specification since the 1944 edition."

The hypothesis is confirmed. The reason that end-grain design values do not exist is due to long-term loading conditions. Fortunately, the installation process we are dealing with does not have long-term loading conditions associated with it. One suspects that the loads applied would be on the nails for less than a week in the vast majority of cases and hopefully it is only a couple of hours before diagonal bracing is applied. Then shortly thereafter sheathing is applied.

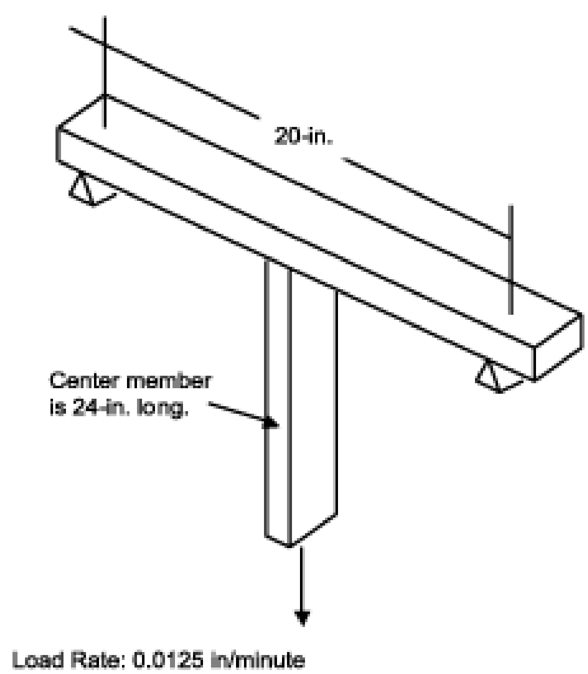
To lend more support to the fact that end-grain nailing can sustain applied loads, FPL supplied us with the following information:

Type of fastening			Nail Characteristics						Joint Characteristics and Performance#						
											Load at slip of			Maximum Joint	
	Nail Size	Number of Nails	Length (in.)	Diameter of shank (in.)	Diameter of head (in.)	Depth of Penetration (in.)	Angle bet. nail & stud	Distance from end of stud	Specific Gravity *	Moisture Content	0.1-inch (lb)	0.015-inch (lb)	0.10-inch (lb)	Load (lb)	Slip (in.)
Assembled and Tested Green															
Toe Nailing	8	4	2.5	0.131	0.28125	1.625	30	0.75	0.379	33.2	369	435	507	508	0.103
	10	4	3	0.148	0.3125	1.75	30	1	0.382	30.6	454	526	745	795	0.192
	16	4	3.5	0.162	0.34375	1.8125	30	1.5	0.423	33.6	675	787	997	1032	0.189
End Nailing	10	2	3	0.146	0.3125	1.375			0.39	34.1	206			224	0.011
	16	2	3.5	0.162	0.34375	1.875			0.378	30.9	323			346	0.011
	20	2	4	0.192	0.40625	2.375			0.411	35.2	551			593	0.014
Assembled and Tested Dry															
Toe Nailing	8	4	2.5	0.131	0.28125	1.625	30	0.75	0.426	10.1	331	365	439	452	0.148
	10	4	3	0.148	0.3125	1.75	30	1	0.404	10	597	665	792	816	0.11
	16	4	3.5	0.162	0.34375	1.8125	30	1.5	0.451	10	542	584	793	871	0.203
End Nailing	10	2	3	0.146	0.3125	1.375			0.417	9.9	283			310	0.019
	16	2	3.5	0.162	0.34375	1.875			0.43	8.7	186			211	0.013
	20	2	4	0.192	0.40625	2.375			0.439	9.3	465	499		518	0.024

Average of Three Tests
* Specific Gravity is based on oven dry weight and volume at test
Data from Scholten and Heyer 1949 unpublished report. Tension/ Withdrawal Tests only.

Scholten, J.A. and Molander, E.G. (1950) "Strength of Nailed Joints in Frame Walls." Agricultural Engineering, Vol31(11):551-555.

