Glue-Laminated Timbers

Designing and building with engineered beams

by Stephen Smulski

Until recently, glue-laminated timbers, or glulams, were used chiefly for commercial and institutional structures. Most people know them as the exposed framework of shopping centers and churches. Home builders generally used steel for long spans and sawn timbers for exposed frames.

But times are changing. Open floor plans remain popular with homeowners, as do exposed beams with long, clear spans. Sawn beams that fit the bill are usually milled from large, old-growth trees, which are becoming scarce and expensive. As a result, more builders are turning to engineered-wood products, including glulams (for a comparison of glulams and competing structural beams, see the table on p. 57). In residential construction, glulams can serve as strong and attractive exposed structural members with long, clear spans. Their uses include arches, headers, girders, ridge beams, joists and rafters (photo above). Not surprisingly, glulam sales are expected to double over the next ten years.

Longer, wider, deeper–Glulams are made in a wide range of sizes, stiffnesses and strengths by face-laminating dimension lumber with structural adhesives. The lamination process yields beams that are longer, wider and deeper than sawn beams, so a glulam uses wood more efficiently than a sawn beam. The wood in a glulam is harvested from second- and third-generation trees, taking some of the pressure off old-growth forests.

The laminations in a glulam beam consist of 6-ft. to 20-ft. lengths of 2x dimension lumber (1x for tightly radiused arches), kiln-dried to an average 12% moisture content. The lumber is end-joined with structural finger joints and a waterproof, synthetic-resin adhesive (melamine, phenol, resorcinol, or phenol-resorcinol-formaldehyde). In the U. S., most glulams are made from Southern yellow pine or Douglas fir, although redwood, Alaska yellow cedar and Western red cedar are also used. In theory, there's no limit to a glulam's size, but like most building materials, they're shipped by truck and rail. This limits lengths to 100 ft. or so (oversized trailers are used to ship glulams longer than 60 ft. over the road).

Almost all glulams are horizontally laminated. Adhesive is spread on one wide face of each lamination; the laminations are then placed in a clamping jig. The adhesive cures at room temperature and develops sufficient strength so that clamps can be removed in 6 hours to 24 hours. The glulam is then set aside for a brief conditioning period during which the adhesive develops full strength.

After conditioning, the glulam is surface-planed and crosscut to length as needed. Tapered glulams and arches are machined to their final shape. Edges are eased, and splits, knots and other surface imperfections are plugged and smoothed to meet appearance-grade requirements. Some manufacturers may bore connector holes and apply end sealers, primers, or surface finishes. Some also supply fasteners, hangers and engineering assistance upon request. Before shipping, glulams are wrapped in kraft paper or a housewrap-rype material that keeps the beam dry, yet lets it breathe. The wrapping also prevents surface marring during storage, transport and erection.

Stiffness and strength–Because the adhesive used in a glulam is stronger than the wood itself, the beam's individual laminations act together as a single unit. Allowable design values for glulams are higher than those for sawn timbers of the same species, depth and board footage (large photo, facing page). This superior performance is engineered into glulams during fabrication in subtle, but effective ways.

Straight glulams, for example, are made with a measured camber, or crown. Beams are installed "crown up" and the crowned face is always clearly marked "TOP." Because the camber is equal to the amount the beam will deflect downward under the structure's dead load, the beam will ultimately lie flat or retain a minimal residual camber.

A glulam's performance is further enhanced by being made from dry wood. Dry wood has higher design values than green wood, but large sawn timbers usually dry in place, where they warp, check, split and release water vapor. This can weaken the timber, raise energy costs and encourage condensation problems in the house during the first heating season. The checking and splitting can be minimized by slowly kiln-drying 6x6 and larger timbers under carefully controlled conditions, but the process is too expensive (70% of the energy that goes into making a piece of dimension lumber is used up in the kiln; the larger the pieces, the more energy the drying process consumes). Because a glulam is made with dry lumber, its potential for warping, checking and moisture release is minimal.

The most crucial part of the engineering process, however, is the grading and sorting of the lumber that will go into a beam. Glulams are engineered like I-beams, which means that strength is built in where it's needed most. In a straight, simply-supported beam, for example, the bottom surface will be stressed in tension and the top surface in compression. Consequently, glulam manufacturers place the highest-quality lumber in the bottom lamination and the next highest-quality in the top (left photo, facing page). Lower-quality lumber goes into the beam's interior. This lets the manufacturer restrict most stiffness- and strength-reducing defects (such as knots and slope of grain) to the least critical parts of the beam.

