The housing industry has documented over 700 cases of a new and unpredictable phenomenon called the rising truss. Metal-plate truss roof systems are bowing upward, causing the ceiling structure to separate from partitions and walls. How does the rising truss relate to forestry? Percival et al. (1982) have determined that the bowing is likely caused by juvenile wood. Fast tree growth is increasing the percentage of juvenile wood in timber harvested from plantations in the South and West.

Plantation foresters herald new, “improved,” “genetically engineered” trees as an answer to future timber shortages. They may be right, but advocates of “bigger and faster is better” face a two-sided problem: maintaining wood strength and dimensional stability while increasing stem diameter growth. The race to produce maximum timber volume per acre cannot ignore consumers’ needs for forest products best produced by slow growth (Harris 1981). Maximum volume, obtained by plantation culture or by silvicultural manipulation, may be fine for pulp and paper but not for studs. An underlying concern for forest managers must be product quality. Fast-grown, short-rotation conifers lack the wood fiber needed for products requiring structural strength. Forest managers and silviculturists need to be directly involved in decisions concerning management tactics and product performance.

The impetus for plantations came initially from the desire of the pulp and paper industry to maximize fiber output from timberland. The result was a successful research effort to select, genetically screen, and silviculturally manage tree species to produce more volume per acre and shorten the harvest rotation time. This was a logical course of action for the paper industry. Even so, many pulp mills still prefer old-growth stems with narrower rings, higher density, higher pulp yields, and lower costs.

Maximum timber yield entails additional costs of regular thinning cuts and short rotations. Wood processed into
pulp does not return the profit per unit of wood used for other purposes. Inevitably, wood cultured and managed for pulp is being processed for lumber.

A significant percentage of harvested timber is currently diverted from the pulp mills for manufacture into more valuable products. Small log mills can now produce two-by lumber from young stems with a disproportionately large percentage of juvenile wood. The architect, designer, or end-user more often than not is unaware of this wood's low quality for structural purposes. Processing problems are becoming commonplace; potentially dangerous misuse of structural lumber coming from plantations is a growing concern.

Increasingly, plantations are being looked to for clear lumber in high grades. In South Africa, with over 2.5 million acres of manmade forests, average rotation for sawlogs is 30 years with thinnings producing small sawlogs as early as 13 years for several pine species (Kromhout 1981). Palmer (1981) reports on eucalyptus plantations in Chile, where 1 million acres were planted from 1975 through 1980. Trees are reaching 9 inches in diameter in 10 years (nearly 1-inch diameter growth per year). Brazil planted 3.2 million acres from 1967 through 1973 and 10.4 million acres by the end of 1983. New Zealand plants about 110,000 acres per year of radiata pine that reaches sawlog sue within 25 years. Another 20 million acres of plantation hardwoods and softwoods have been established in developing countries.

In the United States, planting is extensive and increasing rapidly throughout the South and West. Plantation foresters estimate that they will double the volume of wood per acre in the future. The southern pine regions readily produce six-ring per-inch growth.

Three-ring-per-inch trees produce merchantable 20-inch diameter trees in 30 years (Koch 1972a). Selective genetic screening may achieve rotation ages of 20 to 25 years with acceptable density (Zobel 1972). Fertilization and irrigation may enhance growth rates even more. Specific gravity and growth rate are not always correlated, but, in conifers, decreased density is accompanying faster growth rates (Bodner 1983).

Bassett (1969) reports that plantation thinning can result in 13-inch diameter loblolly pine trees, certainly sufficient size for small-log sawmills, in 21 years without any decrease in specific gravity. Burton and Shoulders (1974) report 15-inch mean diameter sawlogs of loblolly pine with 3.7 rings per inch in 27 years under intensive management. Specific gravity was an acceptable 0.53 for 10-year and older wood. Control trees reached only 10 inches mean diameter compared to the 15-inch fast-grown trees. The researchers state that 18- to 20-inch trees, averaging three rings per inch, should be feasible. Thinnings at age 24 produced sawlogs to an 8-inch top diameter. Ledig and Porterfield (1982) suggest rotation ages of 80 to 120 years with thinning cuts at 40 to 50 years for Douglas-fir, a species that previously required much longer growthcycles.

