STRAIGHT TALK ABOUT WOOD STRUCTURES

By David Wickersheimer

Field modifications and careless construction are creating structural problems

As a consulting engineer to cities and counties, I have seen the number of structural problems in wood-frame construction grow during the latest building boom (see Figure 1). Many of these problems did not exist a few years ago. These problems are not serious enough to cause failure or collapse. But they do cut into the minimum factors of safety engineers use to establish safe building design. And, they create long-term problems in the durability and service life of buildings. Moreover, they haunt contractors with repeated call-backs and sometimes lawsuits.

Reasons for Structural Problems

One cannot expect contractors to know all there is to know about today's buildings. The construction industry has been changing fast – so fast that builders can no longer say, "We've done it this way for 50 years." Some key changes are:

- Technological innovations have led to introduction of a vast array of products. However, their performance is often not fully understood until tested in the field. Also, contractors sometimes use new products in ways the manufacturer never intended.
- Architects and buyers insist on open spaces, longer spans, cathedral ceilings, large expanses of glass, and openings in two-story walls.

In addition, contractors face a host of day-to-day pressures:

- To stay competitive, contractors must finish buildings on schedule. To head off delays, contractors may use damaged or improperly dimensioned materials instead of returning them to the yard. Bad weather may add another wrinkle to the time pressures.
- Budget constraints force contractors to use less material, and fewer components or fasteners, taking stresses to the limit.

It's not surprising that the number of problems is rising. Poor building practices overstress materials and magnify movement in the structure. They make floors bounce or vibrate, windows crack, doors stick, walls separate from ceilings, and drywall joints open.

Problems With Foundations

Concrete foundations. When foundations are not level or smooth, the mud still does not lay tight against the foundation. Gaps between the top of the concrete and the bottom of the sill are either left open or randomly plugged with dimension-lumber shims (see Figures 1e and 1f). The end result is a spongy, non-level floor, prone to vibration and squeaks. Air infiltration and wind-driven rain can come through this gap. To avoid these problems, you should carefully level the tops of foundation walls.

Field layout. Errors in the layout of foundation walls cause problems with floor trusses. Floor-truss fabricators generally base truss spans on the working drawings rather than on as-built, field-verified wall locations.

So if the foundation measurements are off, the floor trusses will not fit – they will be too long or too short. Top-chord-bearing floor trusses that are too short create a reduced bearing length. They exceed the TPI (Truss late Institute) requirement that limits the distance between the outside edge of the first connector plate and the inside edge of bearing. The distance should be no more than one inch (see Figure 2). I have seen 4 1/2-inch conditions. This violation can produce a bending stress near the rupture level of the top chord.

Trusses that are too long should also not be used. Trusses that are too long cannot be cut to fit without jeopardizing their intended structural behavior. The trusses must be refabricated.

To avoid these problems make sure you field check form locations before pouring concrete, and inform the truss fabricator of any deviations in span requirements.

Problems With Trusses

Floor-truss quality. Too many pressed-metal-plate trusses are fabricated with inferior lumber riddled with large knots that weaken the capacity of connections and/or the members themselves. The ends of members meeting at a joint do not always fit tightly, resulting in visible gaps. Such trusses are not