But while this placement method works for a simply-supported beam, there are situations where it's inappropriate. In a cantilevered or multiple-span beam, for example, both surfaces will be in tension at some point—the bottom will be in tension between the supports, and the top in tension over the supports. So cantilevered and multiple-span glulams must be made with what's known as a balanced layup. These beams use lumber of equivalent design strengths for their top and bottom laminations. (Tension ratings for a stock beam are usually 2,400 psi on the bottom and 1,200 psi on the top; a balanced beam would be rated for 2,400 psi on the top and bottom.) Balanced layups are usually special-order items.

Is all this lumber sorting and placement worth it? You bet. Glulam members with strategically positioned lumber are 10% to 20% stiffer, and up to 100% stronger in bending than those with randomly located lumber.

Sizes and grades—Glulams are produced in three appearance grades—Industrial, Architectural and Premium. Allowable design values for all three grades are identical, but the higher grades have fewer surface defects (knots, checks, splits, wane, planer skips and saw marks).

Preservative-treated glulams are available as a special-order item. They should be used for all exterior applications and for interiors with consistently high relative humidities, such as pool enclosures. When oil-borne preservatives such as creosote or pentachlorophenol are used, the glulam is treated after laminating. With water-borne preservatives like CCA, the individual laminations are treated first, then redried to a 12% moisture content and glued. Otherwise, severe checking would occur as completed members dried after treatment.

Manufacturers can also make glulams with a 1-hour fire-resistance rating. This is done by removing one core lamination from the middle of the beam and adding an extra tension lamination at the bottom. During a fire the extra tension lamination becomes the sacrificial lam. If it's damaged, there will still be other tension laminations to back it up. Even stock glulams have excellent fire-resistance ratings, however; in a fire a glulam will retain its strength significantly longer than a comparable length of exposed steel.

How to buy them—To order a glulam, start with your local building-materials supplier. You may also be able to order what you need directly from a glulam manufacturer (for sources of design information, see the end of this article). You'll have to specify width, depth, length, camber, appearance grade, allowable stress rating and the desired finish. You'll also want to identify any connectors that call for holes to be drilled in the glulam (more on that in a moment). If all that seems like a bit much, most fabricators will provide engineering assistance. Send them a copy of your plans (or give your plans to the retailer if you're working through one), and their engineering staff will figure out what you need.

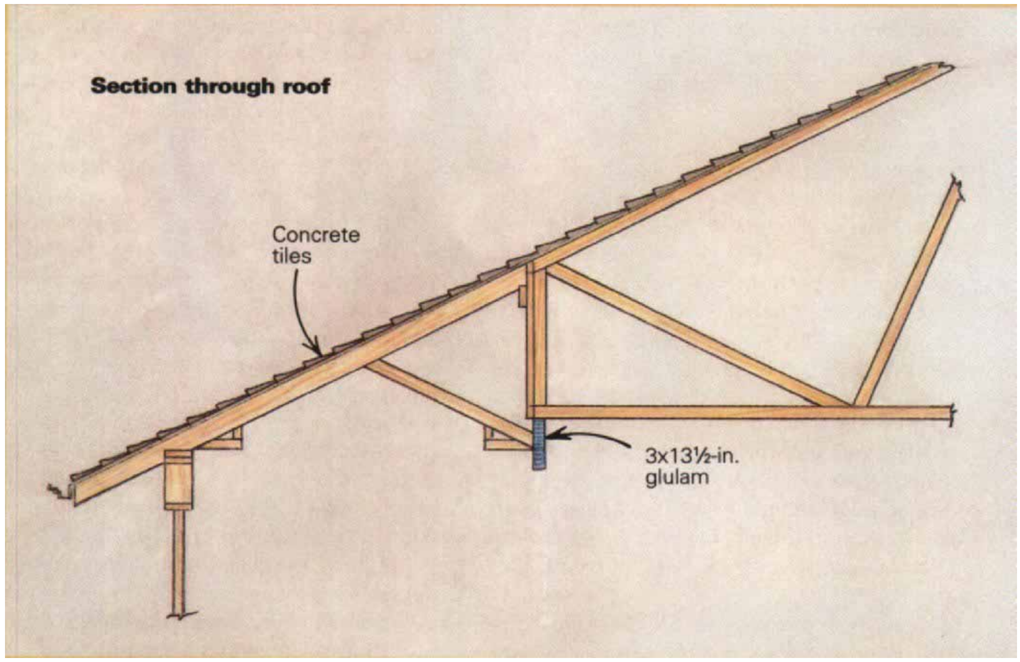
When specifying glulams, pay close attention to their actual (as opposed to nominal) width and depth. Because glulams are edge-planed *after* lamination, the finished product isn't as wide as the original pieces. For example, a stock Douglas fir glulam that's made from 2x6 dimension lumber will finish out at 5⅛ in. rather than 5½ in. Southern yellow pine glulams will be a bit narrower still. A stock Southern pine glulam won't be as deep as its Douglas fir counterpart either, because highly resinous Southern yellow pine boards are surface-planed *before* laminating to present a fresh surface to the glue. Southern pine glulams are laid up with lumber 1⅜ in. thick, rather than 1½ in. Recognizing the confusion this can cause, some manufacturers now make products the size of Douglas fir beams by starting with oversized pieces of Southern yellow pine.