Although technologists disagree on details, the properties of wood from fast-grown plantation species generally are not the same as those from slower-grown, old-growth trees (Olson et al. 1947). Some properties of fast-grown species may be better, and the potential to select specific properties for genetic improvement does exist. Currently, though, trees harvested at an early age are producing wood with inferior properties.

Technologists and wood-users are expressing concern because low specific gravity associated with juvenile growth generally implies low strength properties. The load which a beam can withstand without failing, its modulus of rupture (MOR), is reduced as is its ability to resist deflection under load, measured by its modulus of elasticity (MOE). Elasticity is often a limiting design criterion in structures where too low an MOE value can result in "bouncy" floors. Compression parallel-to-the-grain is also seriously reduced in juvenile wood, impairing the load-hold-
ing capacity of columns (studs, braces, beam supports).

Average cell length is another general indicator of wood strength, particularly in tension parallel-to-the-grain. The shorter cell lengths observed in fast-grown conifers imply lower tensile strength. Products such as the lower chords of wood trusses, highly stressed in tension, in today's markets require a quality 2 × 4 for adequate performance. Higher-than-normal longitudinal shrinkage is associated with the high microfibrillar angle observed in fast-grown coniferous species (Voorhies and Groman 1982). Longitudinal shrinkage tends to cause excessive warp in lumber which, in turn, produces a myriad of problems in the manufacture of nearly all wood products. Essential to all of these concerns are the proportions of juvenile and associated reaction wood appearing in lumber.

**JUVENILE WOOD**

Annual growth rings nearest the pith, regardless of tree height, contain wood of lower than average strength and specific gravity; longitudinal shrinkage and fibril angle are higher than average; cell length is shorter than average. These inferior characteristics identify juvenile wood, as opposed to mature wood. Juvenile wood encompasses the first 5 to 20 growth rings. Management techniques—fertilization, irrigation, pruning, and thinning—produce relatively minor effects compared with the difference in properties between mature and juvenile wood (Haygreen and Bowyer 1982).

Juvenile wood exists in the upper portions of the tree even though the wood near the ground may have been forming mature wood for some years. A schematic relationship between wood properties and number of rings from the pith is shown in figure 1. Transition from juvenile to mature wood is usually gradual. Fast growth during the early years of a tree's life will increase total volume, which will mean increased mature wood once it begins to form.

With a practical rotation age for plantation species of 20 to 35 years, a high proportion of harvested tree volume—now and in the future—will likely be juvenile wood. As rotation ages decrease, the proportion of juvenile wood appearing in products will increase. The general consensus is that juvenile wood is undesirable for products requiring stability or strength. Bigger, faster growth is not better growth for all forest products. Foresters need to grow trees with smaller cores of juvenile wood or select species or varieties with acceptable (better) juvenile wood properties.

**REACTION WOOD**

Reaction wood often appears during the first few years of growth and is frequently associated with juvenile wood—concentrated in the early growth rings. Panshin and deZeeuw (1980) describe reaction wood as an asymmetrical response to growth hormones in stems that are bending. The abnormal wood acts to restore crown uprightness. Appearance, physical attributes, and mechanical properties of the wood are affected. Reaction wood occurs in softwoods as compression wood and in hardwoods as tension wood.
Compression wood has higher than normal density, altered chemical properties (lower cellulose content), and up to ten times larger than normal longitudinal shrinkage. Permeability and strength are reduced; individual cell walls show abnormal checking; and cracks across the grain may appear in drying.

Tension wood, scattered throughout the tree, is difficult to recognize. It contains 40 to 50 percent more cellulose and has less lignin than normal cells. Like compression wood, it exhibits abnormally large longitudinal shrinkage (up to 1 percent). Density is increased 5 to 10 percent. Tension wood exhibits lower than normal strength in compression parallel-to-the-grain (due to lower lignin content), compression perpendicular-to-the-grain, modulus of rupture, elasticity, and shear. In dry wood, tension parallel-to-the-grain is often higher than normal.

