

Dowel-Laminated Crossties

Performance in Service, Technology of Fabrication, and Future Promise

John P. Howe

Peter Koch

Abstract

It is generally agreed that railroads of the United States must substantially increase their rate of tie renewals, if roadbeds are to be maintained in acceptable condition. To accommodate faster trains and heavier loads, future mainline ties may average larger than the 7- by 9-inch size now in common use; fewer 6- by 8-inch ties will be utilized. A logical source of wood for these ties is the enormous inventory of underutilized small hardwoods in the South, East, and Midwest. The process of dowel-lamination can permit manufacture of wane-free 7- by 9-inch mainline ties from logs with small-end diameters of only 8.3 inches—a size plentiful in this inventory. Bigger ties can easily be fabricated from logs only slightly larger. Through use of a new type of conversion machine — the shaping-lathe headrig—lumber recovery can approach 10 bd. ft./ft.³ of log input, with six half-ties produced per minute. Mainline ties dowel-laminated from two half-ties (interface vertical when in place) have suffered no failures in extensive service tests extending over 15 years, and their service life should be at least as long as that usual for one-piece ties. Laboratory tests indicate that dowels withdrawn from dry wood have greater withdrawal resistance if they are inserted in green (rather than dry) wood. When 1/2-inch fluted-steel dowels were inserted in green wood and withdrawn from dry wood of four species, withdrawal forces were highest in hickory and blackgum (average 1,935 lb./in. of penetration) and least in southern red oak and sweetgum (average 1,468 lb./in. of penetration). These findings are useful, because handling costs can be reduced if half-ties are doweled green rather than dry, as is the present practice. Six half-inch fluted-steel dowels per tie should be adequate.

UNTIL WELL INTO THE 19TH CENTURY, railroads in this country laid rails on stone crossties. In 1831, however, this pattern changed when the Camden and Amboy Railroad exhausted its supply of stone, and it is credited with the first use of a wood crosstie (Wingard 1974). From this beginning 145 years ago,

the manufacture of such ties has grown into a major forest products industry. Today, over a billion wood ties support the 350,000 miles of railroad tracks in the United States. The success of these ties in service—particularly under the stress of World War II traffic—is a testament to the utility of wood crossties.

The Problem

After nearly 15 decades of usage of wood crossties by railroads, two problems have lately emerged.

First, a large percentage of the billion ties in the nation's roadbeds have deteriorated because they have been in place longer than their 35-year normal service life. Moreover, axle loads are increasing with passing years causing accelerated wear on the crossties. Railway statistics indicate the serious dimensions of the problem. Replacements of ties diminished from 47 million a year during World War II to a low of 12 million in 1961 (Fig. 1). Twenty-four million ties were expected to be installed in Class I railroads for renewal purposes in 1975 (Anonymous 1975). However, these installations will be down to about 20 million due to the low economic activity in 1975. Predictably, deterioration of roadbeds is contributing to current high accident rates. The Federal Railroad Administration (FRA) has reported that rail accidents hit a 16-year high in 1973; over a third of these accidents were

The authors are respectively, Professor, College of Forestry, Wildlife and Range Sciences, Univ. of Idaho, Moscow, Idaho, and Chief Wood Scientist, So. Forest Expt. Sta., USDA Forest Service, Pineville, La. Acknowledgment is expressed to Robert B. Shoemaker for his help in data collection; the major portion of the work was done at the Pineville Lab. This paper was presented at the symposium "Utilization of Hardwoods Growing on Southern Pine Sites," cosponsored by the Mid-South Section of the Forest Products Research Society and the USDA Forest Service, So. Forest Expt. Sta., March 10-14, 1975, in Alexandria, La. The paper was received for publication in October 1975.

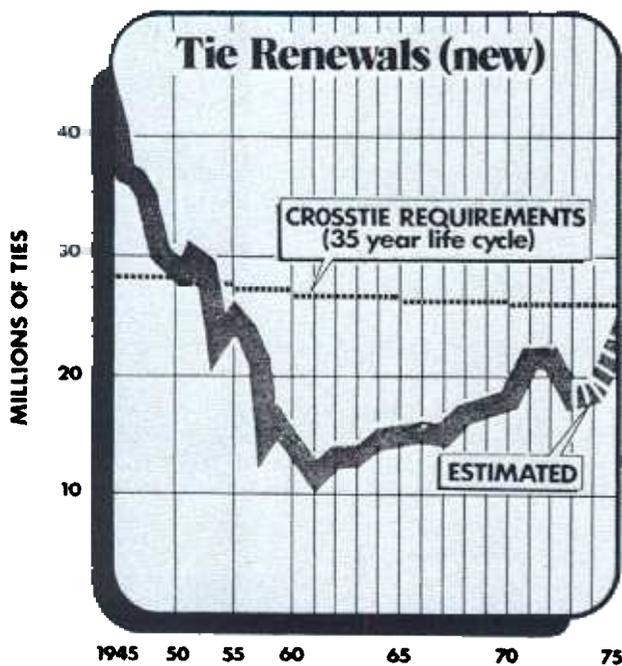


Figure 1. — New crosstie requirements and renewals in the United States, 1945-1975.

caused by deteriorated track, ties, and roadbeds (Anonymous 1974). In the opinion of many engineers, nearly half (44 percent) of the track of the United States' largest railroad is substandard. It is conceded that some stretches of such track cannot even sustain FRA's minimum train speed of 10 mph for Class I track (Anonymous 1974).