Placing a beam—Glulams are usually big, and big means heavy. American Institute of Timber Construction (AITC) and American

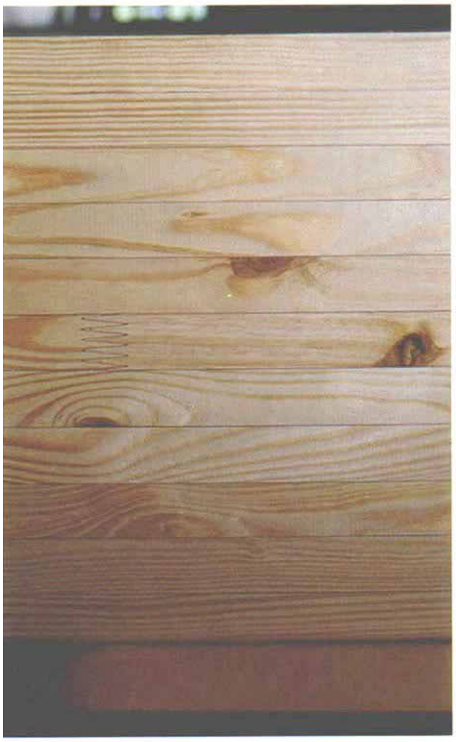
Sizing up a structural beam

by Christopher F. DeBlois

Most residential loads, even large ones, are small enough to be supported in a number of ways. For example, the engineering firm I work for recently acted as structural engineers for a development of narrow, one-story villas. The owner of one of these wanted to extend the main roofline to enclose a small indoor pool. We were asked



Drawings: Christopher Clapp



Lumber sorting. A simply-supported beam is most stressed at the bottom, a cantilevered beam at the top and bottom. As the photo above shows, glulam manufacturers save the best lumber for top and bottom laminations.

Heavy construction. Glulams can shoulder heavier loads than timbers of comparable size. Otherwise, they're no different to build with.

to specify an 11-ft. 6-in. carrying beam for the opening between the pool area and the main house (drawing below left). Simple enough, but this particular beam would resist a total load of almost 1,600 lb. per lf. It would have to carry trusses on one side and rafters on the other, with a heavy concrete tile roof above.

Although we ended up using a 3-in. wide by 13½-in. deep glulam, that certainly wasn't the only option. The table below summarizes the equivalent choices available to us. It should serve as a good approximation of the relative merits of competing beams.

When you evaluate beams for residential construction, it's important to compare apples with apples. I usually only consider beams 3½ in. wide or less—very often, there's just no room for anything wider (this case was an exception in that wider beams were acceptable). I also try not to specify anything that's too hard to obtain. For instance, I won't consider nail-laminated beams made with anything larger than 2x12s.

Type of Beam	Size (in.)	Weight (lb.)	$/lineal ft.	Total $
Solid timber	6½ × 14	228	10.50	126.00
Glue-laminated timber (glulam)	3⅛ × 13½	120	7.00	81.00
Parallel strand lumber (PSL)	3½ × 12	151	8.50	98.00
Laminated veneer lumber (LVL)	3½ × 11⅞	122	6.40	74.00
Flitch beam	3½ × 11¼	320	17.40	200.00
Nail-laminated beam	7½ × 11¼	250	5.95	72.00
Steel I-beam	4 × 8⅛	173	9.07	105.00

Prices in the table are manufacturers' retail prices in Atlanta. Prices and weights are for an 11-ft. 6-in. length, but some of the beams may not always be readily available in this length. To get an 11-ft. 6-in. steel beam, for instance, you might have to buy a twenty-footer. These prices don't include installation labor, which can be a big chunk of the final cost: heavier beams require more workers, and some beams are harder to detail than others. LVL and nail-laminated beams must be nailed, and a flitch beam bolted together on site. It takes more work to hang joists from a piece of steel than from a solid beam. And if the beam you choose is much deeper than it is wide, you'll have to brace it to ensure its lateral stability (see *FHB* #70, p. 14).

