Tree Bracing

TREE PRESERVATION BULLETIN NO. 3

Tree Bracing

by A. Robert Thompson
Forester
National Park Service

TREE PRESERVATION BULLETIN NO. 3 • REVISED 1959

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

NATIONAL PARK SERVICE

Conrad L. Wirth, *Director*

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Foreword

Over 20 years ago the National Park Service was confronted with the problem of improving and maintaining in good condition thousands of valuable shade, ornamental, or historically significant trees within a variety of areas. In order to guide those who were responsible for this work in park areas, a most complete and useful series of nine Tree Preservation Bulletins was prepared between 1935 and 1940 by the late A. Robert Thompson, forester in the Branch of Forestry, National Park Service. The original Bulletin No. 3, *Tree Bracing*, was one of this series.

Although the bulletins were originally intended for park employees, they received wide use of arborists, and this demand has continued. They are being reissued from time to time to meet this need.

The revised series will total seven in number. The original Bulletins Nos. 1 and 2, which were combined in a single publication, are not being reissued because they referred to National Park Service practices only. The original Bulletin No. 9 has been reissued as Bulletin No. 1, *Transplanting Trees and Other Woody Plants*. The original Bulletin No. 8 has been reissued as Bulletin No. 2, *Safety for Tree Workers*. *Shade Tree Pruning*, reissued in 1955, remains as Bulletin No. 4; *General Spraying and Other Practices*, reissued in 1953, remains as Bulletin No. 6; and *Ropes, Knots, and Climbing*, reissued in 1955, remains as Bulletin No. 7. The final publication in the series, *Lightning Protection for Trees*, will be reissued as Bulletin No. 5, retaining its original position.

This bulletin, *Tree Bracing*, remains No. 3 in the series. Except for very minor revisions, it is essentially unchanged from the original, attesting to Bob Thompson's complete and expert knowledge of the subject.

CONRAD L. WIRTH, *Director*.

Contents

Introduction

Tree bracing is one of the most essential phases of an intelligent tree preservation program. One of the most common entrance places for decay fungi is through wounds caused by splitting of limbs. Bracing, therefore, not only prevents the disfigurement of trees but it actually prolongs tree life by preventing the formation of entrance places for fungus spores. Even after a tree is in an advanced stage of decay, bracing may prolong its period of usefulness for many years by providing mechanical support. In order to achieve its fullest purpose, however, bracing should seek to prevent, rather than to correct, damage.

An otherwise sound tree might require bracing for many reasons. Typical symptoms indicating a need for bracing might be found in (1) split crotches, (2) tight **V**-shaped crotches, (3) inherent weakness of species, (4) extra heavy foliage growth, (5) cut or shallow root systems, (6) decay, (7) proximity to structures, (8) removal of nearby trees, (9) borer attack, and (10) prevalence of high wind, sleet storms, or other adverse environmental conditions.

The second symptom in the previous paragraph should be clearly understood. **V**-crotches are often found in species which have multiple or divided trunks. The major limbs may grow so nearly parallel to each other that the cambium and bark are pinched between them, with resulting death of the constricted tissue. The point of contact of the limbs gradually raises as the limbs grow in diameter so that a seam of nonconnecting tissue is gradually developed between them (fig. 1). This results in a weak structural arrangement of the wood elements which may break down under strain. The **U**-shaped crotch, on the other hand, builds up an ever-increasing bond between its member limbs so that it rarely requires artificial bracing. It is, of course, good judgment to prevent the formation of **V**-crotches insofar as this is possible by judi-

Figure 1.—Arrangement of wood elements.

cious pruning and training when the trees are small. Good nursery practice and proper handling of transplated trees will eliminate many **V**-crotches before they become serious.

Among shade trees which often require bracing are maple, elm, willow, hickory, yellow-poplar, linden, and ash. Under certain conditions almost any species might require bracing in order to overcome or correct structural weaknesses, or unfavorable environmental conditions. In deciding bracing problems it should be remembered that it is usually safer to overbrace rather than underbrace, both as to number of braces and strength of materials.

