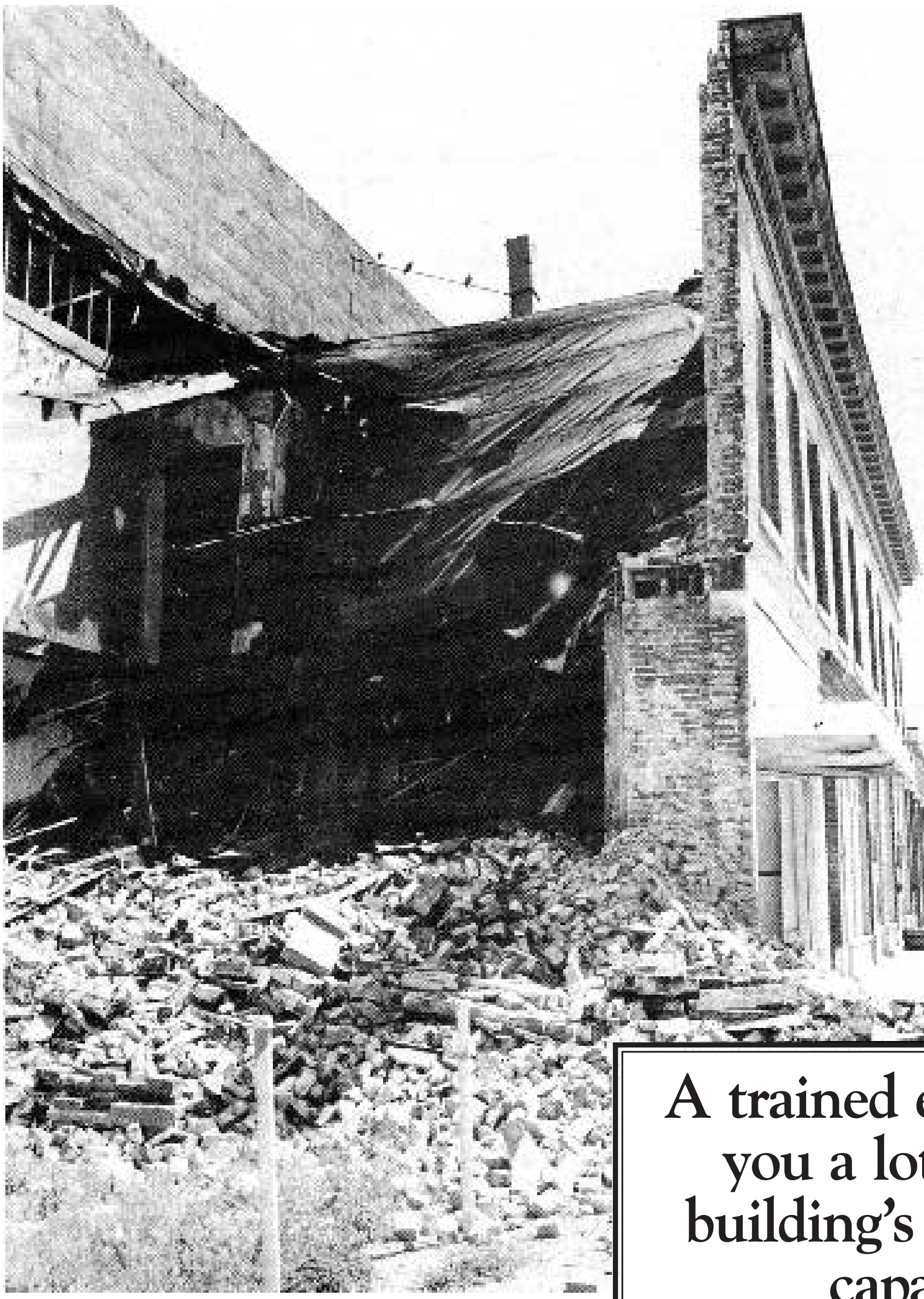
EVALUATING WOOD STRUCTURES

by David Wickersheimer


A few hours before a town dance earlier this year, the unoccupied "Opera House" in Newman, Ill., tumbled down. The building wouldn't have survived the live-loads of dancers later that evening.

How does an engineer know if an existing wood building has serious structural problems? We make educated guesses about the strength of existing buildings based on our experience and on what we see. The same type of structural evaluation can help a contractor too. If you think the way an engineer thinks, you'll spot problems early. You'll know why you're putting in those extra joists. And on buildings that are in really bad shape, you'll be prepared to deal with change orders or structural collapse.