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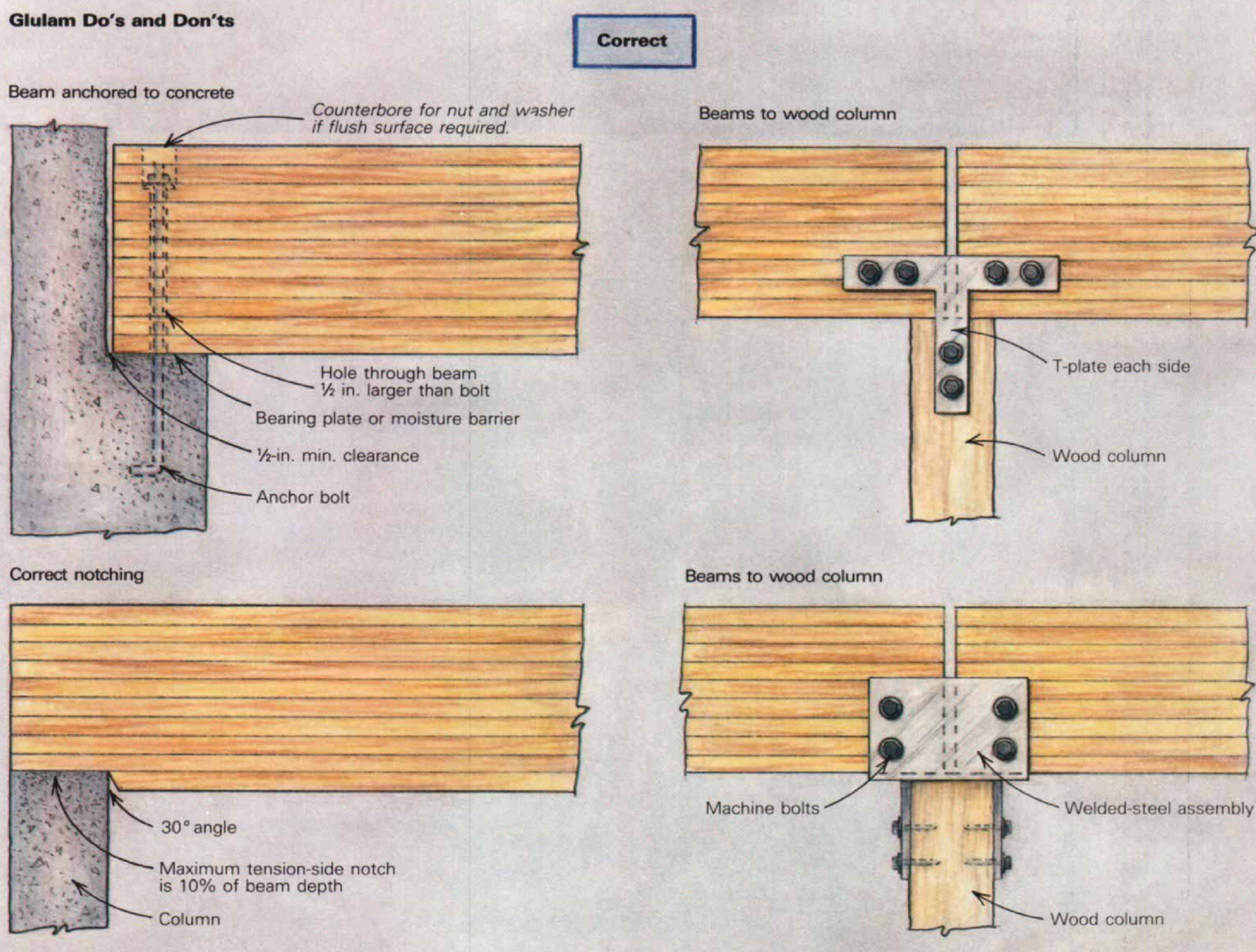
Photo above Charles Wardell

Wood Systems (AWS) span tables give glulams' weight per lineal foot, but you can also figure them mathematically: Southern yellow pine beams weigh in at 36 lb. per cu. ft., Douglas fir at 35 lb. pcf, hem-fir and redwood at 27 lb. pcf. Some glulams can be installed without special equipment—if you have enough help. The 5-in. by 13¾-in. by 17-ft. Southern yellow pine glulam in my house weighs about 300 lb. and three of us lifted it into place by hand. Some jobs, however, require a crane or hoist. In these cases the glulam should be lifted in a webbed-belt sling. To protect the finished edges, place wood blocks between the sling and the glulam. Fine-tune the beam's final position with a rubber mallet, or with a hammer and wood block; otherwise you risk marring its surface.

