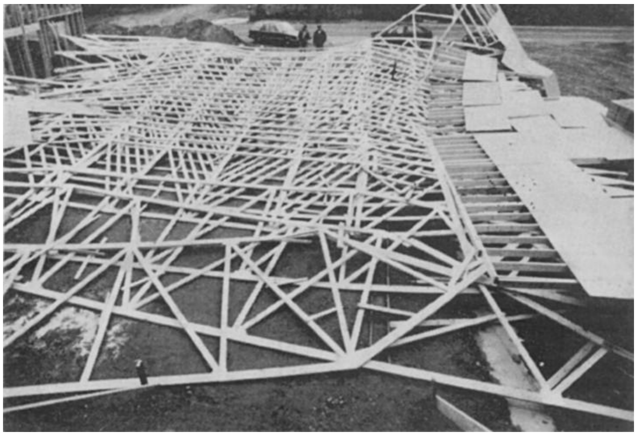
Truss Collapse

Domino-style truss failures can be catastrophic. Good bracing and quality control by the fabricator are essential.

by Raymond A. DiPasquale

The wood truss is a building workhorse. It is economical and efficient, easy to fabricate and erect, and allows clear spans with a minimum of material and weight. Yet roof trusses can fail. Failures are often reported in the Northeast during the winter, when heavy, wet snow loads push roof systems beyond their ultimate capacity.

In addition to overload, other factors can cause a wood-truss system to fail. The case study below illustrates some of these factors.



The Domino Effect

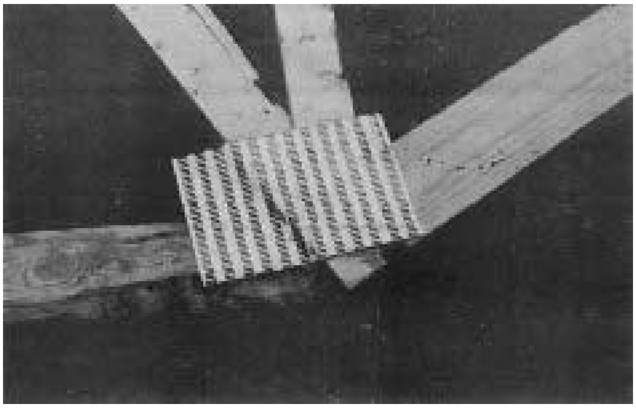
A system of 60-foot-long, clear-span roof trusses collapsed about. an hour after the last truss had been erected, and after the workers had left the site. The trusses involved were the lower sections of two-part, piggyback-type triangular trusses that had a final pitch of 7 in 12. They had been erected with a crane and spreader bar, and were spaced 24 inches on center. The trusses were long and high, with unusual stability problems.

Truss failures of this kind usually have several contributing causes, but only one trigger that sets the system in motion. Since roof sheathing is not yet in place and temporary bracing between elements is only lightly attached, the system cannot resist the momentum of the progressive collapse. Once in motion, the domino effect typically causes complete destruction. An examination of the pieces as they lie is the only reliable way to determine the probable cause.

In this case, it was possible to pinpoint where the collapse had started on the basis of the collapse pattern. The direction and angle of both the horizontal and diagonal temporary bracing between the trusses also influenced the failure pattern. The investigation showed that a specific truss was the trigger. The truss had serious material defects at one end.

A Weak Joint

On the "trigger" truss, there were two knots within inches of the first joint at one end of the lower chord. The knots were about 1 1/2 inches in diameter and about 2 1/2 inches apart. Directly above them, but located in the web member that comes into the same joint, were two more knots of the same size and configuration. The failure appears to have started near these two sets of knots.



In general, knots decrease strength because their grain is at a large angle to the grain of the member, and the grain around them is distorted, When lumber dries and shrinks, checking can occur around knots. The weakening effect of knots is greatest when members are in tension and torsion, rather than in compression. Where shear stresses are present, the knot will reduce strength, primarily because of the diagonal tension that results from the shear.

The stress configuration in wood trusses is anything but precise. At the joint in question, the bottom chord was theoretically in tension, and the diagonal web and the top chord were in compression. But because gusset plates restrain movement at the joint, there were also local bending and shear stresses in the plate and in the members that met there.

In addition, trusses are subjected to all kinds of stresses while being transported and lifted into place. These include stress reversals, torsion, localized stress concentrations, and—invariably—out-of-plane bending. Since trusses are totally unstable in the direction perpendicular to their plane, gussets can loosen during erection. In rare instances the metal itself will yield, but in most cases the wood yields because it is softer. This occurs at the points where the connector lugs are driven into the wood. The connector is thereby loosened and, as was observed in the wreckage in this case, is easily dislodged under slight impact.

This massive failure (left) occurred an hour after the last worker cleared the site. The evidence pointed to a weak joint as the trigger. In general, the trusses suffered from wood defects and badly installed gusset plates (below). Better bracing might have prevented a total collapse.

Bad Bracing or Bad Trusses?

Material defects in prefabricated wood trusses can be traced to the manufacturer. But material defects don't necessarily lead to total failure of the system. If there had been more redundant load paths in the system, the defective member could have failed without taking the rest of the roof with it. Lack of structural redundancy is a particular problem during the early phases of construction. A small glitch at that stage can cause extensive damage.

A more substantial temporary bracing system might have prevented the total collapse of the roof in this case, but the inadequacy of the bracing system was not the primary cause of the failure. There was evidence that the contractor followed many—although not all—of the manufacturer's guidelines for bracing during the installation.