CHART 1
CLICK ON IMAGE FOR LARGER VIEW



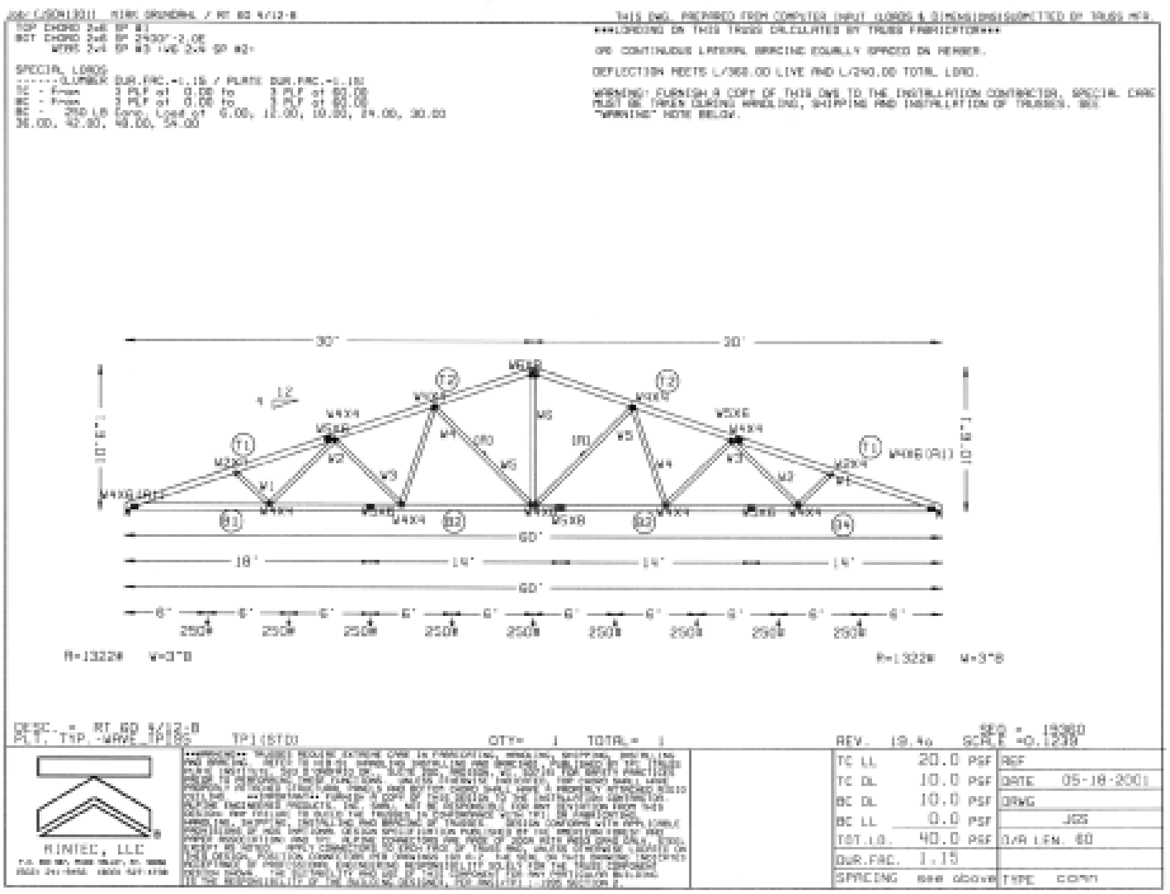
TESTING SET-UP FOR END-GRAIN & TOE-NAILING TESTS
CLICK ON IMAGE FOR LARGER VIEW

End-grain nails do have reasonable capacity, in both green and dry conditions, under short-term loading.