Drilling and notching—There's only one important rule to remember when drilling and notching a glulam: don't do either without first consulting the fabricator or a qualified engineer (that includes drilling holes for connector bolts). Ideally, holes for connector bolts should be part of the beam's design. The reason for this caution is the typically high loads carried by a glulam. While the repetitive design of conventional framing spreads loads across many members, permitting liberal drilling and notching, a single glulam may carry a significant structural load without backup. You just can't bore and cut these things like you would dimension lumber (drawings below). Because shear is greatest at the ends of the beam, holes closer to the ends may lower the beam's shear strength, while those nearer the top or bottom may reduce compression or tensile strength. A rule of thumb is that a simply-supported glulam beam can tolerate a 1½-in. dia. hole at mid-depth of the central one-third of its span.

Notching causes similar problems. Notching a glulam can compromise its strength more than common sense might indicate. When you take a 2-in. notch out of a 12-in. deep glulam, you've effectively created a 10-in. beam. The closer the notch is to the center of the span, the more it weakens the beam. A glulam can withstand limited end-notching to provide clearance or to bring its upper surface level with adjacent framing, but AITC restricts compression-side end notches to 40% of beam depth, and tension-side notches to 10% of depth. Don't even think about notching the tension side of a beam anywhere but at its ends. When making end notches, use tapered, rather than square cuts. The latter can concentrate stresses that may split the beam; the former will reduce that stress concentration. Even if you're within all these guidelines, you should still check with your fabricator or engineer before proceeding. Of course, the best practice is to design the structure so that you won't have to drill or notch the glulam at all.

End supports—The wood fibers at each end of a simply-supported glulam are subjected to compression stresses from imposed loads, so the bearing area has to be large enough to keep these stresses from crushing the wood. The bearing area provided by a 5½-in. wide top plate is generally adequate in residential construction, although it depends on the particular beam and loading situation. A wood or



metal column whose cross section is at least equal to the bearing area should be installed under the top plate at the point of bearing and should transfer the load directly to the foundation. The ends of the glulam may need bracing or fastening to prevent rotation and uplift.

For glulam-to-glulam and framing-to-glulam connections, use standard or architectural heavy-gauge metal hangers. You should be able to order these through your glulam supplier. Fasten them with through-bolts, lag screws or spikes. When using spikes, drill pilot holes to eliminate splitting.

Glulams and moisture—When fastening a glulam, it's critical that the connection permit free swelling and shrinking of the member with seasonal variations in moisture content. Because of its large size, seemingly small variations in moisture will make a glulam swell and shrink quite a bit. During the summer, the seasonal rise in relative humidity in my New England home can cause my Southern yellow pine glulam to grow ⅛ in. in width and ¼ in. in depth. Under such conditions, the stress caused by misplaced fasteners could easily split the wood; if these splits are large or numerous, they could drive the beam to the brink of failure. It's also important not to put more fasteners into the beam than are needed. Coating the beam with a finish will retard moisture pickup and reduce dimensional changes.

On site, store glulams off the ground and cover them with a protective tarp. Create a tent by weighting the top of the tarp and letting its sides drape loosely. The idea is to promote air flow and to keep the tarp from trapping moisture. During long construction delays, end-coat the beam with a couple of coats of paint or water-repellent. To guard against surface marring, keep the fabricator's protective wrap on until after the beam has been installed and the drywall taping and interior painting is done.

For more information—Virtually all glulams made in the U. S. conform to the manufacturing and quality-control specifications of the American National Standards Institute (ANSI A190.1-1983). Two of the largest independent agencies that provide inspection and testing services to glulam manufacturers are the American Institute of Timber Construction (11818 SE Mill Plain Blvd., Vancouver, Wash. 98684; 206-254-9132) and American Wood Systems (P. O. Box 11700, Tacoma Wash. 98411; 206-565-6600), a related corporation of the American Plywood Association. An AITC or APA-EWS quality mark stamped on a glulam signifies conformance with ANSI quality standards.