A second problem facing railroad purchasing agents and crosstie producers is that, as a general rule, the average hardwood tree is getting smaller each year. Consequently, the cost of large logs often precludes their use for 7- by 9-inch solid mainline ties.

A Solution

Although the supply of hardwood logs larger than 12 inches in diameter (i.e., large enough to yield a 7- by 9-inch tie) is limited, the nation is amply endowed with smaller hardwood trees. Forest Survey data show that across the 12-state southern pine region, for example, there is about 0.8 cubic foot of hardwood on pine sites for every cubic foot of pine. The major portion of this very large—but underutilized—hardwood resource is in diameter classes from 6 to 10 inches DBH. Small hardwoods also stand in profusion in the forests of the Northeast and the Midwest.

In the authors' opinion, these hardwood stands contain more than enough wood to satisfy our crosstie needs now, and in the foreseeable future. Admittedly, most stems are too small to yield a one-piece mainline tie measuring 7 by 9 inches in cross section by 8-1/2 feet long. But they can yield 8-1/2-foot-long half-ties 4-1/2 or 5 inches wide by 7 inches thick. A pair of such half-ties can be steel-doweled together to yield an excellent mainline tie. This procedure is advanced as a solution to the problem.

Dowel-laminated ties have all the advantages of solid wood ties. They are strong, flexible, relatively light in weight, and inexpensive. They wear well, absorb impact, prevent noise, are natural insulators for track circuits, provide a convenient means of changing rail size, and keep well into the ballast to maintain a smooth roadbed surface (Howe 1975). Doweled ties check and split less than solid ties. Moreover, such ties can be more effectively treated because of greater surface-to-volume relationship and because preservative under pressure can reach the central interface of the doweled joint as well as peripheral surfaces. For these reasons, and because defects in adjacent half-ties are randomly staggered, there is justification for believing that the dowel-laminated ties will have longer service life than one-piece ties.

In addition, dowel-laminated wood can easily meet demands for larger ties. This demand is due to increasing use of faster and heavier cars, heavier loads, and heavier rails. Broadening the base of ties increases their load-carrying capacity and thereby permits wider spacing between ties with resultant reduction in quantities of ties and tie hardware.

Advantages of the concept accrue not only to the railroads. Harvest of small hardwoods for half-ties can be a real help to the forest manager, because such harvest gives him the opportunity to cut off-site and suppressed trees and restock with more desirable trees and species. Moreover, half-ties can be made from nonmerchantable top logs as well as small trees; more of each tree harvested can thereby be utilized.

Objective

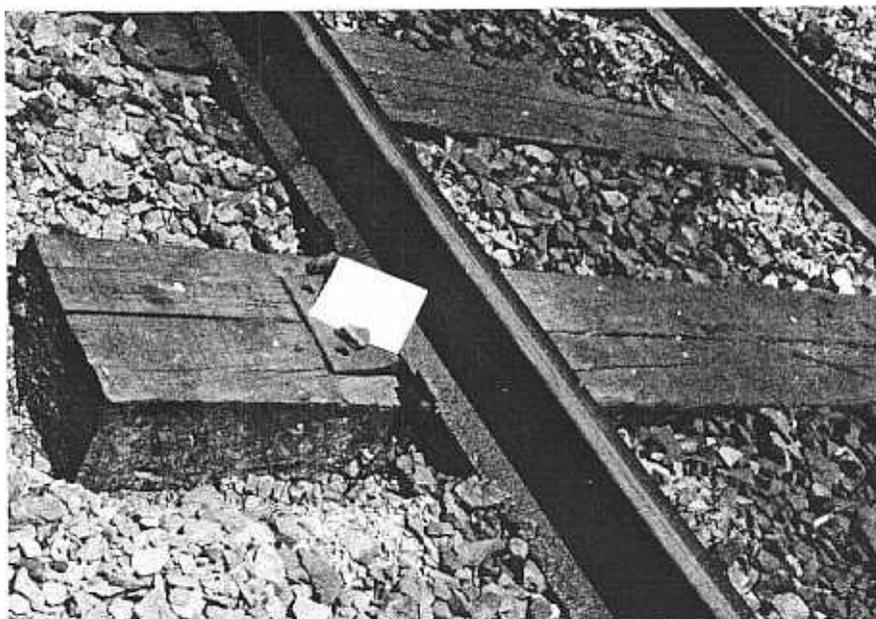
The objective of the research here reported was to evaluate the service performance of dowel-laminated ties, to compare present manufacturing methods with the concept of producing half-ties on a shaping-lathe headrig, and to evaluate the effectiveness of fluted-steel dowels as a means of securing pairs of half-ties into single units.

Service Performance in Track

In 1934, the Pennsylvania Railroad first tested the fluted-steel dowel as an antisplitting device. The dowels were driven horizontally across the grain near the ends of each tie. Subsequent experience of the railroads, and studies by the Association of American Railroads (AAR), proved doweled ties to be the most effective, practical, and economical antisplitting procedure so far developed (Magee 1961). Moreover, the cost of doweled ties was greatly reduced with the introduction of mechanized doweled equipment (Code 1953).