EXAMPLES OF STRUCTURAL DEFECTS TO AVOID

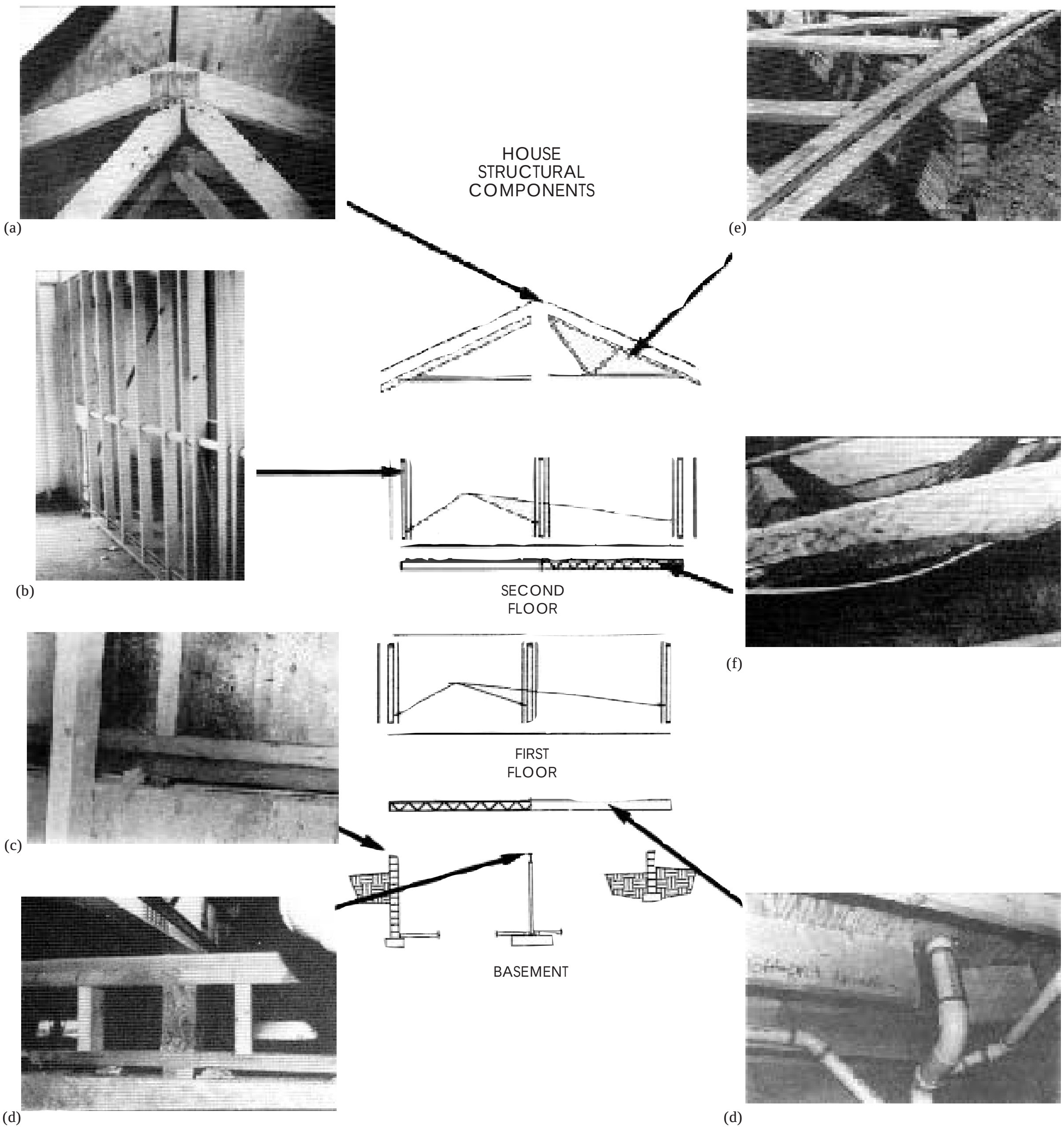


Figure 1. *Structural problems are on the rise due to poor building practices, substandard materials, or field modifications. Defects a through g are all too typical:* (a) *Truss plates have pulled completely out of web members.* (b) *the middle third of load-bearing studs have been drilled. They should not be notched or drilled.* (c) *Shims were placed under the mud sill to fix an out-of-level foundation. As they were crushed, the floor above dropped.* (d) *Crushed beneath the loads of this center girder, these shims should not have been used in the first place.* (e) *Trusses have been damaged by careless handling. Bending pulls plates loose, loosens joints.* (f) *This floor truss is weakened by poor lumber quality (wane) of the bottom member.* (g) *The plumber completely severed this floor joist to get this waste pipe in.*

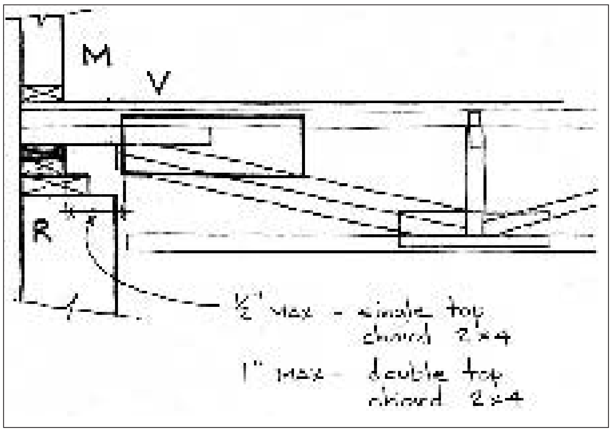


Figure 2. *The arrows point to the edge of the truss plate and the inner edge of the mud sill. For single top-chord trusses, this distance can be no more than _ inch. For double-top-chord trusses, the distance can be no more than 1 inch.*

as strong as those with tight-fitting joints.