When you have a question about the structural capacity of a wood member, you're trying to find out two things:

- What is the current strength of that member? (This is so you can assess a factory of safety.)
- What is its stiffness (resistance to potential movement)?

To find answers to these questions, you must evaluate the wood's properties. You want to find out if it will be strong enough to carry anticipated loads (see "When to Do An Evaluation").

Use Your Eyes

You evaluate building strength two ways. One is non-destructive. In this approach, you examine the building visually, but you don't remove samples. The other approach is the most informative and exact—destructive testing. You cut out members and load-test them, or you cut out samples and send them to a laboratory. Destructive testing costs more, but you get more accurate information.

Start with non-destructive evaluation. Use your eyes. If you start to see things that really bother you, you may need to do destructive testing. You can use the building's age to give you clues. Dust and cobwebs covering damaged areas tell you the damage occurred a

A trained eye can tell you a lot about a building's structural capacity

When To Do An Evaluation

by David Wickersheimer

There are several reasons to find out all you can about a structural system's capacity. Before you start to remove a building, you may want to know if the building can continue to carry its current load. This is important when you develop a remodeling bid.

A structural capacity evaluation is also useful when a building changes occupancy. The building may require structural components to carry larger or more concentrated loads than they carried before. Commercial construction changes functions all the time. I recently had to figure out whether the second-floor wood framing of an old commercial building could hold heavy water-filled tanks for a tanning salon. In cases like this we frequently need to upgrade the structure.

Upgrading is often necessary where residential buildings are converted to commercial uses. For example, I helped convert a two-story house into a law office. The conversion made significant changes in the load requirements. The law library couldn't be carried by second-floor construction, but the clients wanted the library on the second floor anyway. We put steel in the attic and hung the library shelves off the steel. The steel rested on bearing walls. The wood floor joists just couldn't have carried the weight.

Finally, you might want information about structural capacity to satisfy new code requirements. Codes change. When you make changes exceeding a certain dollar amount or exceeding a certain square footage, you have to upgrade to meet current code provisions. A good example is the recent change made in snow-loading requirements. The old BOCA code only required uniform snow loads. When the new BOCA code came out, it required triangulated loads to account for snow accumulation at projections above the roof plane. These code changes meant big changes in roof framing. On one job, we were called in to evaluate the structural capacity as part of a major reroofing job on a performing arts center. We found the building needed structural upgrading next to the theater stage to bring it in line with the new code requirements.

These jobs went smoothly because the contractor understood that the structural capacity of the building required changes. He was in a better position to bid the job and predict the completion time accurately.

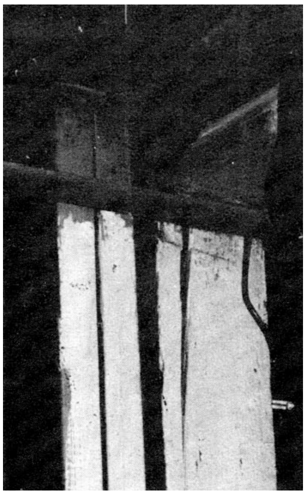


Figure 1. *This 10x10 column fractured because it was overloaded either in the original design or due to renovations.*

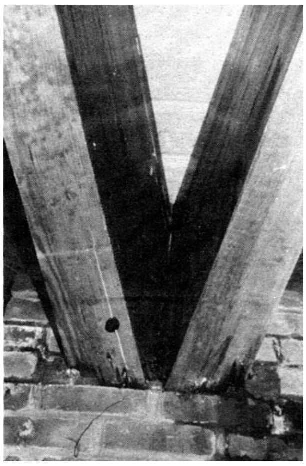


Figure 2. *Decay is visible at the edge of this masonry pocket, wet from an exterior leak. This building is relatively new.*

long time ago. Recent fractures or cracks won't be covered by dust.

Fractures. Just as a doctor looks for pain, you should look for visible symptoms of distress in wood (see Figure 1). Look for fractures in members. Fractures tell you where high stresses have occurred. They may indicate that a member was under-designed to begin with. Fractures often start at wood defects, such as a loose knot or split.

Wood stains. Any time you see large dark stains on the wood, you know you're seeing water damage. If the wood has gone through years of wet/dry cycles, you'll have decay. Decay fungi reduce wood strength.