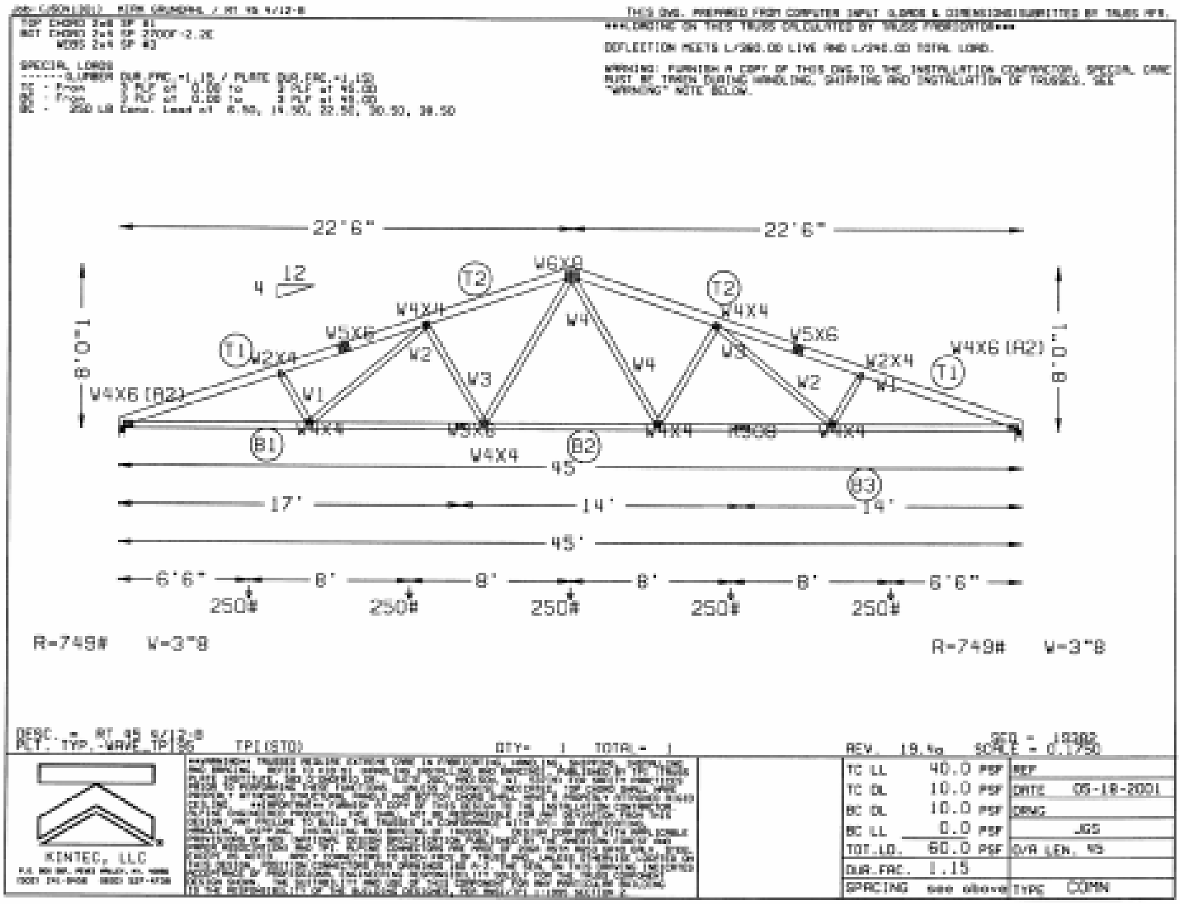
The Always Diagonally Brace for Safety TTB delineates spacing requirements for lateral rows of bracing/spacers of 6' for 45'- 60' trusses; 8' for 30' - 45' trusses; and 10' for spans up to 30'. This is a simplified approach (which we hope will facilitate use in the field) to lateral bracing/spacing. By using this method, framers will only have to remember three numbers to properly brace the top chords of roof systems.

Does This Approach Make Sense?

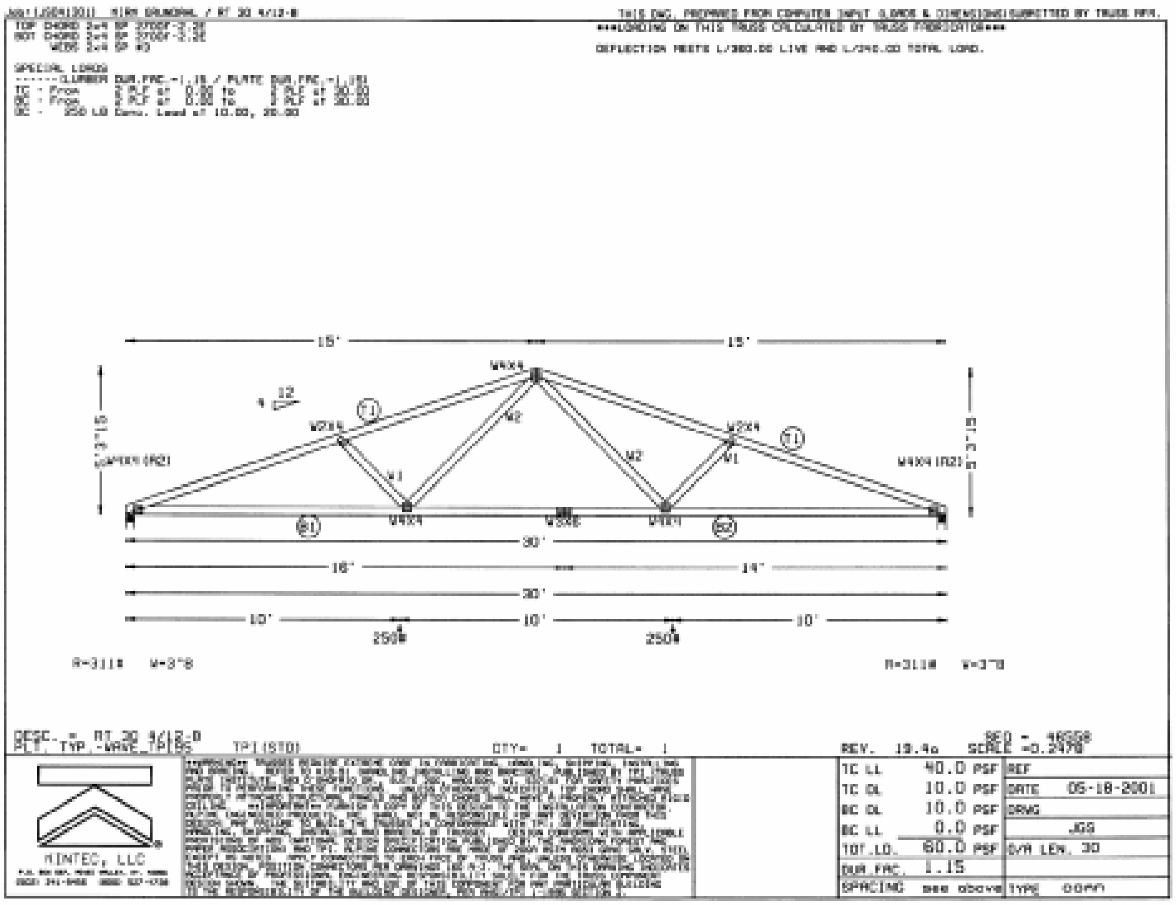
To answer this question I had these three truss designs created by one of our member manufacturers.