Joint problems also occur because the pressed plates are not always laid out accurately across the members at a joint. They mare barely connect to some members (see Figures 1a and 1f).

These problems should be caught by quality control checks at the fabrication plant. If they make it through to your site, reject and return them.

Storage, handling, and erection. Trusses are only intended to carry loads in the plane of their depth, and are very weak and unstable perpendicular to that plane. When storing or handling trusses, workers must remember that trusses are fragile building components. Trusses stored flatwise, on supports that are not level, will bend easily. Bending dislodges the teeth of embedded truss plates. Don't attempt to hammer the plates back into place – the mechanical bond cannot be restored (see Figure 3).

attempts to fix existing conditions requires input from the truss fabricator's engineer.

Truss spacing. All model building codes reference a document called the National Design Specification (NDS), which contains all the information engineers use to design wood buildings.

The NDS permits floor framing members a 15-percent increase in the allowable bending stress if the following criteria are met:

- Three or more parallel members are spaced not more than 24 inches on center.
- The members are attached to a floor or roof plan that can distribute load to the adjoining members.

Engineers generally take advantage of this 15-percent increase for truss and joist design. If trusses or joists are spaced farther apart (such as for mechanical ductwork placement) no increase is allowed. Design engineers

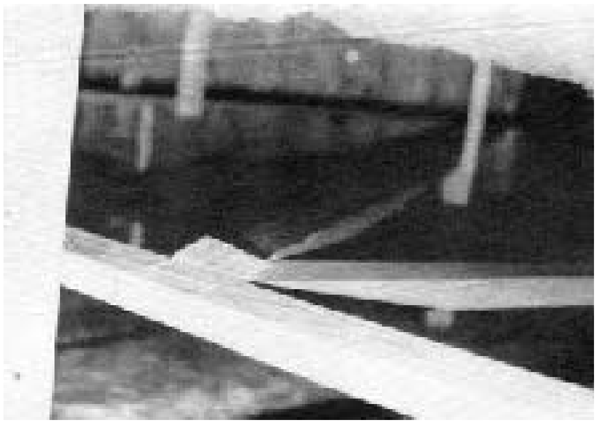


Figure 3. *This truss plate came loose because of improper handling. Damaged trusses should not be repaired in the field.*

Reject and replace any trusses damaged during handling. Never attempt to fix damaged or fractured members of a truss without consulting with the truss fabricator's engineer.

Truss shop-drawings. Floor and roof trusses are generally designed to carry uniformly distributed loads. Whenever a truss will support a concentrated load, such as a 4x4 column, the engineer must design the truss accordingly.

Concentrated loads should bear at a panel point on the truss, not in between panel points. Again, any should be warned, therefore, if such uniform spacing does not, in fact, exist.

Continuous vs. simple-span floor trusses. Trusses have an advantage over dimension lumber. A fabricator can make a floor truss any length the builder requests. The only limitation is transporting the truss to the site. Most often, trusses are shipped the full width of the home. However, some trusses are intended to span continuously over an interior support while others are intended to act as two simple spans resting on an interior bearing wall or girder.