Commercial plantations have now reached harvestable size for thinnings or sawlogs, and problems with juvenile and reaction wood are becoming a common occurrence in the lumber industry.

**SHRINKAGE**

Juvenile wood shrinks along the grain much more than mature wood does. Pieces containing nonuniformly distributed rings of juvenile wood warp readily during kiln drying. This results in rejection of perhaps several percent of the pieces in each kiln charge. Severely warped pieces of juvenile wood are usually suitable only for chipping. Rejection at this nearly finished stage of lumber processing is expensive. In addition, warped lumber tends to distort other members in a stack and may cause down-grading or rejection of what otherwise would be usable lumber (fig. 2).

In the machine-stress-rating (MSR) process of grading structural lumber, low-density juvenile wood rarely makes the higher grades. The MSR process efficiently culls this material out and drops it into a lower strength category.

MSR profitability is seriously reduced, though, if large amounts of juvenile wood are encountered.

Current U.S. grading rules for structural lumber do not allow for pith-associated (juvenile) wood. A bonus is given for slower growth rates and for large summerwood percentages in dense grades of southern pine and Douglas-fir and western larch lumber. Restrictions probably eliminate most juvenile wood in dense grades of these two species. However, non-dense grades for these and other species have no restrictions on juvenile wood, and the most effective control of juvenility in structural lumber appears to be in the MSR grading process.

**WARPAGE**

Carrying the shrinkage-warpage process a step further, kiln-dried lumber will warp in service if it continues to dry. Structural lumber is usually dried to an average moisture content of 15 percent in the United States. However, moisture content values for lumber in houses drop considerably lower than that during winter when relative humidity is low. The result may be uneven floors, buckled walls and paneling, weakened joints, and doors and windows that won’t open or close properly if juvenile wood is present. Warpage in transit and job-site rejection of warped lumber adds to construction costs. Similar problems occur when hardwoods are used in furniture manufacture.

Studies have been made on the bending strength and elasticity of full-size lumber containing pith-associated wood (Moody 1970, Gerhards 1978). These studies show that properties of both solid wood and finger joints that fasten pieces together end-to-end are inferior when juvenile wood is present in significant amounts. Reductions in strength and stiffness are drastic—in the range of 30 to 50 percent. Juvenile wood is a matter of obvious concern to construction in general and to the laminating industry in particular.

Juvenile or compression wood appears to be at least partly responsible for the rising truss phenomenon. The ¾-inch ceiling gaps, while apparently not structurally dangerous, are creat-
ing severe frustration among U.S. builders. Reports are coming in from other countries as well. Careful screening for truss chords and culling of lumber containing juvenile wood have been suggested as remedies.

The advent of large-scale southern pine plantations has created the need to utilize thinnings and small logs. A popular answer is the chipper-canter operation: slabs are chipped for pulp and the remaining pith-centered cant is then sawn into dimension lumber. Chipper-canter lumber from small, rapidly grown log centers is predominantly or totally juvenile wood. Normal log diameters range from 4 to 26 inches, with an average diameter of 12 to 16 inches or less (Koch 1972b, Williston 1976). Dimension lumber sizes are predominantly 2 × 4 and 2 × 6; however, a 14-inch diameter log can yield a 12-inch square cant for processing into 2 × 12’s.

The difficulty arises when an architect or designer specifies dimension lumber for a building, based upon the allowable design stresses associated with various grades. Designers, well informed on grade names and allowable design values, may not be familiar with lumber per se. They rely on lumber graders or MSR producers to grade lumber accurately so that it lives up to allowable design stresses (strength values) assigned to various grades. Allowable design stresses are derived from average species strength values, which take into account wood defects, variability in strength, and a safety factor. This process has traditionally produced structural lumber that is safe and has performed well. Structural failures due to inadequate strength have been relatively rare.

