Shear-out at High Tension Connections: "Chunk-out" Re-examined

by Steve Cramer, Kirk Grundahl & Dave Brakeman

Curious about the technicalities behind "chunk-out" checks in design software? Find out what it is meant to prevent and plans for future testing.

at a glance

- A new design check, initially termed "chunk-out," appeared in the truss design process with the adoption of TPI 1-2002.
- The appropriate technical term for chunk-out is actually "shear-out."
- Understanding shear-out requires defining the stress distribution around the plate and comparing the magnitude of stresses to the wood shear strength under the plate.
- Future finite element stress analysis and testing has been planned in order to define the nominal stresses associated with the shear-out condition.

In the May 2005 issue of ***SBC,*** Rachel Smith first reported on "chunk-out" messages that truss technicians were getting when designing trusses to ANSI/TPI 1-2002. Smith explained that a new provision in Section 8.9.2 of the standard applies to trusses with plating on the narrow face of lumber, like floor trusses. The chunk-out provision programmed into design software was meant to address a design mode of failure where high tension forces can tear out the wood at the edge of the teeth along the grain of the wood. The "chunk-out" phenomenon is re-addressed providing TPI TAC and TPI Board approved language along with the needed commentary through this article.

Introduction

With the adoption of TPI 1-2002, a new design check appeared in the truss design process embodied in TPI 8.9.2. "For wood thickness greater than two inches with plates embedded only on the surface normal to the thickness, the tension, T, introduced by a single joint into a wood member, shall not exceed 1600 pounds per inch of wood width,...." Some component manufacturers found long standing truss designs impacted by this provision prompting questions about the basis of the provision. Recently, TPI-TAC approved a new interim guideline:

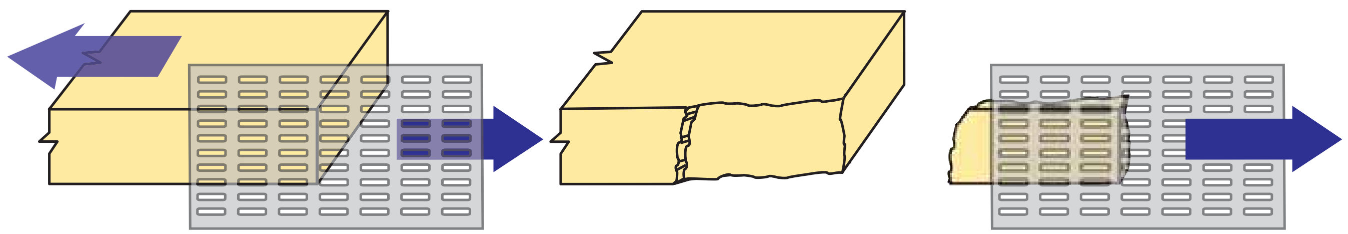
> It is recognized by the metal plate connected wood truss industry that block shear (failing of the lumber beneath the connector plate teeth), is a failure mode that needs to be checked in truss design. The current design value of 1600 lbs/inch was established based on limited information and is considered conservative. Values of up to 3100 lbs/inch have been justified by some in the industry based on engineering experience, full and small scale truss testing and engineering analysis. There are many variables that affect this issue, including the species and grade of the material, and the length of the connector plate involved in the connection. Empirical evidence, field experience and engineering judgment may be used to consider design values significantly higher than the current design value stated in the standard.
>
> Block shear for axial tension members has only been identified as a concern at the ends of a member. The provisions of section 8.9.2 do not apply to joints in the middle of a piece, such as chords that are continuous through a joint.

This allows other limiting values to replace the 1600 pound per inch of wood width when test data or engineering can justify an alternative value. Needless to say, this provision has generated considerable excitement in the technical truss design community and herein we will shed light on the problem and the path to total resolution.

Chunk-out, Shear-out, Shear-plug, Tear-out?