Obsolete Bracing Methods

Early efforts in tree bracing involved expensive equipment and made-to-order materials which were difficult and costly to prepare and install. These obsolete methods included the use of long, rigid iron bars placed high in the trees, iron collars placed around split crotches, chains to hold limbs in position, and various systems of wires and homemade cables (fig. 2).

This work was not only very expensive, cumbersome, unsightly, and difficult to install, but in many cases the results were actually

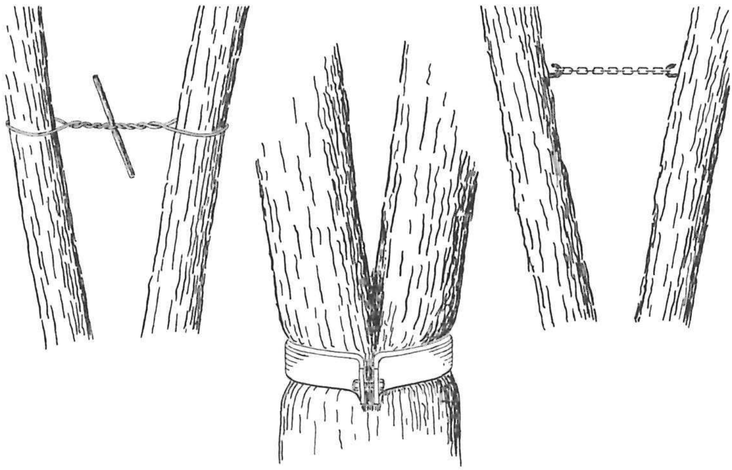

Figure 2.—Typical obsolete bracing methods.

harmful to the trees. The rigid bars tended to resist normal wind sway instead of allowing some movement and thus tended to increase the danger of splitting; the crotch collars retarded sap movement and tree growth, thus weakening and sometimes killing the tree; the cumbersome chains were noisy, ugly, expensive, difficult to install, and inefficient; and the self-made wire cable systems were weak and had many other obvious defects.

Modern Objectives and Materials

The objectives of modern tree bracing are fourfold: First, the bracing materials must be inherently strong; second, the installation must be correct from an engineering viewpoint; third, the installation must injure the tree as little as possible; and fourth, the bracing materials must be reasonably inconspicuous in place.

We are more fortunate today than were our predecessors of

50 or even 15 years ago in our choice of stock materials. Whereas formerly it was necessary to have a blacksmith prepare the cumbersome bands, rods, and chains, today we can order from the nearest supply house such standardized materials as galvanized, copper, or copper-covered wire and strand; galvanized lag hooks, hook bolts, or eyebolts; galvanized and bronze thimbles, threaded galvanized or duralumin screw rod with hexagonal or eye nuts to fit; round, oval, or diamond-shaped washers, special tools and drills to fit pneumatic and electric power units, etc.

These materials may be used in various combinations for such purposes as crown cabling, guying, crotch bracing, cavity bracing, and the bracing of intersecting limbs. While bracing problems will always tax the ingenuity of the tree worker, certain principles and practices have been fairly well standardized through laboratory tests and field experience.

Types of Tree Bracing

Modern arborists usually consider tree bracing under two major divisions: Cabling, and rod bracing. The former term is usually applied to flexible cables installed high up in trees to take a portion of the loads off structurally weak crotches. Under the general heading of cabling, we can properly consider also the guying of transplanted trees.

The term "rod bracing" usually is applied to bolts or threaded rod used for rigid bracing of weak or split crotches, for sewing up long splits in trunks or limbs, for holding rubbing limbs together or apart, and for various types of cavity bracing. It is frequently necessary to resort to both types of bracing in the same tree, but for the sake of clarity we shall consider them as separate subjects.

Cabling

Flexible cable may be used in bracing trees to strengthen weak crotches, to brace trees together, or to support a transplanted tree until the root system is reestablished. As a general rule, cables should be placed as high in the tree as practicable so as to take maximum advantage of the law of the lever and fulcrum and also in order to use as small size and as inexpensive material as practicable to achieve maximum efficiency. It is usually possible to place a cable about two-thirds of the distance from the crotch to the branch tips.