In the past 42 years, doweled ties to prevent splitting has grown into a fully developed commercial practice, and significant numbers of ties have been reclaimed that otherwise would have been discarded (Anonymous 1973). During this period Koppers Company studied the use of steel dowels as a means of laminating ties; service tests resulted from these and other studies (Fig. 2). In June of 1974 major

Figure 2. — Dowel-laminated ties in mainline track of the Chicago and Northwestern Railway between Deval and Shermer, Ill. At time of inspection, the ties had been in service 7 years.



test sites were visited by the senior author, with results as follows.

Field Test at Reevesville, Illinois

Ed McGehee of Koppers initiated trials with installation of 25 dowel-laminated oak ties in the Illinois Central Railroad's main track at Reevesville, Illinois, in August 1961. Each tie consisted of two 8-1/2-foot-long pieces measuring 6 by 7 inches in cross section doweled together to form a 7- by 12-inch tie (Martin 1974). Three different patterns of placing 4, 5, and 7 dowels were used. The ties were installed on 30-inch centers.

In company with Ronald Landry, superintendent of track at the location, these ties were inspected and found to be in very good condition after 13 years of service; Landry commented that these ties performed better than one-piece ties.

For years railroads used wood ties of varying sizes, depending on track load, but spaced all sizes approximately 20 inches apart. Tie size requirements and spacings were never designed in a scientific fashion. In 1965, however, the Railway Tie Association (RTA) entered into a major research program with the AAR to determine the most effective system for supporting rail on wood ties. One phase of this study showed that 7- by 12-inch by 8-foot 4-inch ties spaced on 30-inch centers should give superior performance with respect to track settlement when compared to the conventional 7- by 9-inch by 8-1/2-foot ties on 20-inch centers.

As a follow-up to these conclusions, the following three major field tests were initiated in 1967.

Field Test at Antioch, Tennessee

In March 1967, the Louisville and Nashville Railroad and the Southern Wood Piedmont Company cooperated in a test of 721 dowel-laminated ties installed in mainline track at Antioch, Tennessee

(Bescher 1969). Three types of dowel-laminated ties were included in the test.

The second type of tie had the same overall dimensions but used 3- by 6-inch pieces for the base and a 4- by 8-inch piece for the top. The method of doweeling was the same.

Two of the three types were designed to utilize lumber sizes more readily available than crosstie timbers. The first consisted of two 8-1/2-foot-long pieces measuring 4 by 6 inches in cross section doweled together with four, 4-fluted, 1/2-inch steel dowels to form a 12-inch wide base. A top board 3 by 8 inches in cross section was secured over this base with 8 additional dowels making a finished tie 7 inches thick with an 8-inch wide face and a 12-inch wide base.

These two tie designs used 12 combinations of wood species. Oak, hickory, and mixed hardwoods were used as top lumber. The same species plus pine were used for the bases. A few of the ties were made entirely of pine. About one-fifth of the ties used 1/2-inch lag screws and metal washers. Our inspection showed that the horizontal laminations had pulled apart so much that several ties of these two types had already been replaced.

On the other hand, a third type of dowel-laminated tie was in excellent condition. These 8-1/2-foot ties had been made by doweeling together two pieces measuring 6 by 7 inches in cross section to form a 7- by 12-inch tie. Three patterns of steel dowel applications had been followed, using 4, 5, and 7 dowels per tie.

Field Test at Murfreesboro, Tennessee

In May 1967, a set of 123 dowel-laminated oak ties was installed in the mainline of the Louisville and Nashville Railroad approximately 1-1/2 miles north of Murfreesboro, Tennessee (Bescher 1969). For this trial, Koppers doweled together pairs of 7- by 6-inch by 8-

1/2-foot pieces to make 7- by 12-inch ties. Of the 123 ties, 58 were held with 4 dowels and 65 with 5 dowels. All were installed on 30-inch centers.

At the same time and location a second set of 137 dowel-laminated oak ties was installed on 25-inch centers. These ties measured 7 by 10 inches in cross section and 8-1/2 feet long and were made of two pieces 7 by 5 inches in cross section. Both sets of ties were in excellent condition when inspected in 1974.

Field Test North of Chicago

In November 1967, work was completed on the installation of dowel-laminated ties under 40 rail lengths of a heavy tonnage track on the Chicago and Northwestern Railway between Deval and Shermer, Illinois. These ties were made of two pieces of 6- by 7- inch by 8-1/2-foot red oak doweled together to make a 7- by 12-inch tie. Five 3/4-inch diameter, 3-fluted steel dowels were used on half of the ties and 10 such dowels were used on the other half. Half of the rails had ties spaced on 29-1/4-inch centers while the other half had ties spaced on 23-3/8-inch centers (Anonymous 1968). All of these ties were in excellent condition in 1974.