Juvenile wood, often well below normal average strength, is not adequately represented in average strength values used to derive allowable design stresses. Allowances may need to be made in design to achieve the expected performance for pieces containing juvenile wood. A similar statement may be made about elasticity, which is even more responsive to the effects of juvenile wood. A weaker-than-normal piece of lumber will usually shift at least part of its share of load to its stronger neighbors: however, lumber from plantation thinnings may contain few stronger neighbors.

COMMERCIAL LIMITS

Recognizing the influence of juvenility on full-sized structural products, the American Society for Testing and Materials and the American Institute of Timber Construction have approved practical limitations on the amount of pith-associated wood permitted in critical tension laminations for laminated beams (American Institute of Timber Construction 1979, 1982; American Society for Testing and Materials 1981). No more than one-eighth of the cross section of better grades can contain pith-associated wood. The laminating industry also applies specific-gravity criteria to critical tension laminations. Only better wood obtains critical tension properties. Juvenile wood limits
The general consensus is that juvenile wood is undesirable for products requiring stability or strength. Bigger, faster growth is not better growth for all forest products.

IMPLICATIONS FOR FORESTERS

Plantations and rapid growth per se are not bad. Maximum volume growth per year may be economically justifiable for pulp production or for certain species (ring-porous hardwoods, for example). Forest managers should realize, however, that rapid growth to obtain large tree diameters or to shorten rotation periods for softwoods will result in larger amounts of juvenile wood and lower density fiber—serious threats to the quality of some wood products.

Genetic improvement by species selection should stress both rapid growth and high density. Silvicultural treatment, such as fertilization, at older ages may be effective to promote formation of mature wood. Manipulating habitat by thinning or pruning may also be appropriate in regulating growth rate and age relationships.

Foresters should learn the products proposed for timber coming from a tract, and something about the quality requirements of those products, before writing a management plan. If strength of wood is required, longer rotations to increase amounts of mature wood may be economically justified. Plantation foresters can help offset the deleterious effects of juvenile wood through research and forest management. Unless accounted for in some manner, the effect of juvenile wood on strength and performance of future wood products could be disastrous.

Literature Cited


KROMHOUT, C.P., AND D.L. BASMAN. 1981. The in-

(Continued on page 484)
When Does Juvenile Wood Mature?

In 1979, Purdue University and the Forest Products Laboratory at Madison, Wisconsin, began a cooperative research project to study juvenile wood in loblolly pine (Pinus taeda L.) and cottonwood (Populus deltoides Bartr.). Six trees were selected at random from an established plantation for each species; plantation selection was based on availability and tree age. Researchers wanted to determine when juvenile wood changes to mature wood for various properties.

Specimens, 1/8-inch thick and approximately the width of a single annual increment, were taken from the first-formed growth ring and thereafter throughout the life of the tree. Tests were made for specific gravity, modulus of rupture, bending elasticity, and maximum crushing strength in compression parallel-to-the-grain. Percentage of reaction wood, average cell length, and microfibrillar angle were measured for each growth ring.

Data on wood properties (except for microfibrillar angle) exhibited a similar pattern of low property value in the first annual rings, which increased over time at a decreasing rate. Maximum, stable property values were not reached within the age limits of the trees studied. The demarcation line between juvenile wood and mature wood was not clearly established for any tree, and it varied with property.

Early annual rings for both species showed short cell lengths with cells lengthening and stabilizing in length with age. In pine, early annual rings were wide until about age 12 to 14 years and later were much narrower, suggesting that ring width and wood property are correlated. In the mature wood of an older tree, however, a wide growth ring (due to fertilization or a thinning operation) could have considerably higher strength than the same width ring in juvenile wood. A clear cause-effect relationship between ring width and property value is difficult to ascertain, though evidence supports a correlation (Johnson 1981). Specific gravity also increased over time. Maturity, defined by stabilized values, occurred at an earlier age for mechanical than for anatomical properties. Data trends were not as well defined in cottonwood where ring width, maintained longer, was more irregular.