Wood in masonry pockets. Any wood bearing on masonry or pocketed in masonry is suspect. Make sure the ends of the wood haven't rotted away. Moisture can come through a brick wall, percolate down from the roof, or filter down the walls. You may have to take out a brick or two to get a good view of the pocket (see Figure 2).

Moisture in wood. Moisture content affects wood strength. Saturated wood has less strength than dry wood. If you're walking through a building and you see wet wood, it may have a reduced capacity, even if the joist size and spacing meet minimum requirements. Once wood reaches the fiber-saturation point (approximately 30% moisture content), it doesn't get any weaker. The building's daily temperature and humidity levels play a big role in the strength of its wood members.

Fire damage. It's surprising how many buildings have been affected by fire. Even minor fires may affect the members you need to evaluate and possibly upgrade. See what you can scrape away on fire-damaged wood. If the char has gotten to the point where you can peel away the carbon, keep going until you get to the solid part of the cross section. Then use 75% of that as the usable cross section.

Just as a doctor looks for pain, you should look for visible symptoms of distress in wood. For instance, fractures in members tell you where high stresses have occurred. Fractures often start at wood defects, such as a loose knot or split.

People always say wood is the best construction material to structurally withstand fire. But dimension lumber is only 1 1/2-inches wide; if it burns, there's hardly anything left. With heavy timber, wood below the char may not be affected (see Figure 3). Check the "unprotected construction" section of the code for size requirements of heavy timber if the building you're investigating has heavy timber members.

Insect damage. You can usually find insect infestation with a little detective work. The damage may not be visible initially. Sound the timber with a hammer or mallet. If it sounds hollow, you may have termite damage. Some of the worst damage I've seen occurred in members where the perimeter wood fibers were totally intact (see Figure 4).

Notches and holes. You may not find any insect damage in the wood members. But look for people damage—notches for pipes or duct runs (see Figure 5). See if they're in critical locations, such as a notch at midspan on the tension side of a joist, or a large hole near a support. The first indicates a loss of bending stress. The second indicates high shear stress. Bottom-side notches at the ends of members, intended to lower the floor elevation, may have developed horizontal splits at the corner of the cut (see Figure 6). The split can travel 3 to 4 feet out toward the center of the span. That member is virtually useless. The only strength you've got left is the capacity

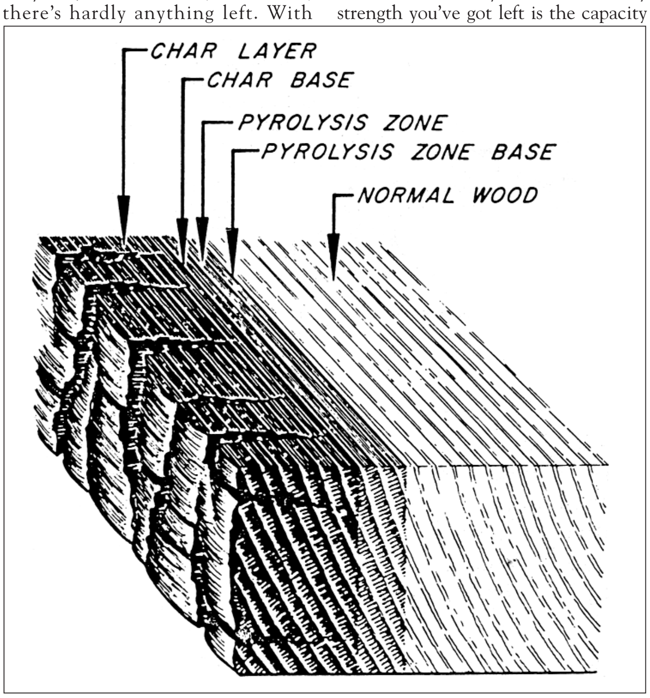


Figure 3. *Layers of char can protect heavy timbers. But 2-by dimension lumber is too thin to provide support once it burns.*

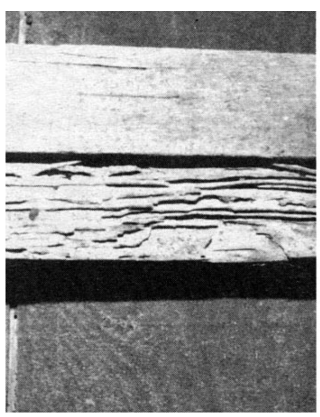


Figure 4. *The surface of this 2x6 looked fine, but termite channels had severely weakened the member.*