More Recent Field Tests

In June 1971, dowel-laminated ties were installed in the tracks of the Atchison, Topeka, and Santa Fe Railroad at Oklahoma City, Oklahoma, near the Wilsher Avenue Crossing. Each tie was made of two 6- by 7-inch by 9-foot mixed hardwood pieces surfaced before doweeling; the composite unit was surfaced again after doweeling. Five 5/8- by 12-inch, 4-fluted steel dowels were used, two in each end just outside the rail base and one in the center. These ties were spaced on 30-inch centers for comparison with a set of concrete ties also on 30-inch centers. Inspection showed the wood ties to be in excellent condition. The concrete ties were cracked and were being replaced by wood ties.

In the fall of 1973, 600 dowel-laminated ties were installed in the track of the Louisville and Nashville Railroad between Cedar Grove and Springfield, Tennessee. They were made by doweeling together two

5- by 7-inch by 8-1/2-foot mixed hardwood half-ties. Our June 1974 inspection showed them to be in excellent condition.

Manufacturing Procedures

Dowel-Lamination of Pairs of Half-Ties

Several companies in the United States are equipped to produce dowel-laminated ties using relatively simple procedures. For example, the Koppers plant at Guthrie, Kentucky, follows these manufacturing steps to produce the tie shown in Figure 3:

- 1) unload green half-ties at plant (from truck or trailer);
- 2) incise and end-trim;
- 3) inspect and separate by grade and species and transfer to yard for air-drying;
- 4) transfer to doweeling machine and clamp two half-ties together, bore holes, and insert dowels;
- 5) transfer to adzing machine and adze and bore holes for railroad spikes;
- 6) transfer to treating cylinder and treat;
- 7) ship out or transfer to storage.

In the doweeling operation at Guthrie, a pair of drills enters one side of the pair of clamped half-ties to bore two 3/8-inch diameter holes (Fig. 4). Half-inch fluted-steel dowels are then forced into the two holes from the opposite side of the tie. This process is repeated for the pair of dowels in the center of the tie and the pair in the opposite end. Use of a thrust bearing on insertion rams allows each dowel to rotate and thread itself into the wood, thus imparting maximum withdrawal resistance.

Dowels are made of merchant quality M 10/20 hot-rolled steel fluted one turn per 2-1/2 inches (Fig. 5).

The doweeling machine used at Guthrie was made by Bohr and Hughes of Chattanooga, Tennessee, and was initially designed for the insertion of dowels in the ends of solid ties to prevent splitting. The Lewis Corporation of Tulsa, Oklahoma, has designed a machine specifically for doweeling half-ties together.

Manufacture of Half-Ties

As late as 1920, virtually all ties were hewn by hand—a fact now hard to believe. Today, equipment to

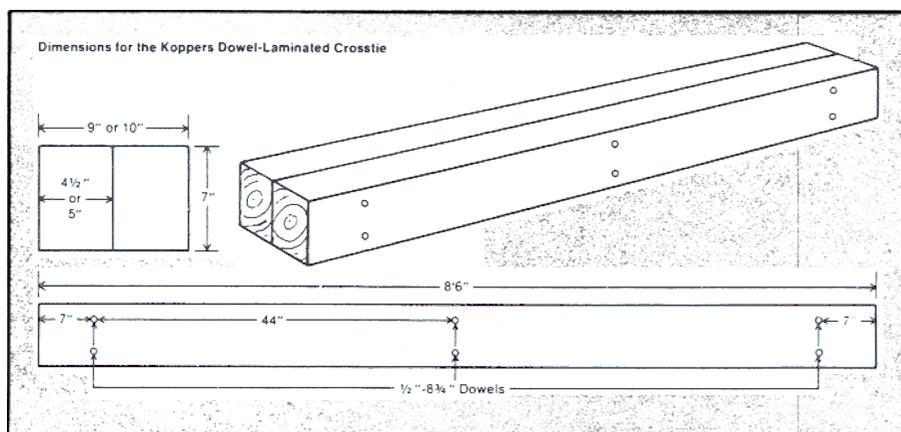


Figure 3. — Koppers dowel-laminated crosstie.

Figure 4. — Plant manager, Glenn Winget, operates machine that dowels two half-ties together.

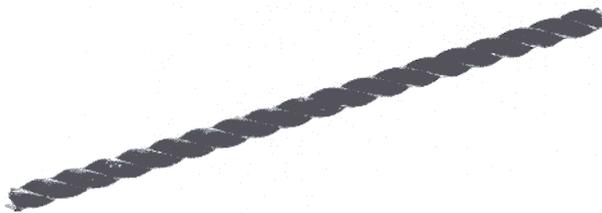
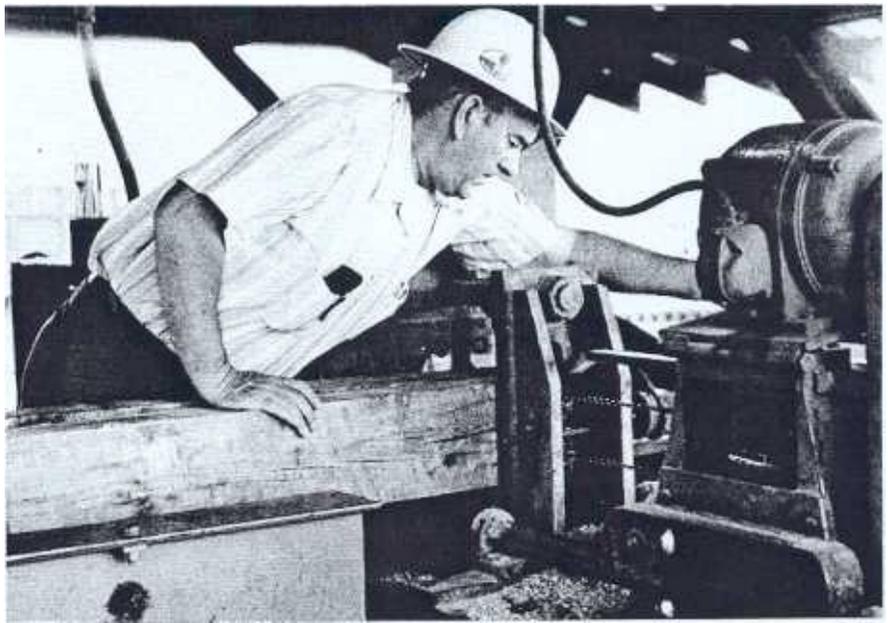