Cabling Systems

The simplest type of a cable brace is a single line of cable placed between two limbs arising from a single crotch.. When several limbs in the same tree are to be braced or when trees are to be cabled together, the problem becomes more complex.

Several general systems of applying a multiple set of cables are in use. Some of these are of questionable merit from an engineering viewpoint. Major systems may be classed as box or rotary, hub and spoke, multiple direct, and triangular. These systems are illustrated in plate I, where it should be noted that the same organization of limbs has been used to illustrate each multiple system.

The triangular system, since it involves the best features of other systems, has been found to be most efficient for general use. It is realized that every application of a cabling system presents individual problems and that it is not always possible or practicable to use the triangular system. In such cases deviations will suggest themselves.

It is thought well to explain briefly the various systems mentioned previously and which are shown on the chart.

Simple direct. This system involves the installation of a single cable directly supporting two limbs arising from a single weak or split crotch.

Triangular. The triangular system combines the best features of all in that it provides direct support for weak or split crotches and provides lateral supports which minimize twisting and act as supplements to the direct supports (fig. 3).

Box or rotary. This is based on a rotary system of cables which are attached to the main limbs of a multibranched tree. Each connected limb is given lateral support, but no direct support of weak or split crotches is provided. The box system permits maximum crown movement.

Figure 3.—Triangular cabling system.

PLATE I
CABLING SYSTEMS

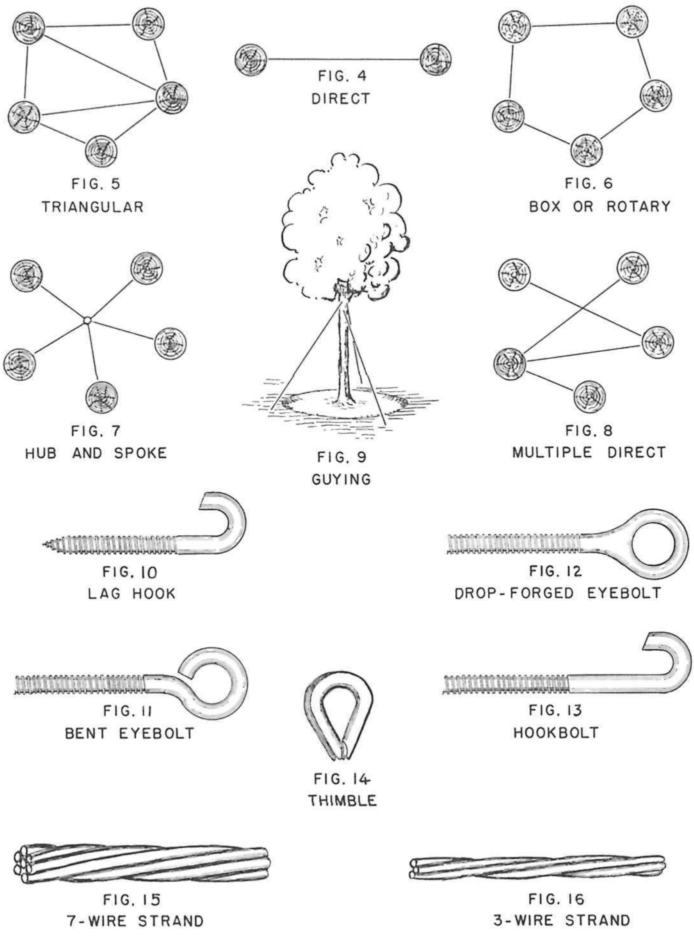

FIG. 4 DIRECT

FIG. 5 TRIANGULAR

FIG. 6 BOX OR ROTARY

FIG. 7 HUB AND SPOKE

FIG. 8 MULTIPLE DIRECT

FIG. 9 GUYING

FIG. 10 LAG HOOK

FIG. 11 BENT EYEBOLT

FIG. 12 DROP-FORGED EYEBOLT

FIG. 13 HOOKBOLT

FIG. 14 THIMBLE

FIG. 15 7-WIRE STRAND

FIG. 16 3-WIRE STRAND

Hub and spoke. This system is based on a group of cables which radiate from a ring in the center of a series of branches. It is usually of minor value since no lateral support and little direct support is provided.