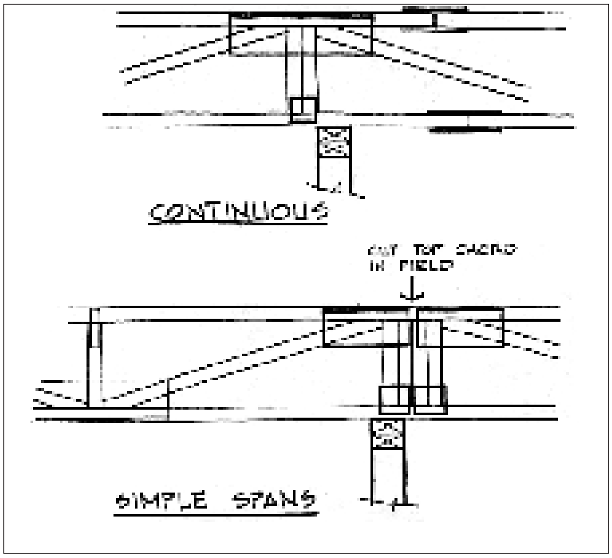


Figure 4. *If a support beneath two simple spans is placed off-center, only the single bottom 2x4 member is carrying the loads from the span. This is not a problem with continuous-span trusses.*

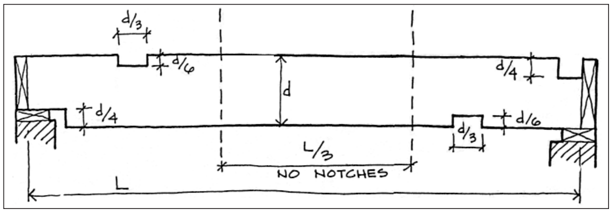


Figure 5. *No notches should be made in the middle third of the joist. Notches should only be as wide or as deep as indicated on the drawing. The depth and width of notches depends on their location: top, bottom, or joist ends.*

For bottom-chord-bearing trusses intended to function as two simple spans, a colored note is usually attached to each truss. The note tells the builder to cut the top chord after the truss has been placed. This cut must be made, or the truss will not function as intended.

Two simple-span trusses joined in the middle, will have a pair of vertical web-members directly above the interior support. These vertical members must be centered over the bearing wall or vertical support beneath them. If the stud wall or girder line is off center, the support is unevenly (eccentrically) loaded.

When two simple spans meet over an off-center girder or wall, the top chord – if directions are followed – is cut. Now only one 2x4 at the bottom carries one span's reaction (see Figure 4). When a continuous truss spans over an off-center wall or girder, both the top and bottom 2x4 chords share in carrying one span's reaction. This most likely will create overstress conditions in bending and shear. The situation is dangerous.

The correct approach is the obvious one. Position the bearing support line on center with the truss verticals, and avoid eccentric loading. Make sure you check this bearing detail during construction so the support line can be adjusted. Don't fix things after the fact without an engineer's input.

Problems With Dimension-Lumber Joists

Joist spacing. I've seen floors where entire lines of nails completely miss the dimension-lumber joists below. This means that the second design criteria mentioned above (that joists be attached to a plane) is no longer satisfied. The 15-percent allowable stress increase is not allowed, and actual stresses may not meet code.

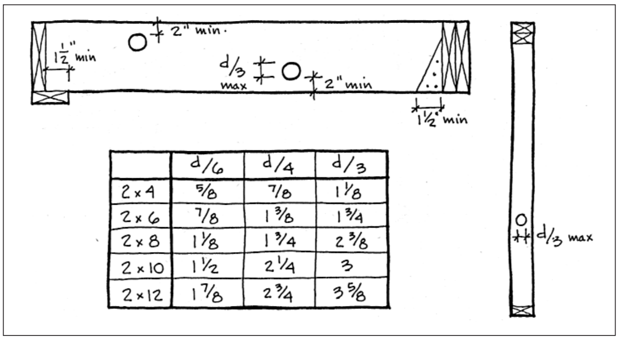
Holes and notches in joists. Problems with holes and notches are familiar to every builder. All building codes outline placement and size of the holes and notches in load-bearing members. The rules are set up to minimize abrupt changes in dimension-lumber cross section.

Notching and drilling affect both strength and deflection. In general, builders must avoid notches within the middle third of girder and joist spans (see Figure 5). The full dimension of the lumber is needed to carry anticipated loads. Notching in the middle third of a span reduces the load-carrying capacity to that of lumber with the shallower cross section.

Holes, on the other hand, can be placed in the middle third of a span if they are no closer than 2 inches from either edge. Structurally, it is best to place the hole the same distance from either edge (see Figure 6). Avoid clustering groups of holes. Spread them out.