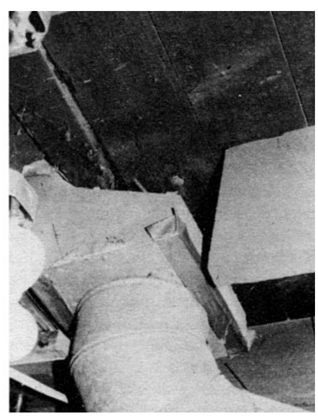


Figure 5. *The joist was in his way, so the sheet metal worker cut it off. Alternative support is now needed.*

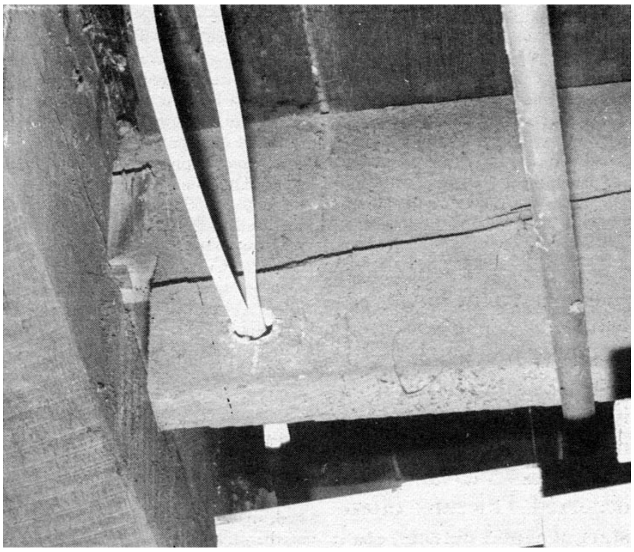


Figure 6. *This lateral split in a notched joist makes it nearly useless.*

of the cross section above the notch.

Built-up lumber. As lumber dries over time, nails or spikes pull out. This can pose a problem for columns or beams built up from two or more pieces of dimension lumber. Originally, the built-up section behaves as a composite (working as a total section). But when the nails pull out, the "beam" suddenly behaves as individual lumber pieces.

Look for nail pull-out. When you compare a column built of three pieces of dimension lumber to a solid piece of lumber, you only get about 65% of the capacity. That's when the built-up member is appropriately glued and nailed. Once the nails pull out, you have only the sum of the capacity of each of the three individually—only about one-third of the 65%. The strength deteriorates rapidly. A solid section is better than a built-up section; and a built-up section is better than a separated built-up section.

I have seen serious problems in the compression chord of built-up wood trusses. Built around 1900, these trusses were common in warehouses, religious buildings, airplane hangers, and meeting halls. The members were intended to behave as a composite, but because the spikes pulled out, the pieces were acting individually.

Insect damage may not be visible initially. Even if the wood appears totally intact, sound the timber with a hammer or mallet. If it sounds hollow, you may have termite damage.

Cracks and splits. If you're in an older building that's using heavy timber, you are likely to find shrinkage cracks. Because of its heavy cross section, timber dries out first at the edges. The shrinkage works its way toward the core. You usually get a split through the center of the section. I've seen splits on 12x12- and 16x16-inch columns that broke the column into four separate pieces. Again, the four remaining pieces don't have the strength of the total. You may find steel straps around split columns, just like the clamps around a radiator hose. Make sure any pre-existing straps weren't put on by the night janitor. Check for corrosion too. If you see a problem, have an engineer design straps or plates before you make any repairs.

Column crushing. Timber columns often bear directly on a basement slab. The end grain sucks up any water on the floor into the section and reduces the strength of the column at that end. In older homes, decay often renders the column useless. The decayed wood fibers crush down to the point where dry fibers can carry weight again. This shortening of the column makes any floor framing that bears on the column sag.

Corrosion. If you have water stains on the wood surface, you probably have corrosion on metal fasteners too. Search out corrosion at fasteners—lag bolts, steel plats, hangers, straps. Extended exposure to a corrosive (high-moisture) atmosphere can reduce the metal cross section to zero; bolt heads may snap off or disintegrate. The webs of steel beams can look like Swiss cheese. Corrosion of metal fasteners often plays a big role in structural weakness.