Multiple direct. This type of cabling is good as far as it goes, but lateral as well as direct support should be provided.

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Guying. Guying involves the installation of three or more guy wires to prevent a transplanted tree from being blown over. Wires may be run through short sections of hose to prevent rubbing and constriction where they pass around the trunk, but better practice is to connect wires to lag screws which are inserted in the tree. Grounded ends of guys may be attached to logs, rocks, or steel anchors sunk in the earth as deadmen, or they may be attached to heavy stakes. Guys may be tightened by twisting if several single wires are used, or by turnbuckles if wire strand is used. To be effective, they must have regular maintenance.

Intertree bracing. This is a practice of some value when protecting trees have been removed or where anchor roots have been cut or exposed. Cables should be placed comparatively high in the trees, and support should be given from several directions, especially from the direction of prevailing winds. Generally this practice should be avoided and used only in exceptional cases.

Cabling Material Tests

In order that bracing standards might be based upon scientific knowledge, the National Park Service, in 1935, obtained a large quantity of practically all materials and sizes used in tree bracing and prepared several hundred units, which were tested through the cooperation of the Bureau of Standards. The objectives and results may be briefly stated as follows:

1. OBJECTIVE. To determine the most efficient size hole to drill in several species of live wood for all commercial sizes and lengths of lags in order to achieve maximum holding power.

RESULT. Lead holes one-sixteenth of an inch less in diameter than lags were determined to be generally satisfactory for all commercially available lag hooks.

2. OBJECTIVE. To determine the tensile strength of all sizes of lag hooks, hook bolts, open eyebolts, eye screws, drop-forged eyebolts, 7-wire galvanized strand, and so-called Amon nuts.

RESULT. The relative strengths of materials tested are given in table 1.

3. OBJECTIVE. To determine the most efficient method of making a cable eye splice.

RESULT. A wrapped eye splice with a thimble was shown to be as strong as the strand itself, two wraps of each wire being ample for maximum strength. Previous tests have shown that wire rope clips are only 13 to 15 percent as efficient as the strand.

4. OBJECTIVE. To determine the rate of stretch of 7-wire galvanized strand.

RESULT. Galvanized strand stretches approximately 1.1 inches per square foot before reaching a breaking load.

As a result of these tests we now know the proper size holes to drill for lags, the tensile strength of various sizes and types of lag hooks, eyebolts, 7-wire strand, and thimbles, and the most efficient type of cable eye splice. Knowing these facts we were able to devise an efficient technique and proper combinations of materials for given tensile loads.

These standards for cable bracing are shown in table 1.

Cabling Technique

In deciding the location of cables, several factors must be kept in mind. Cables should be so placed that they will not rub against limbs and cause abrasions. Lags are as satisfactory as bolts in bracing sound hardwood branches, but eyebolts are safer for use in bracing softwoods or hardwoods having some decay. Lags should never be placed in the direct line of intersection of crotches, and if it is necessary to install a lag or bolt near a crotch it is better to stay from 6 to 12 inches above or below the crotch intersection. A cable usually should be so placed that the cable anchors (lags or bolts) on each limb are equidistant from the crotch. In a triangular system the purpose is to build up a triangle or a series of triangles between limbs so that each limb being braced is benefited from at least two directions. Only one cable should be attached to a lag, and lags should be at least 1 foot apart.