Although inadequate bracing is often the major cause of roof-truss collapse during construction, this investigation turned up several other areas that did not conform to good practice and standard specifications.

Some of the defects noted were:

- Undersized or badly trimmed lumber at highly loaded joints.
- Knots located in gusset-plate area.
- Gusset plates not centered on several joints.
- Gusset-plate lugs not adequately embedded in the lumber.
- Defective lumber. An attempt had been made to repair split lumber with a plate; truss should have been rejected at plant.
- Poor fit of members at truss end and joints.
- Undersized connectors.

In light of the material defect that triggered this failure and the many other deficiencies in the fabrication of the trusses, the truss manufacturer bore the burden for this incident.

Starting Over

Because the truss ends were only nominally anchored to the wood at the time of the failure, the wall had remained intact. The fix was therefore easy. New trusses were fabricated and installed, but in the rebuilding, the contractor followed the recommendations of the Truss Plate Institute (TPI) for bracing the system.

The fabricator supplied the new trusses and the contractor paid for the erection, since there was some question as to whether additional bracing would have confined the failure to a local area. No legal action was taken. ■

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RESOURCES

The booklets *Bracing Wood Trusses: Commentary and Recommendations* and *Handling and Erecting Wood Trusses: Commentary and Recommendations* are available, along with *Quality Standards*, for $3.50 each from the Truss Plate Institute, 583 D'Onofrio Dr., Suite 200, Madison, WI 53719.

Two other booklets, *In-Plant Quality-Control Procedures for Metal-Plate-Connected Wood Trusses* and *Code of Standard Practice*, are available from the Wood Truss Council of America, 111 E. Wacker Dr., Suite 600, Chicago, IL 60601.

TRUSS INSPECTION CHECKLIST

All trusses should be inspected *before* they are erected. Things to look for:

- Use of inferior lumber. Since trusses are generally hidden from view, the fabricator may be tempted to use material with excessive knots or splits, or of a stress grade below that assumed in the design.
- Installation of the gusset plates. These have to be large enough to embrace all members that meet at a joint. They must be centered on the joint so the lugs or nails are fastened to all members in proportion to the forces transferred at the joint.
- Use of warped lumber or inadequately dried lumber. This can result in joint eccentricities or shrinkage distortions, which can produce secondary stresses during service loading.
- Improper joint fit. If individual members are not cut to the correct length, then the truss will be distorted in order to make the connection, or the gap will be too great under the gusset. This also results in eccentricities and secondary stresses.
- Knots in the vicinity of gussets. Such trusses should be rejected.
- Damages during handling, shipment, and erection. Trusses are extremely flexible in the direction perpendicular to the plane of the truss, and can be deformed during shipment on a flatbed. During handling they are often lifted in the weak direction, which puts excessive stress on the joints and members. Consequently, joints can fail before the truss is ever installed. Look for loose lugs or nails, or deformed or bent gussets.
- Repairs made to damaged members. Reject such trusses.

Check out the fabricator and his operation. Since trusses are relatively easy to make, many lumber dealers may be willing to fabricate them, but without having the quality-control procedures that would assure a good product. When a manufacturer is under pressure to fabricate a large order in record time, quality control can suffer.

Specifications for a truss are usually of the performance type, and do not dictate how to make the truss—only that it perform satisfactorily under service conditions. However, the performance specification should also insist that the truss be fabricated under the direction of a licensed design professional. We've always insisted that the shop drawings be sealed by a professional, but having a professional direct the fabrication is something new.

The performance specification should be explicit about the roofing and ceiling materials, and the loads to be applied to both the top and bottom chords. Information is sometimes sketchy, and all the loads anticipated are not delineated. Failures have been caused by such under-design.

The potential for failure can begin during the very early life of a wood truss. Units that do not meet standards should be returned to the fabricator for replacement. Once the truss is incorporated into the job, it is extremely difficult to replace.

Bracing trusses during installation is critical, yet often done in a haphazard manner. Most wood-truss failures during erection are caused by instability—and bracing is what prevents it.

There are guidelines, published by the Truss Plate Institute (TPI), which spell out in detail the recommended procedures for lifting, installing, and bracing wood trusses trusses (see Resources). ■

—*R.A.D.*

Will They Meet the Load?

Wood trusses are designed and made to order. The architect or builder specifies the overall profile and the live loads (generally, snow load). Orders are usually processed by lumber-supply companies and fabricated either by them or by a specialty manufacturer.

Several consulting firms specialize in the analysis and design of wood trusses for the many lumber companies that fabricate them in their own facilities.

The basic structural analysis and design approach assumes that all the joints are pins (free to rotate like a hinge), and that loads are applied only at the joints. The members are then designed as either in pure compression or pure tension. Most of the analysis and design work is done by computer these days, since it is fast and accurate and can handle secondary effects. Computers can produce a graphic diagram of the truss configuration, the size of each member, and notes about the connections.

Even though the typical design approach assumes that each joint in a truss is free to rotate, in actual fabrication the connection is made with a gusset plate, which gives the joint some rigidity. This restraint of movement results in some secondary stresses when the trusses are loaded. Only some of the computer programs account for this in designing the members and joints.

Another assumption—that all loads, whether dead or live loads, are applied at the joints—is also not completely true, since the sheathing is nailed to the top chord, and load is applied continuously along its length. This introduces local bending in the top chord. The same is also true if a ceiling is attached directly to the bottom chord.

Only the most sophisticated computer programs fully consider these secondary stresses, but it is important that the end user, designer, and specifier understand that these loading conditions exist. The conditions could, by themselves, over-stress the trusses and cause a failure. ■