Figure 5. — One-half by eleven-inch steel dowel fluted one turn each 2-1/2 inches of length.

cut ties and half-ties includes conventional circular and bandsawmills, scrag mills, and more recently developed chipping headrigs.

As traditional small tie mills succumb to timber shortages, environmental restrictions, OSHA requirements, labor shortages, and other problems, an ever greater share of the nation's tie output comes from larger mills. Whole-tree utilization plants typical of large manufacturing complexes have proved to be efficient producers of ties. These plants receive tree-length stems and obtain maximum value from them by producing combinations of lumber, ties, pallet stock, and chips depending on species and quality of logs.

The 54-inch shaping-lathe headrig.—A new type of conversion machine—the shaping-lathe headrig—is particularly well adapted to manufacture pallet cants and half-ties from bolts and logs produced in such a whole-tree-utilization plant. The shaping-lathe prototype has been operating for more than a year at the USDA Forest Service utilization research laboratory in Pineville, Louisiana (Koch 1974). The first commercial machine was completed by Stetson-Ross Machine Co., Seattle, Washington, in September 1975, at which time it was viewed by about 100 industry executives. This initial commercial machine

will accommodate logs 40 to 54 inches long; it will be placed in operation in early 1976 manufacturing pallet cants at the Parsons, West Virginia, plant of Hinchcliff Products Co.

The new headrig offers four main advantages over traditional chipping headrigs. It cuts in the 0-90 mode (veneer direction) rather than in the 90-0 or 90-90 mode (Figure 6) and therefore produces a smoother machined surface than other headrigs. Operating on the principle of a shaping-lathe, it relies for workpiece position on end chucks rather than on through-feed chains or rolls; thus, it can accept short logs with butt swell, crook, or sweep while other headrigs cannot. Unlike other headrigs, this version can produce rounds, hexagons, octagons, or trapezoids as well as rectangular cants because cant shape is determined by replaceable cams. Cants produced by the shaping lathe are exceptionally accurate in size, with well-machined corners and smooth surfaces free of tearout around knots. Moreover, its residue is veneer-like particles well adapted for use in structural exterior flakeboard that should be competitive in price and function with sheathing grades of plywood (Hse, et al. 1975, Koch 1975).

Bolts are clamped in the chucks of the workpiece spindle, which turns at about 15 rpm. Attached to the spindle is a replaceable cam having the shape and dimensions of the desired cant. The cam rotates and moves with the workpiece until it strikes a follower aligned with the cutterhead. As the workpiece makes a single revolution, the center distance between cutterhead and workpiece changes in response to the cam, and the workpiece (log) is machined to the shape and dimensions of the cam. Since the log makes only a single revolution while being sized, machining time is brief—approximately 4 seconds. Feed rate is about six bolts per minute.

The 54-inch-long cutterhead is turned at 3,600 rpm by a 300-h.p. motor. Its 12 knives are notched with 3-