Wherever holes or notches occur, concentrations of stress build up. Saw-cut, sharp-cornered rectangular notches magnify stress levels. But you can reduce the stress concentrations by making notches with rounded corners. This is easy if you use a reciprocating saw instead of a circular saw, and if you drill holes at the corners of a notch before sawing. It is even better is the notch can be made wider and shaped like an ellipse. Don't exceed the proportions shown in the illustration, and avoid saw-cut overruns.

Natural holes and notches can occur from wood defects – primarily



	d/6	d/4	d/3
2×4	5/8	7/8	1 1/8
2×6	7/8	1 3/8	1 3/4
2×8	1 1/8	1 3/4	2 3/8
2×10	1 1/2	2 1/4	3
2×12	1 7/8	2 3/4	3 5/8

Figure 6. *Holes can be placed anywhere in a joist, except near the ends and within 2 inches from the edge. No hole should be larger in diameter than the joist size divided by three. Avoid holes in the mid-section of bearing studs.*

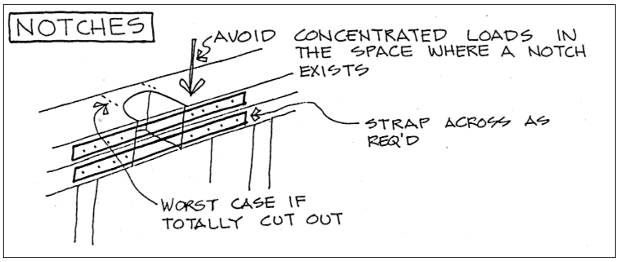


Figure 7. *Strap across notches made by subs. This is especially important where notches go through double top plates.*

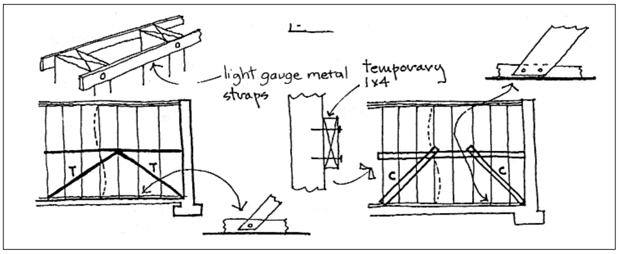


Figure 8. *If center bearing walls are not sheathed, they can be temporarily braced with light-gauge metal straps or 1x4s.*

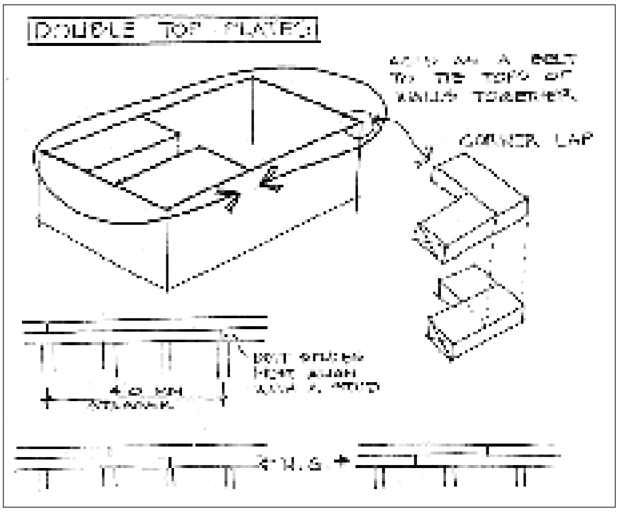


Figure 9. *Staggered joints (4'-0" min.) and lapped corners are needed to tie walls together and to create a strong double-top*