TRUSS DRAWING #1: 60'
CLICK ON IMAGE FOR LARGER VIEW



TRUSS DRAWING #2: 45'
CLICK ON IMAGE FOR LARGER VIEW



TRUSS DRAWING #3: 30'
CLICK ON IMAGE FOR LARGER VIEW

- 60', 45' and 30' trusses were designed for the loading condition of 40 psf TCLL, 10 psf TCDL and 10 psf BCDL and optimized. This gave me a baseline set of trusses to use that would be typical of a common loading condition that would cover the vast majority of trusses throughout the U.S.

We found the dead weight of the truss and applied that as the top and bottom chord dead loads and added a 250-pound man at each lateral brace location. For the 60' truss this resulted in a loading of 3 plf TCDL and 3 plf BCDL and nine-250-pound loads being applied to the bottom chord. We then took two percent of the maximum axial force in the top chord to determine the amount of lateral force that may be exerted due to any buckling that took place. We used two percent as it is the common rule of thumb. (There is university research that suggests that the two percent rule may be conservative in some cases and liberal in others, so over time we may be able to refine this rule of thumb as well.) All of this resulted in the following:

- For the 60' truss the lateral force perpendicular to the top chord would be 73 pounds, based on the highest axial compression force found along the top chord.
- For the 45' truss the lateral force perpendicular to the top chord would be 40 pounds, based on the highest axial compression force found along the top chord.
- For the 30' truss the lateral force perpendicular to the top chord would be 17 pounds, based on the highest axial compression force found along the top chord.

Since we took the highest axial compression force this is going to be a conservative approach to buckling as this force is in the first panel near the heel of the truss.

Additionally, I hope it is readily apparent that these lateral forces perpendicular to the trusses are very conservative values given the fact that each of the applied 250-pound loads would be about half this amount, as both a man's feet are not going to be on one truss simultaneously. Also, in the case of the 60' and 45' trusses it is likely they will never have nine and five people, respectively, on the truss at one time. For the 30' truss it is reasonable to assume that there will be the potential of two people standing on the truss at one time.

Finally, if one assumes that the lateral force perpendicular to the top chord is twice the two percent rule due to S-buckling of the top chord of the truss, and that one would apply this perpendicular force to each sloping surface of the truss, the worst case total lateral load is 292 pounds (four multiplied by 73 pounds) for the 60' truss.

Two 16-penny nails provide 176 pounds lateral resistance for SPF lumber with no stress increases. For the 60' trusses there are 38 nails in lateral resistance for Option 2A (see Option 2A found on page 3 of the Always Diagonally Brace for Safety document) which would yield a resistance of 3,344 pounds. For the five trusses erected prior to the diagonal bracing being applied, the lateral resistance provided to the first truss would be 18 nails. This truss provides a lateral resistance of 1,584 pounds. This is all at NDS allowable design loads and does not encroach on the nail factor of safety at all. Clearly 1,584 pounds of resistance is much greater than 292 pounds of possible buckling force.