The phenomenon embodied in provision 8.9.2 has caused considerable confusion as to exactly what failure mode or problem the TPI 1-2002 standard is intending to prevent. The appropriate technical term for this problem is shear-out or shear-plug failure. This occurs when a metal connector plate fastened to a high force tension web transfers the forces from the plate to the wood web member. It is this transfer of load and the resulting nonuniform stress distribution that can prompt the wood to shear underneath the plate and with a significant portion of wood remaining embedded in the plate as the joint pulls apart. Figure 1 on page 72 illustrates the subject failure mode. Although there has been no complete test data set nor field experience presented that clearly demonstrates this failure mode and its likelihood of occurrence, some members of the TPI 1 Project Committee and TPI TAC believe that there are circumstances where this failure mode can occur at a load below the tensile strength of the connecting wood member and the plate tooth withdrawal and associated plate values.

Continued on page 72



Shear out failure mode
(plate shown on one side only for simplicity)

Figure 1.

"Chunk-Out" Re-examined

Continued from page 70

The TPI 1 Project Committee and TPI-TAC believe that section 8.9.2 presents a necessary truss design check and in fact recent additions to the National Design Specification for Wood Construction adds analogous design checks for bolted connections. But the corresponding problem in trusses is more complicated because the teeth in the plate don't penetrate the full width of the wood member. Thus, we are faced with a complex stress analysis problem that includes how stresses dissipate from the wood adjacent to the teeth at the surface to the center of the wood member. Whether these stresses will control truss failure depends on the shear strength of the wood as influenced by the grade, the species, potentially even the ring structure of the wood and the occurrence of other high stresses in the truss. In other words, we still have more to learn about when and where a shear-out failure mode check should control truss design.

What Got Us Here?

Ultimately, understanding the shear-out problem requires defining the stress distribution around the plate and comparing the magnitude of stresses to the wood shear strength under the plate. One can then determine the likelihood that these conditions exist in everyday truss design and target design provisions accordingly. Since we cannot "see" stresses nor easily measure them, mechanical load tests provide only an end-result, single-outcome indication of this problem or its absence. If a test produces a shear-out failure, obviously one knows that the stresses exceeded the shear strength for the conditions of that test. Generalizing test results to a wider variety of situations in absence of stress data is merely an engineering art, not an absolute.

Small scale tests formed the original basis for the 1600 lb per inch of width provision currently in the TPI-1-2002 standard but these tests were few in number and did not provide conclusive evidence of the conditions or stresses associated with shear out. Given the outcome of these tests and the conditions examined in the tests, the 1600 pounds per inch of width is considered conservative by TPI TAC.

The shear-out failure mode is most often associated with top chord bearing, parallel chord trusses of considerable span with large plates attaching the first panel 4x2 or larger tension web. Some engineers have reported what they believe to be the shear-out failure mode in truss tests of this configuration but the observations have been few and not well documented. California Truss Company undertook a series of 44 tests in 1986. To date, this is the best and most extensive set of data available on the subject although the tests did not specifically include webs as narrow as 4x2. We are very fortunate that California Truss was willing to share these data, because without it, clarification of ANSI/TPI 1 section 8.9.2 would have been more difficult to make. This testing was conducted on top chord bearing trusses manufactured with Douglas-fir lumber with double 4x2 or single 4x6 chords with 4x4 or 4x6 webs in the first panel. These 44 trusses ranged in span from 31' to 60' and the trusses were tested to failure. None of the 44 truss tests yielded a shear-out failure even though web forces exceeded 2.1 times the 1600 lb per inch width limit (a conversion to take the 1600 lb from a design to an ultimate load basis) in many cases.