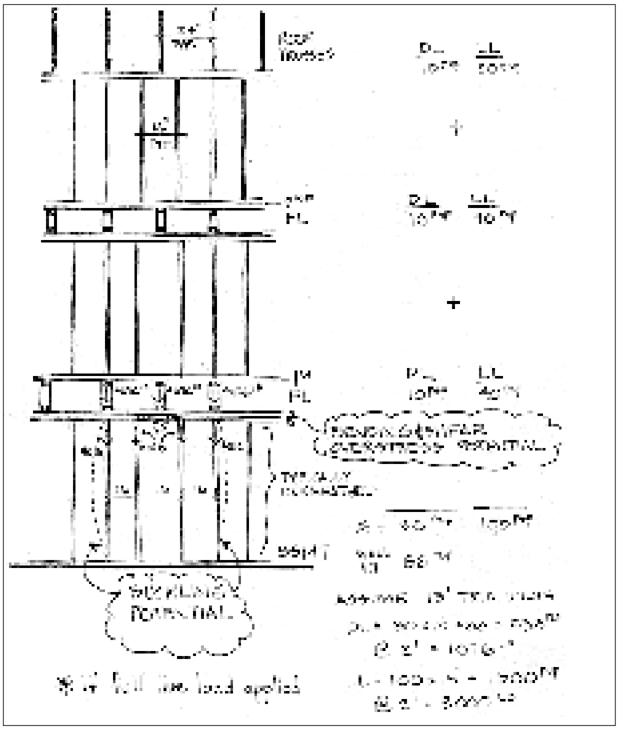


Figure 10. *Trusses fall between studs in every other bay. Concentrated loads cause plates to sag.*

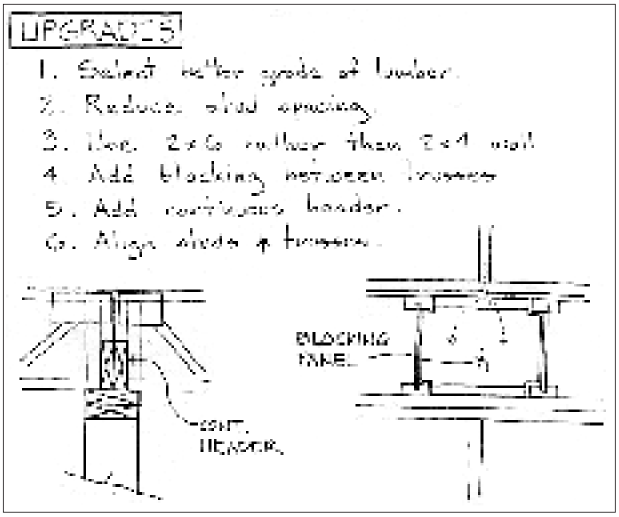


Figure 11. *Whenever concentrated loads occur (between studs over double top plates) the builder may need to add support. Possible fixes are shown.*

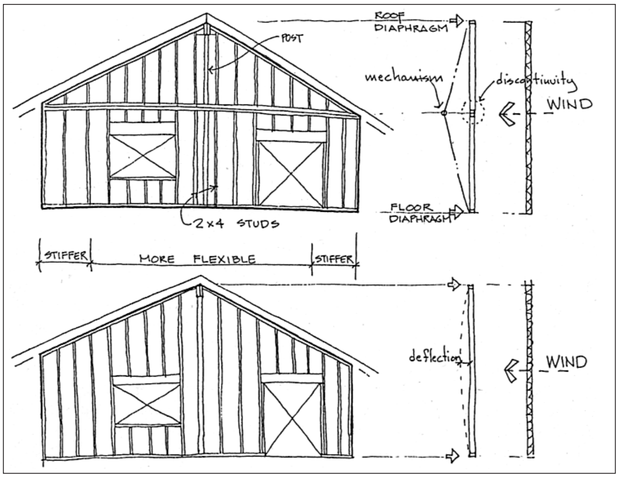


Figure 12. *A platform-framed gable end functions like a hinge when wind strikes it. The balloon-framed end is a much better choice for two-story spaces.*

loose knots, splits, or shakes. Carpenters should watch for such defects and turn the lumber so the defect will be on the compression side (the top, if it is a joist), or find another use for the joist.

Man-made holes and notches are normally made by the mechanical, electrical, and plumbing subs, who often violate the size and location limits set by building codes (see Figure 7).

Educate your subs to help avoid structural damage to the building shell.

Joist and girder bearing. When the bearing area is too small, compression stress perpendicular to the wood's grain can crush wood fibers. I have seen 1-inch wood shims crushed paper-thin under built-up lumber girders (three 2x10s) bearing directly on concrete block piers. A flatwise dimension-lumber bearing plate should be placed between girders and block piers, such as the typical perimeter mud sill.