After a decision has been reached as to the general location of required cables, the comparative tensile load to be placed upon each cable must be judged. This is not simple, and considerable experience is needed to be able to judge fairly the size of cable needed in each location. Thought must be given to species, general condition of the tree, exposure to winds, presence or absence of decay, whether cavity work has been done or will be done in

TABLE 1.—*Tree cabling material combinations*

[Safe loads for dynamic stresses based on a safety factor of 4]

Safe load (pounds)	Anchor units				Flexible cable				
	Lag screw hooks [1]	Bent hook or eye-bolts [1]	Drop-forged eyebolts [1]	Amon nuts [1]	7-wire galvanized strand [1]	7-wire copper strand [2]	Single-wire copper-covered steel [2]	3-wire copper-covered steel strand [2]	7-wire copper-covered steel strand [2]
	Diameter (in.)	*Diameter (in.)*	*Diameter (in.)*	*Diameter (in.)*	*Diameter (in.)*	*Diameter (in.)*	*No., A.W.G.*	*No., A.W.G.*	*Diameter (in.)*
100	1/4	...	...	...	3/16	3/16	1 No. 12	...	...
200	5/16	...	...	...	3/16	3/16	1 No. 12	...	...
300	3/8	...	...	...	3/16	3/16	1 No. 10	...	...
500	1/2	...	...	...	1/4	1/4	1 No. 6	3 No. 12	...
600	1/2	1/2	...	...	5/16	5/16	1 No. 6	3 No. 10	...
900	5/8	5/8	...	...	5/16	3/8	...	3 No. 8	...
1000	...	5/8	...	...	5/16	3/8	...	3 No. 8	...
1200	...	5/8	...	...	3/8	3/8	...	3 No. 8	...
1400	...	3/4	3/8	...	1/2	...	...	3 No. 7	5/16
2200	...	...	1/2	...	1/2	...	...	...	11/32
3000	...	...	5/8	...	...	...	...	...	7/16
3300	...	...	...	5/8	...	...	...	...	7/16
3700	...	...	...	7/8	...	...	...	...	1/2

[1] Based upon N.P.S.–N.B.S. tests.

[2] Based upon manufacturers' tables.

the tree, condition and shape of crotches, amount of foliage, size of limbs, etc.

The obvious difficulty in applying these factors is the human element which must be depended upon to estimate the maximum load which will be supported by the cabling system. As far as is known, no sure formula has been determined for estimating this load. Attempts have been made to use formulas based upon dead weight of limbs, wind stress on tree crowns, distance of support from crotch, diameters of limbs, etc., but none of these will apply generally, owing to the vagaries of growth. An examination of several hundred galvanized cable systems which had been installed by thoroughly experienced men led to the conclusion that a ¼-inch cable or its equivalent is a safe size for limbs up to 6 inches in diameter at the point of attachment, and a 5/16-inch cable or its equivalent is satisfactory for limbs up to 10 inches in diameter at the point of attachment. In most cases the point of attachment was about two-thirds the distance from the crotch to the end of the limbs.

A decision having been reached concerning the tensile load to be provided for, reference to table 1 will give the proper combination of materials for maximum efficiency.

The most efficient working party for an extensive cabling operation is usually a 3-man crew with one man on the ground for splicing and the other two in the tree, one man working at each end of the cable locations.

Lag Installation

As a rule, lags should be inserted in holes which are drilled one-sixteenth of an inch smaller in diameter than the lag. The hole should be drilled slightly deeper than the length of the lag thread so as to prevent splitting, and it should be so drilled that the cable and lag form a straight line at the point of attachment. Lags should be screwed in up to a point which will just allow slipping the cable splices over the hooks.

After the lags are inserted, the limbs may be drawn together slightly by means of a rope slung between the limbs and tightened by twisting, a lineman's come-along, a running bowline, a block and tackle, or by the use of right- and left-hand lags. This is done to avoid slack in the cable which would surely appear after the cable has had a chance to stretch. Our tests have shown that 7-strand cable achieves a final stretch of about 1.1 inches per foot of length before reaching a breaking point. It is important that no slack be left in a cable or appear later so as to avoid sudden heavy loads placed upon the cable by jerks caused by gusty winds.

The distance the limbs should be drawn together is dependent upon the size of the limbs, the foliage load, and the distance to the crotch, and no specific rules can be laid down. Judgment must be carefully exercised in each case to avoid immediate or later slack. Care must be taken so that the upper foliage is not drawn too tightly together.