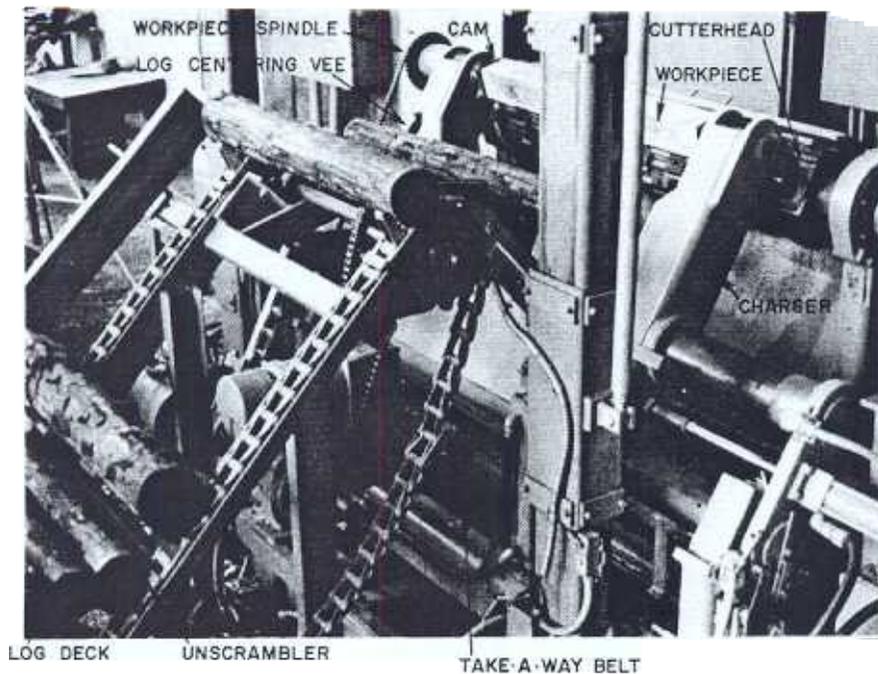


Figure 6. — Commercial version of the shaping-lathe headrig cuts six logs per minute. Smoothly machined cants have the shape and dimensions of replaceable cams mounted on the workpiece spindle.

inch-long cutting edges to produce a 3-inch flake length and staggered so that only six knives cut any given point on the log (Fig. 6). If desired, half the knives can be removed so that only three are cutting. By altering knife holder and knife design, flakes of any length can be cut.

Dull knives must be removed from the head and sharpened on a long-knife grinder. Knives will dull after cutting 1,200 to 1,400 hardwood bolts—a 4-hour run. To minimize downtime, the cutterhead is carried in quick-release bearings that permit fast removal of the entire cutterhead, via monorail hoist, to the grinding room and immediate replacement with another head holding freshly sharpened knives. Downtime for cutterhead replacement is estimated at 25 minutes. Knives can probably wear 1/2 inch before replacement is necessary.

The 8.5-foot shaping-lathe headrig.—Operating on the same principle, a larger version, now in early design phase, will mill 8-1/2-foot-long logs as small as 8.3 inches in diameter into half ties 4-1/2 by 7 inches in cross section at rates up to 6 per minute. Final design of the 8-1/2-foot machine will be settled following observation of the 54-inch machine in production. For half-tie manufacture from 8-1/2-inch logs, an octagonal cross section is proposed (Fig. 7). From such cants a pair of 13/16-inch sideboards can be ripped for pallet lumber leaving a 4-1/2- by 7-inch half-tie. Larger logs could yield a half-tie plus four side boards cut from the four sides of a somewhat larger octagonal cant. By this process, lumber recovery can be high, approaching 10 bd. ft./ft.³ of log. The machine works equally well on both hardwoods and softwoods.

A major advantage of half-ties produced on the shaping-lathe headrig is uniformity in size and shape; accurately milled half-ties are easily processed

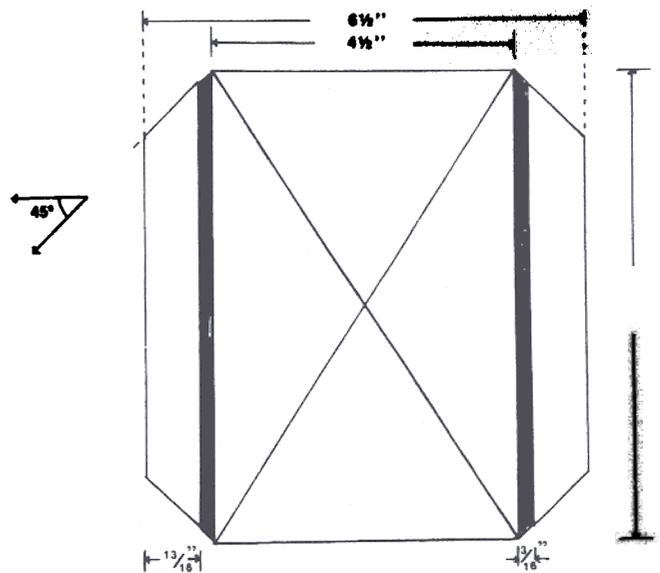


Figure 7. — Octagonal cross section of bolt produced on the shaping-lathe headrig. Removal of two sideboards yields a 4-1/2-by-7-inch half-tie.

through doweling machines, and resulting uniform ties are readily machine-inserted into roadbeds. Half-ties produced on more conventional machinery tend to be less uniform, leading to hang-ups in doweling and placement machines.

Strength of Doweled Joints

Dowels are usually inserted in half-ties after they have been air-dried. Handling costs could be reduced if half-ties were doweled green (after first dipping in a fungicide to forestall rot initiation during drying), since the numbers of pieces to be handled during drying could be halved by this procedure.

One objective of this research, therefore, was determination of force required to insert dowels in green, compared to dry half-ties. A second objective was comparison of withdrawal forces from dry wood, of dowels that had been inserted in green and dry half-ties. The third objective was correlation of insertion and withdrawal forces with wood specific gravity (SG).

Procedure

Logs of four species were cut from trees felled on the Kisatchie National Forest in central Louisiana, as follows: sweetgum (*Liquidambar styraciflua* L.), blackgum (*Nyssa sylvatica* Marsh.), southern red oak (*Quercus falcata* Michx.), and hickory, true (*Carya* spp.). These species are commonly used for ties and represent a broad range of SGs.