Visible sagging. If you can see that floor framing has sagged, run a string from one end of the joist to the other to record the amount of sag. You may be seeing wood creep. Creep is a factor in wood that people don't think very much about, but it does influence long-term deflection. If wood has been in service for a long time with a large dead load on it, it probably has crept into a deflected shape. Creep deflection can easily be twice as large as elastic, short-term deflection.

Creep isn't harmless. You have to figure out what caused it. You'll have to decide whether creep has rendered the floor unserviceable.

Crunching the Numbers

If you're going to help an engineer come up with meaningful numbers, you need to measure the cross sections at many locations. In older buildings, the cross sections varied. You want to deal with the minimum cross section for your calculations—the smallest joist. You also will find quite a variance in

Structural Upgrades

by David Wickersheimer

Let's say you find the building is under the required capacity. What upgrades can you make?

If creep is the problem, you may need to level the floor with a floor leveler such as Gypcrete. But you have to know if the floor can take the additional dead load. In one restaurant we worked on, the owner had such sags he couldn't set tables and chairs. The contractor shored up the foundation and put in a wall down the center of the basement to cut joist spans in half. The joists couldn't have handled the additional weight of the floor leveler without the reinforcing.

Another approach lets you correct problems with sagging big-timber sections that are slightly undersized. Longitudinal post-tensioning lets you change your beams into king- or queen-post trusses. You can put steel plates on the ends, hook cable to the plates, and jack (see Figure A). The center member(s) kick up and give the timber a reverse curvature. That's an expensive repair, and one that requires sufficient space to operate.

You can also do flitch beams; bolt steel plates through the cross section. This upgrades the strength and can be used to repair composite construction (see Figure B). You can also put the plates on the side or in the center of the beam.

You can improve a joist floor's capacity with additional lumber. Maybe the joists are 2-foot on-center. Put in additional joists 1-foot on-center to cut the amount of load that goes to the existing joists in half.

Epoxy repair can also be used to repair damaged structural members (see JLC Restoration Primer 4/89). Epoxy repair should always involve an engineer. Also, work with the epoxy supplier, and make sure you understand each step of the process.

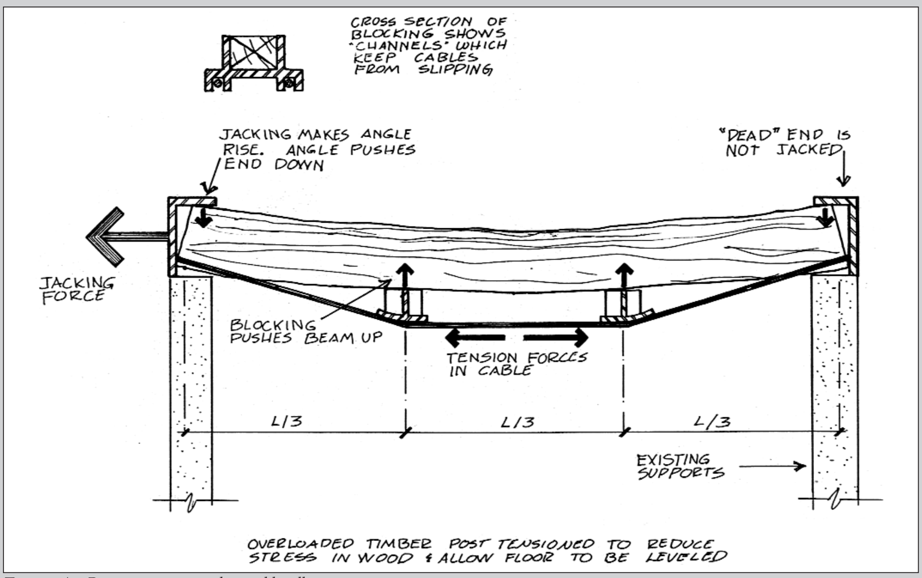


Figure A. *Post-tensioning with a cable allows you to convert a sagging beam into a king- or queen-post truss.*