With the lags in place, the distance between is carefully measured with a tape and the information given to the ground man. In the meantime he has prepared an eye splice in the end of the cable roll, as described later, and he now kinks the cable at the point indicated by the cablers and cuts the cable at a point 10 to 12 inches below the kink so as to allow material for a splice. After the splice is made, the cable with a splice at each end is hauled up the tree and hooked over the lags. If the lag has previously been turned in so that when the head is at right angles to the direction of the limb there is just enough space to slip the splice over the hook, then the lag should be given a quarter turn so that the head is parallel to the direction of the limb. The opening of the hook should touch the bark of limb and the splice becomes locked in place and cannot jump off the hook. Cables may also be locked by inserting a nail in a hole in the hook of the lag if a drilled lag is used or one strand of the splice may be left free for wrapping around the lag hook. The rope sling or other tightening device may then be released and the job is completed.

Perhaps a word should be added here regarding the superior value of copper-covered steel wire and strand as opposed to the commoner galvanized strand. It is true that the former material is slightly higher in initial cost, but size for size it is considerably stronger. It will not rust, and therefore the ultimate cost of the bracing operation is reduced.

Eyebolt Installation

If eyebolts or hook bolts are used as cable anchors, the general cabling procedure is approximately as previously described for lag installation. The holes for such bolts should be drilled the same diameter as the bolts, however, and it is necessary to provide a countersink for the nut and washer. A countersink is prepared in the following manner. The exact shape of the washer (round, oval, or diamond) is first marked with a chisel on the bark. Then this bark and about one-eighth of an inch of wood is excavated so that the wound will heal properly (fig. 17). The cambium edge

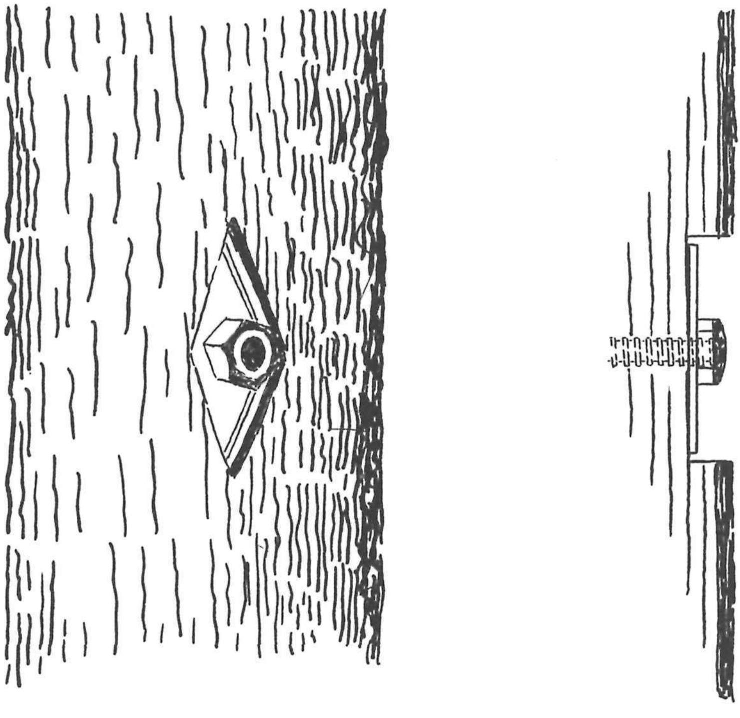


Figure 17.—Countersink.

should then be shellacked. The back of the countersink must be exactly at right angles to the direction of the bolt so that the washer may lay perfectly flat.

The splicing of the cable is easier done on the ground but may be accomplished readily after the bolts are inserted in the holes. Use may be made of the threads on the bolt to draw the cable taut if the bolts are long enough, although it is usually necessary to use some other method of drawing the limbs together also.