A set of ten 6-1/2-inch long bolts of each species were crosscut from these logs and turned to 4-1/2- by 7-inch cross section on a shaping-lathe headrig. The blocks were then end-coated with paraffin and air-dried to 12 percent moisture content (MC).

A second set of blocks identical to the above was then turned on the lathe. A 3/8-inch diameter hole was bored in one of the broad faces of each of these green blocks; holes were located 1-1/2 inches from a side and equidistant from each end. A 1/2- by 11-inch fluted-steel dowel was then inserted in each hole to the full 4-1/2-inch depth of block (Fig. 8). Dowels were of merchant quality M 10/20 hot-rolled steel, fluted one turn per 2-1/2 inches of length. The dowels were furnished by Wadsworth Equipment Co., Akron, Ohio.

The universal testing machine used to insert the dowels was equipped with a thrust bearing on the pressure ram so dowels were free to rotate as they threaded themselves into the wood. Insertion rate was 1.25 inches per minute. The green blocks were then end-coated with paraffin and dried to 12 percent MC.

When the first set of blocks had dried to 12 percent MC, it also was bored, and dowels were inserted as described above. The dowels were then withdrawn from both sets of dry blocks at a rate of 0.8 in./min., and withdrawal forces were measured. Each load determined in these tests was converted to pounds per inch of penetration by dividing load by depth of the dowel's penetration in the block.

Results

Dowel insertion forces.—Average forces required to insert dowels into green and dry half-ties did not

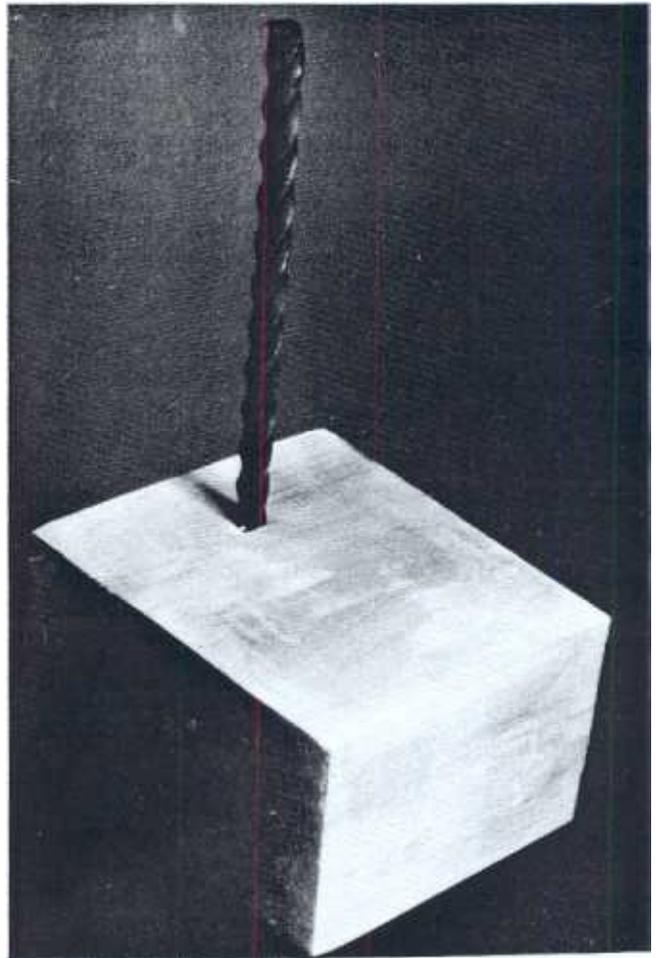


Figure 8. — Fluted steel dowel inserted in a block produced on shaping-lathe headrig. The block is a short section of a half-tie.

Table 1. — AVERAGE FORCES^{1, 2} REQUIRED TO INSERT DOWELS IN GREEN AND DRY WOOD OF FOUR HARDWOOD SPECIES.

Species	Insertion force (lb.)		SG ³	MC
	Green	Dry		
Sweetgum	576	564	0.457	122.5
Blackgum	740	747	.540	82.4
Southern red oak	815	721	.614	86.3
Hickory	1,049	1,254	.707	56.0

¹In pounds per inch of dowel penetration.

²Each value is the average of 10 observations.

³Basis of green volume and oven-dry weight.

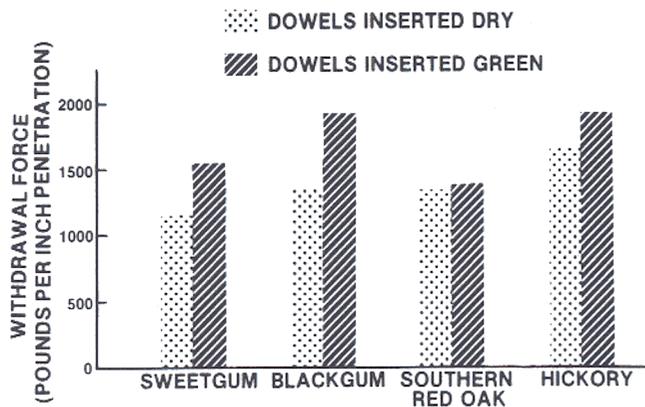


Figure 9. — Average forces required to withdraw fluted dowels inserted in dry and green half-ties. The wood was dry when dowels were withdrawn.