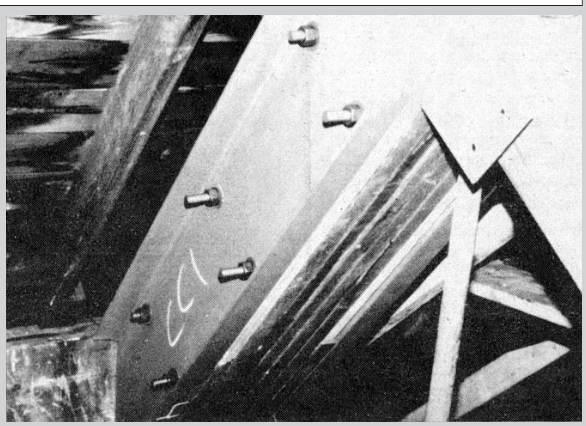


Figure B. *To repair separated members of a 1900s built-up truss, the author used a steel flitch plate and bolted the separated members together. This forces them to act as a composite, and the steel strengthens the cross section.*

the spacing of structural elements. you want to measure to find the widest spacing. You're looking for the minimum cross section and the maximum spacing to properly assess existing framing capacity.

Those are the basic structural items one can visually assess. Then you have to determine some reasonable level of quality in the wood. By that I mean the species, density (specific gravity), modulus of elasticity, and any other properties you need to perform your analysis. This is where the real guessing game begins. If you don't want to extract a sample of wood to send to a testing lab to identify the species, then you've got to play it conservatively.

We do the following. Look for defects in the wood—knots, splits, shakes, wanes. If I see a lot of those, I lower the estimate of the allowable bending stress and the allowable modulus of elasticity. If I see a large warp when I sight down a joist, I know the joist doesn't have the same strength it would have if it were straight. Warping reduces the cross section's properties and thus the capacity of that section. I'm looking for straightness, absence of defects, and no warpage. Based on that, if I see the lumber is fairly clear and doesn't have any water stains, I can probably assume a 1,200 psi bending stress (for repetitive members such as joists); and something like a 1,500,000 modulus of elasticity. These have been common starting values for us. If we see lots of defects and warpage in the wood, we reduce to 1,000 psi for bending and 1,400,000 for modulus of elasticity.

It's a guessing game based on years of experience. You can find numbers and formulas for common wood species in builders' handbooks such as Basic Building Data, by Don Graf (Van Nostrand Reinhold Co., New York, N.Y.). But you should get an engineer involved if your rough calculations point to a problem.

Testing Alternatives

If you've looked at the wood's quality, there's one other thing you can do with inexpensive testing equipment. You can determine the humidity in the space and check the moisture content of the wood. Use a sling psychrometer to check the humidity. Stick a moisture probe in the wood to test moisture content (see Figure 7). If the moisture content is high (around 20%), I reduce my guess of 1,200 psi bending strength. If it's around 12 to 15%, I may not. You typically see higher moisture values in exposed framing in the basement. In second-floor framing, you'll usually have a lower moisture content. You might play allowable-stress assumptions more conservatively on the first-floor framing than on second-floor framing.

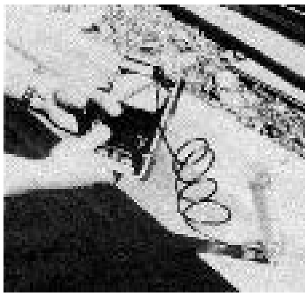


Figure 7. *A moisture probe can accurately determine moisture content. Wet wood loses strength.*

On the high-tech end, Engineering Data Management (736 Whalers Way, Suite G-200, Fort Collins, CO 80525; 303/223-0457) is developing sonic wave spectral analysis to evaluate wood's strength and stiffness—in place. This is a very expensive approach, but it is non-destructive. They originally developed the technique to test telephone poles. They're working on other equipment to evaluate wood beams in buildings and heavy timber.

Let's say the building you're assessing is important and you don't want to accept the guesses I've just stated. Then you've got to do a destructive evaluation. You need a wood technologist who will take your sample to a lab. He'll determine the species, the specific gravity, the E-value, and other properties. An engineer can compare these values with new material and statistically evaluate how much the building has degraded.

When you've gathered your information, you'll end up with two sets of numbers. One set describes the code-required loads the building must be designed to carry. The second set describes what the building actually can carry, based on its current capacity. An engineer compares these numbers to see if there is a reasonable factor of safety. If not, the building must be structurally upgraded before it can carry the anticipated loads safely (see "Structural Upgrades").

If you spot something that looks like trouble, get an experienced engineer to work through the numbers. The calculations can give you some security that the scope of work will match the time and money you've estimated for the job. Change orders usually take care of major revisions. But the fewer surprises on a project, the better. ■

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