The percent of juvenile wood in any given tree may be estimated using modulus of rupture and elasticity values. An approximate tree cross-sectional area may be calculated by including sequential growth rings from the pith outward and choosing, somewhat judgmentally, an age at which the wood may be termed mature—15 years. Making no allowance for chipping the outer slabs, the portions of each tree usable for dimension lumber are presented in table 1. Loblolly pine trees were 29 to 30 years old and cottonwood trees were 25 to 26 years old at harvest. Note that the diameters at 30 years for the pine trees do not indicate particularly rapid growth for a plantation: more rapid growth would probably produce even larger percentages of juvenile wood.

Beyond about age 12 to 14, the growth rate (ring width) begins to slow appreciably. For the rotation ages proposed for softwood plantations, juvenile wood will constitute roughly 25 to 60 percent of wood volume usable for purposes other than pulp chips. Kellison (1981) states that loblolly pine stems may contain 19 percent by volume of juvenile wood at age 45 and as much as 85 percent by volume at age 15, counting only the first ten rings from the pith as juvenile wood. Data for cottonwood are similar. Obviously, if rotation age is lengthened beyond age 30 to, say, age 35 or 40, the effect of juvenile wood will be less.

### Table 1. Estimated percent juvenile wood in plantation-grown loblolly pine and cottonwood trees.

<table>
<thead>
<tr>
<th>Species</th>
<th>Tree number</th>
<th>Tree diameter (in.)</th>
<th>Percent juvenile wood</th>
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<tbody>
<tr>
<td>Pine</td>
<td>1</td>
<td>12.2</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>12.1</td>
<td>54</td>
</tr>
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<td>3</td>
<td>10.1</td>
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<td>6</td>
<td>11.2</td>
<td>31</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>11.0</td>
<td>46</td>
</tr>
<tr>
<td>Cottonwood</td>
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<td>40</td>
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<tr>
<td></td>
<td>2</td>
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<tr>
<td>Average</td>
<td></td>
<td>15.1</td>
<td>39</td>
</tr>
</tbody>
</table>

*Age of sample trees was 29-30 years for pine and 25-26 years for cottonwood.*
The effect of juvenile wood on strength and performance of future wood products could be disastrous.

References:

fluence of short rotation forestry on wood production for sawnwood and veneer. P. 60-75 in Proc., Div. 5, 17th IUFRO World Congress, Japan.


ZOBEL, B. 1972. Three rings-per-inch. dense southern pine—can it be developed? J. For. 70:333, 335.

Questions for Future Research

The Society of American Foresters is working to bring foresters and wood technologists together. On October 17, 1985, the Portland Chapter of the Oregon SAF and the Pacific Northwest Section of the Forest Products Research Society will cosponsor a workshop on “Juvenile Wood—What Does It Mean to Forest Management and Forest Products?” The program will be repeated on November 7 in Bellingham, Washington, with the North Puget Sound SAF Chapter. In March 1986, the FPRS will sponsor, in cooperation with SAF, a 2½-day national conference on “Managing and Marketing the Changing Timber Resource.” SAF has taken part in recent meetings sponsored by universities, the USDA Forest Service, and the Canadian Institute of Forestry. Among topics being addressed are the following:

How can relative physical and mechanical properties of juvenile wood in various species (including hardwoods) be quantified with regard to plantation stock?

Can a practical means be developed to visually segregate lumber containing juvenile wood from that containing mature wood, particularly for structural uses? Or should machine-stress rating be used to assign low-strength lumber—properly identified—an appropriately low-design or nonstress grade?

What are the effects of extensive amounts of juvenile wood on product performance? How does abnormal wood affect composite products such as laminated-veneer lumber, plywood, and particleboard?

Can the extent of juvenile wood and the onset of mature wood be altered by fertilizers and silvicultural treatments?

Can tree varieties of genetically superior stock grown on relatively short rotations also provide end-product suitability?

Can the wood technology community and forest managers, working together, formulate practical guidelines so that forests can produce increased volumes of wood with desired properties?