Even where shims will not be

crushed, they should still not be used to reduce gaps between structural members. For example, don't shim floor joists with slivers of wood, shingles, or beveled siding. Shims will leave you with a squeaky, out-of-level floor. Wood in compression (almost any wood shim) creeps with time, particularly when it is under high levels of stress. Shims, therefore, should be a stiff material that will not creep, such as metal or masonry.

Problems With Walls

Center bearing walls. Builders of large homes or apartment buildings use modern I-section joists with laminated veneer flanges, metal-plated trusses, and vertically laminated veneer beams to span longer distances. These engineered systems generally incorporate two-span continuity, as shown in Figure 5, to help reduce deflection and/or framing depth. However, this shifts more load to the central support.

Center walls or supports are affected by the increased load. Suddenly they must shoulder 25 percent more load than conventional framing. In today's large homes, it is not unusual to have two floors of dead and live load and the roof load bearing down on a central stud wall.

If the basement space is left unfinished, the center wall's bare studs act as individual columns. Columns always buckle about their weakest axis – the $1^{1}/_{2}$-inch dimension. The designer, however, probably assumed that the studs would be sheathed. If sheathed, studs buckle about their strongest axis – the $3^{1}/_{2}$-inch dimension. The strength difference is substantial.

Unsheathed studs in basement center walls can show visible signs of lateral bending even during construction.

Whether the center wall uses 2x4s, 2x6s, or 2x8s, the maximum stud height that can be used (according to code) for unsheathed walls is 6'-3". Obviously, no builder is going to build a center bearing wall with 6'-3" headroom.

The alternatives are to sheathe the wall early in the construction process (with either drywall or plywood) or to install diagonal bracing (see Figure 8, page 25). The wood trussing approach is temporary and can be used until sheathing is installed. Steel straps can remain in place even if sheathing is added later.

Holes in bearing studs. The building codes limit hole sizes through studs to those shown in Figure 6.

Since the cross section of a stud from the lower quarter point to the top quarter point most influences its buckling capacity, holes should be avoided

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in this region. The quarter-span ends are most influenced by compression stress, and are not at risk of buckling.

Violations of these structural requirements occur all the time – especially where plumbing is installed. But these weak structural members can be upgraded with plywood reinforcement or by doubling or tripling the number of studs.

Double top-plate. Any contractor who has ever walked a wall remembers nailing the double top plates. These act as a continuous tie around the top of the walls. To work as they are supposed to, they must be lapped at corners and T-walls (see Figure 9). Also, butt-splices must be staggered at least 4'-0" on center apart. Notches that break the continuity (from heating ducts or vent stacks) must be metal strapped to tie the double plate back together.

The double top plate is even more important in truss construction. The double plate serves as a beam to transfer loads to the studs below. To make sure the double plate acts as a beam, butt splices cannot occur between studs and must be centered on the studs below. To make sure the double plate acts as a beam, butt splices cannot occur between studs and must be centered on the studs below. Since floor trusses are usually spaced at 24 inches on center and studs at 16 inches, every other truss places a concentrated load midway between two studs (see Figure 10). The concentrated loads of a two-story house can cause sagging double top plates – especially if there are poorly placed butt splices.

Where sags occur, the floors directly above will be out-of-level, spongy, and prone to vibration. Possible remedies are shown in Figure 11.

Two-story exterior end walls. Cathedral and two-story spaces create stud walls that are very tall and flexible. When platform framing is used, the

Where the sags occur, the floors directly above will be out-of-level, spongy, and prone to vibration.

wall is unstable. The double top plate at the 8'-0" level acts as a hinge, or pin connection (see Figure 12).

Problems show up on outside walls of platform-framed two-story spaces when wind loads cause the walls to flex. Openings within the wall for windows or doors make the wall even more flexible.

Balloon framing, where studs span continuously from floor to roof, is the best framing method to use.

Quality Control

Even if a wood-frame structure is well designed, ultimately it is the contractor, not the architect or engineer, who contributes most to quality control. Indeed, contractors and their subs are key members of the design team. New materials, open-space building design, and engineered structural systems have made the builder's job more difficult. By knowing the pitfalls of these new systems, the contractor can raise questions with other members of the design team and avoid unwise field modifications. It takes well-informed and conscientious builders to assure the quality of our wood-frame buildings. ■

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