It is important that the bolt and cable form a straight line so as to minimize movement of the bolt in the hole, which would prevent healing. For the same reason and to prevent the cable jumping off the hook, it is necessary that the head of a hook bolt be drawn snugly against the limb. The eye of the hook or eyebolt should, of course, be left parallel to the direction of the limb.

Before the bolt is thrust into the hole it is well to cover the threads with a thick plastic material such as roofing putty or tree dressing, in order that water and air may be excluded. The entire countersink should be painted with a good tree-wound dressing.

Cable Splicing

A cable may be attached to a lag or eyebolt by means of an eye splice or a cable clamp, such as is used by line companies and some tree workers. Tests have shown that a cable clamp has an efficiency of only one-seventh of the cable itself, while our tests have definitely shown that a properly constructed eye splice squals the cable in efficiency. The eye splice is also more desirable than the cable clamps because of relative inconspicuousness.

An eye splice in 7-wire strand is made as follows (fig. 18): First a loop is made by bending the cable about 10 to 12 inches from the end, then a thimble, or eye, is inserted in the loop. The wires of the 10-inch section are then unwrapped and laid along

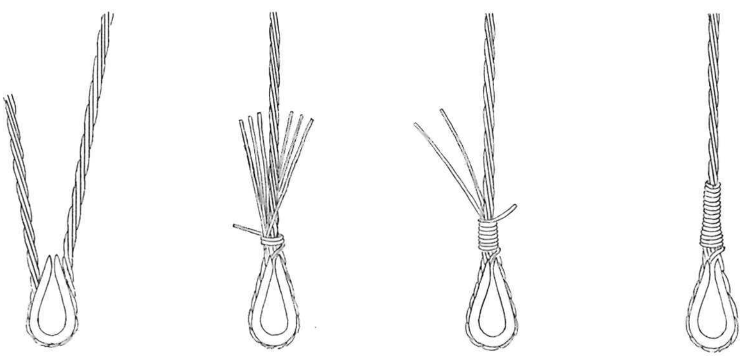


Figure 18.—Steps in making an eye splice in 7-wire strand.

parallel to the main piece of cable. One strand is selected and wrapped with pliers tightly around both the cable and the remaining six strands. Two wraps are made with this strand, which is then cut off. The rest of the strands are then wrapped, one at a time, as with the first strand. This results in a tapered eye splice which is not only efficient but is inconspicuous. Our tests have shown that one wrap of each strand will give maximum efficiency, but, since it is practically as easy to make two wraps, this number should be used for the sake of a possible margin of safety and for the improved appearance.

An eye splice in copper-covered steel wire or strand is formed essentially as described above except that in twisting the individual wires a wire server is used instead of pliers, which would scrape the copper coating.

Cable Maintenance

In practice it has been found that no matter how carefully cable systems are installed, it is good judgment to provide periodic inspections in order that slack may be taken out of an occasional sagging cable, that rust spots may be touched up, or rusty sections replaced, etc. Normal tree growth may cause cable sag, and this normal growth may also indicate need for additional cables placed higher in the tree. No exact figures are available on the average life of a cable, but common sense dictates that each cable should be thoroughly checked and replaced if necessary at least every 3 years. Ordinarily, cables should be checked each time the tree is worked and corrections made as necessary.

Bolting or Rod Bracing

The term "bolting," or "rod bracing," is applied to rigid bracing accomplished with the use of prepared lengths of steel rod of various diameters which have been threaded with lag thread or machine thread. The common term for such material is screw rod, and it may be used with or without nuts and washers on the ends of the bolts.

When nuts and washers are not used, the holding power of the screw rod is dependent upon the self-threaded channel made in the wood as the rod is screwed in, and hence the hole must be of smaller diameter than the rod. When nuts and washers are used on the rod ends, it is customary to drill the rod hole the same diameter as the rod or larger. Since it is good judgment to use all of the holding power available, however, the rod hole should normally be drilled smaller than the screw rod to be used, except where it is necessary to draw parts of a tree together.

The screw rod has four major uses in modern practice of tree preservation. These major uses may be classified as crotch bracing, lip bolting, holding limbs tightly together or apart, and cavity bracing (pl. II).