The classic reference for glulam and heavy timber construction is AITC's *Timber Construction Manual* (J. Wiley & Sons, Inc., 1 Wiley Dr., Somerset, N. J. 08875; 800-225-5945, $59.95 plus shipping). Two free publications you'll also want for your bookshelf are AITC's *Glued Laminated Timbers for Residential and Light Commercial Construction,* and AWS's *Product Application Guide—Glulams.* □

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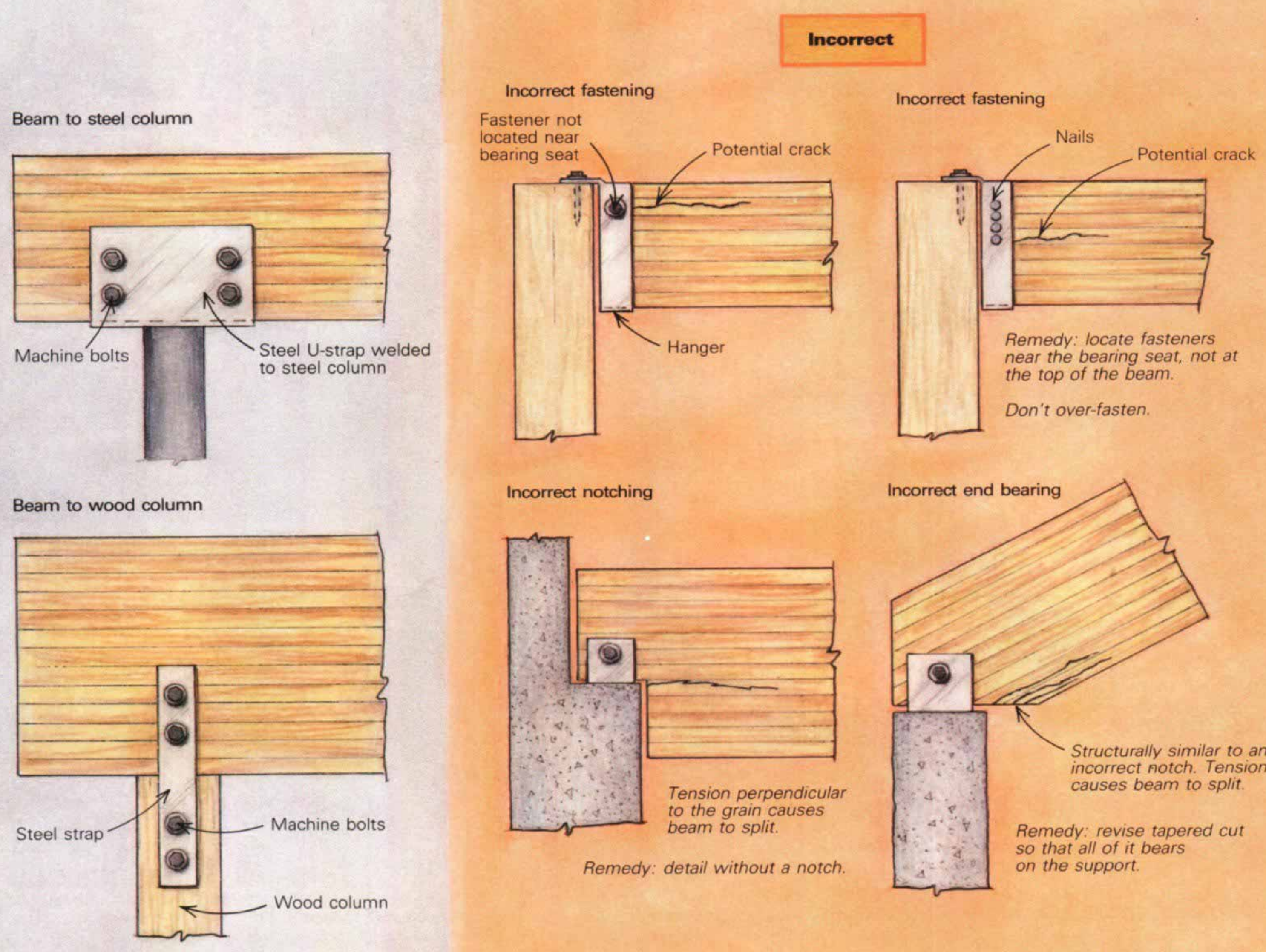

Drawings above rendered by Chris Clapp after originals from the American Institute of Timber Construction