This is also under the assumption that buckling of the truss has already begun, which is a significant assumption. To illustrate this point, remember that many of the trusses that are erected in this country do not buckle at all. This has to suggest that truss buckling is not the immediate reaction of a truss as it is installed on a building.

Even if one accumulates the 292 pounds of buckling force over the five trusses that are being set, the total load of 1,460 pounds does not exceed the 1,584 pounds of lateral resistance capacity of the originally set truss with the 18 nails in it. If the lateral resistance is the accumulation of all 18 nails in the five trusses, then the load capacity of the entire five-truss set is 7,920 pounds of lateral resistance. This is far in excess of the 1,460 pounds of buckling force. From this analysis, the capacity of the lateral spacers in TTB option 2a is sufficient to carry the loads and keep the trusses upright until the diagonal bracing is applied to stabilize the system. It should also be clear the ultimate strength capacity of the 18 nails is far in excess of the 7,920 pounds of design capacity, so a significant factor of safety is still available.

For Option 2B (see Option 2B found on page 3 of the Always Diagonally Brace for Safety document) let's assume that the design load for nails in end-grain withdrawal are 50 percent of the withdrawal values listed in the NDS. This would result in an end-grain withdrawal resistance of 21 pounds per nail for SPF. (As we have seen above the capacity of end-grain nailing with a factor of safety of three would be 70 pounds under the worst case scenario.) For the 60' truss that has inset spacers and diagonal bracing, the total lateral resistance can be estimated to be 798 pounds (38 nails multiplied by 21 pounds). For the end spacers alone, the lateral resistance would be 378 pounds (18 nails multiplied by 21 pounds). Both exceed the 292 pounds of force. If one accumulates the loads as above for the five-truss set, the result is 1,890 pounds of capacity having to resist the conservative buckling forces of 1,460 pounds. The ultimate capacity of the all nails in end-grain, given the test data, above is 18,990 pounds. This means we are still quite conservative, as the conservative truss buckling forces are not close to approaching the ultimate capacity of the nails. Once the diagonals are in place, the system will be stable.

Clearly there is little more risk in setting up the five trusses prior to installing the diagonal bracing under Option 2B given the lower capacity of the nails. However, we have again been very conservative.

It does appear that, if the first truss is adequately braced and nailed as shown in our TTB, that there is sufficient capacity of the nails to resist the lateral buckling forces for each of the first five trusses set. Once the diagonal braces are in place, the trusses will provide rigid support for the next five trusses to be set.

This entire analysis is conservative for the following reasons:

- The applied concentrated loads will not likely be of the magnitude or number that we have assumed for the purposes of this analysis.
- The nail design values that we used are far below their ultimate strength so there is reserve nail capacity in this analysis to accommodate imperfect field conditions.
- The loads applied to the nails are for very short-term loads.
- We believe that the buckling loads we have proposed that must be resisted are conservative. One could make the case that the top chord buckling that needs to be resisted is one directional and that each sloping surface of the top chord would only have to resist 73 pounds of force.
- All of this assumes that the truss sees loads and support conditions that will prompt buckling. We are fairly certain that, with all the trusses erected in this country, if trusses were predisposed to buckling during all installations, there would be a far greater frequency of buckling failures than are actually seen today.

Doing the same analysis for the 45' and the 30' truss and using 10-d and 12-d nails (2 nails = 158 lbs. for both nail types and carry more load in end-grain nailing than 16-d nails do, as defined in this analysis) results in the ability to carry all the lateral loads for all TTB options, with no risk of exceeding ultimate capacities.

Why did we select five trusses to be set first prior to placing the diagonal bracing?

- If the spacing is used properly and the diagonals are placed as shown, the triangulation measures between 38 degrees (10' lateral spacing) and 52 degrees (6' lateral spacing). A diagonal brace that is 12' (6' lateral spacing) to 14' (10' lateral spacing) long can be easily used and is easily available.
- Our desire is to facilitate installation speed. Using reasonable length 2x4's for the diagonal bracing, having an angle of application that was close to 45 degrees and practicality were all factors in the decision on this spacing.

One of the activities that I get involved with fairly frequently is defending truss plants after a collapse. This TTB was developed with this experience in mind. I do not think any of us in the truss industry likes to see collapses due to the lack of bracing or the injuries that can occur from this. It is our hope that the educational materials produced by WTCA will reduce these accidents and the bracing failure litigation that accompanies them.

We appreciate all the positive comments about the need for this brochure in the field and the fact that it is critical to have an industry organization in touch with field realities—one capable of utilizing engineering and principles of safety to overlay on field realities. This sentiment really energizes us to undertake more of this type of work.

SBC HOME PAGE

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