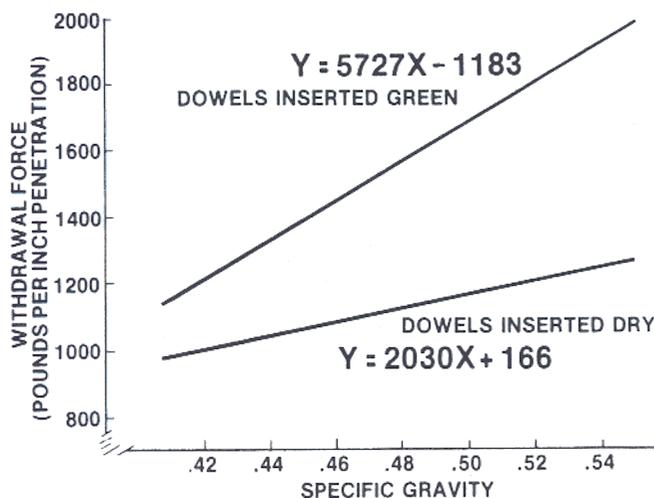


Figure 10. — Correlation between specific gravity (basis of green volume and oven-dry weight) and force (per inch penetration) required to withdraw dowels from sweetgum. The wood was dry when dowels were withdrawn.

Table 2. — CORRELATIONS BETWEEN SG OF WOOD (BASIS OF OVEN-DRY WEIGHT AND GREEN VOLUME) AND FORCE TO WITHDRAW DOWELS FROM WOOD AT 12 PERCENT MC.

Species	Dowel inserted in green wood	Dowel inserted in dry wood
Sweetgum	0.663*	0.742*
Blackgum	.894*	.850*
Southern red oak	.038	.053
Hickory	.526	.019

*Significant at the 0.05 level.

differ significantly (0.05 level) for any of the species tested. Hickory, with specific gravity of 0.707, required about twice the force (average 1,152 lb.) needed for sweetgum of 0.457 SG (average 570 lb.); forces for southern red oak and blackgum were intermediate as were their SGs (Table 1).

Dowel withdrawal forces.—As noted previously, all dowels were withdrawn after the sections of half-ties had dried to about 12 percent MC. With the exception of southern red oak, withdrawal forces were significantly higher when dowels were inserted in green wood (Fig. 9); for southern red oak withdrawal forces did not differ with wood MC on insertion.

For dowels inserted in dry wood, withdrawal forces were significantly highest for hickory (1,664 pounds per inch of penetration) and lowest for sweetgum (1,149 pounds per inch of penetration). For dowels inserted in green wood, withdrawal forces were highest in hickory and blackgum (average 1,935 lb./in. of penetration) and least in sweetgum and red oak (average 1,468 lb./in. of penetration).

In sweetgum (Fig. 10) and blackgum, withdrawal forces had significant (0.05 level) positive correlation with wood SG; this was true for dowels inserted in both green and dry wood. Correlations for southern red oak and for hickory proved to be not significant (Table 2).

Literature Cited

- ANONYMOUS. 1968. RTA-AAR-C&NW test track inspection. *Cross Tie Bulletin* 49(6):9-12, 14, 16, 18, 20.
- ANONYMOUS. 1973. Look what's happening to the wood tie. *Railway Track and Structures* 69(5):16-19.
- ANONYMOUS. 1974. Railbed work may cost \$500 million yearly. *Engineering News-Record* 193(3):16.
- ANONYMOUS. 1975. Seen for 1975: further expansion of rail, tie renewals. *Railway Track and Structures* 71(1):22-23.
- BESCHER, R. H. 1969. Report of RTA Committee on Research and Product Development. Meeting of Railway Tie Association, Philadelphia, Pa. October 22-24.
- CODE, C. J. 1953. Tests of crossties on the Pennsylvania. *Cross Tie Bulletin* 34(6):9-16, 18, 20.
- HOWE, J. P. 1975. Look for wood in crossties. *In Proc. of the 30th Northwest Wood Products Clinic, Missoula, Mont.* May 5-7.
- HSE, C.-Y., C. W. McMILLIN, P. KOCH, and E. W. PRICE. 1975. Laboratory-scale development of a structural exterior flakeboard from hardwoods growing on southern pine sites. *Forest Prod. J.* 25(4):42-50.
- KOCH, P. 1974. Development of the shaping-lathe headrig. USDA Forest Serv. Res. Pap SO-98, So. Forest Expt. Sta., New Orleans, La. 20 pp.
- . 1975. Shaping-lathe headrig will convert small hardwoods into pallet cants plus flakes for structural exterior flakeboard. *In Proc. of the 9th Particleboard Symp., Washington State Univ., Pullman, Wash.* April 1-3.
- MAGEE, G. M. 1961. Research potential for treated wood crossties. *Cross Tie Bulletin* 42(11):51-52, 54, 56, 58, 60.
- MARTIN, G. C. 1974. Personal correspondence with manager, Research Projects Technical Center. Assoc. of American Railroads, Chicago, Ill.
- WINGARD, R. R. 1974. The Railway Tie Association looks to the future. *Cross Ties* 55(5):23, 26-30.