By taking the computed tensile force in the web at ultimate load and dividing it by 2.1 and the web width, appropriate comparisons can be made to the original 1600 lbs per inch design load limit. In 18 of the 44 tests, the truss failure load was high enough such that the design value of the first web member in tension was in excess of the section 8.9.2 limit of 1600 lbs per inch. In these cases, section 8.9.2 would have limited the design of the truss causing the web member size to increase to accommodate the web member design forces. In all 18 cases, the truss failed outside of the first panel where the highest web member tension forces existed. The highest web design force in these trusses without a failure was 2285 pounds per inch of web width. These tests provide evidence that tension webs can safely sustain forces well beyond 1600 pounds per inch but only in the conditions associated with these tests. Additionally, none of these tests were designed to prompt failure in the first panel. Conversely, these trusses demonstrate the anecdotal feedback that has been received that suggests that this type of failure is a very rare occurrence.

Current Design Considerations

As noted above, the TPI 1 Project Committee and TPI TAC members believe that there are conditions where the shear-out failure mode should control the design of the truss. TPI TAC has provided the guidance needed to recognize that the current design value of 1600 lbs per inch is to be considered conservative and that by working with your truss design engineer, other design values can and should be used so that we do not limit the truss design process when we know that the truss being designed can safely and effectively carry the applied loads. The section 8.9.2 design limit can be justifiably adjusted up to and potentially beyond 3100 lbs per inch of width based on engineering experience, full and small scale truss testing and engineering analysis. Until additional analysis and data are available to further shape design guidelines, the key to implementation will be to work with your truss design engineer and use the experience that you have with these types of trusses to determine the section 8.9.2 design limit for your truss designs.

One approach to guide selection of the design limit is to apply the species and grade NDS allowable adjusted shear strength times the contact area of the plates on both faces of the connection to yield a computed shear-out design limit. Sometimes the wood shear values will be less than the corresponding plate withdrawal values and therefore will control. Such an approach will yield alternative design limits in the approximate range of 2000 lbs per inch of width to 3600 lbs per inch of width depending on assumptions such as the minimum plate length necessary to prompt the shear out failure mode. One limitation of such a calculation is that it assumes that the shear stress in the wood under the plate is uniform when in fact it is not. Nonetheless, higher values are appropriate for species with higher allowable shear strengths and vice versa.

The typical truss design conditions where the section 8.9.2 limits will come into play include:

- Short span high load top chord bearing floor trusses.
- Heavily loaded commercial floor trusses.
- Purlin trusses in panelized roof systems.

The Path Forward

Finite element stress analysis and testing planned for the future offer a path to define the nominal stresses associated with the shear-out condition. Such an analysis combined with full and small scale verification tests is one of the steps in defining when shear-out plate failure is likely to control truss design and the appropriate limits that should apply. Computing stresses is much easier than attempting to measure them in tests. But testing will also be necessary to affirm computations. Testing of discrete truss situations will provide additional evidence of when the shear-out failure mode should control a given truss design.

There are no known in-service truss failures in the public domain that have been associated with the shear-out failure mode as defined in section 8.9.2. In contrast, there have been lumber shear failures and tooth withdrawal failures even though there are design properties readily available for these failure modes. This is not reassurance by itself that shear-out can be neglected in truss design. Only a relative handful of truss tests have exhibited this failure mode, but it is unclear to what degree these few truss tests represent a wider set of conditions. Better definition of the mode of failure, the truss designs likely to raise shear-out failure concerns, and the percentage of such truss designs in the marketplace will then help define a strategy to deal with this design provision most appropriately. Fortunately, our planned industry testing facility will provide a testing vehicle to help develop the data and design methodology needed to provide our industry with a sound long term solution. This will be one of the testing programs, combined with appropriate stress analysis and small scale tests, we intend to implement in the early stages of the testing program. SBC

Steve Cramer, P.E., is a professor at the University of Wisconsin–Madison; Kirk Grundahl, P.E. is the Executive Director of WTCA; and Dave Brakeman, P.E., S.E., is Vice President - Engineering at Alpine Engineered Products, Inc.

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6300 Enterprise Lane • Suite 200 • Madison, WI 53719
608/310-6706 phone • 608/271-7006 fax
www.sbcmag.info • admgr@sbcmag.info