Crotch Bracing

Screw rod is used in modern practice where it is necessary to provide a rigid crotch brace. Split crotches usually require such provision, and weak but unsplit crotches are often benefited by rigid bracing as a supplement to cable bracing. No attempt will be made in this bulletin to describe the wound treatment required by a split crotch since this matter is discussed in Tree Preservation Bulletin No. 4, *Shade Tree Pruning*.

Single rod. It is sometimes sufficient in small trees to drill one hole through or just above the crotch and insert a piece of screw rod so that the two sections of the crotch are securely fastened together (fig. 20, pl. II). The problem usually is not so simple, however, and large split or weak crotches may require two or more lengths of screw rod in order to achieve necessary strength and rigidity.

Parallels. When two rods are used in bracing a single crotch, these rods are usually placed parallel to each other and side by side, rarely one over the other. These rods are known among arborists as "parallels" by reason of their position (fig. 19, pl. II). If the rods are to be used simply to maintain the relative position of the two limbs being braced, the holes for the rods are drilled

PLATE II

ROD BRACING

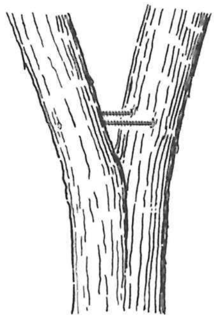


FIG. 19
PARALLEL RODS

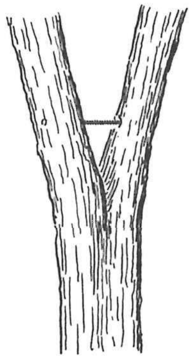


FIG. 20
SINGLE BOLT

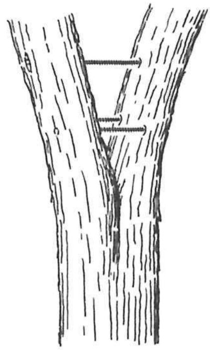


FIG. 21
PARALLELS AND SAFETY BOLT

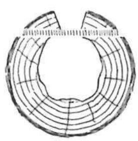
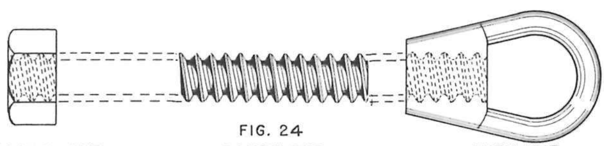


FIG. 22
LIP BOLT

FIG. 23
CROSS BOLTS



HEXAGONAL NUT

FIG. 24
SCREW ROD

AMON NUT

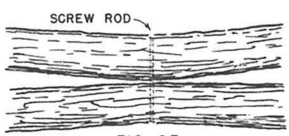


FIG. 25
LIMBS BOLTED TIGHTLY TOGETHER

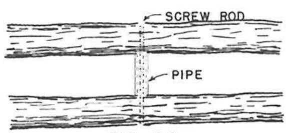


FIG. 26
SEPARATED AND FIXED IN POSITION

one-sixteenth of an inch less in diameter than the rods so that the threads may cut a similarly threaded channel in the wood as the rods are screwed in. If the rods have a holding length at each end of at least 6 inches of sound wood, this self-threaded channel will provide sufficient holding power. But if the wood is even slightly rotted or is apt to become so in the future, or if the wood thread is less than 6 inches, it is necessary to cut countersinks (as described under "Cabling") and to place nuts and washers on each end of each rod.

Parallel rods rarely should be placed closer than 5 inches or farther than 18 inches from each other. A rule of thumb which may be used in deciding how to place parallels is based upon the diameter of the limbs of the crotch at the point of insertion. In using this rule, parallels are separated a distance which is equal to one-third to one-half of the diameter of the limbs. Thus parallels used to brace two 15-inch limbs should be placed from 5 to 7½ inches apart.

Safety bolts. Very often it is necessary to increase the safety factor of braced crotches over that provided by parallel rods. The rigidity should often be increased also. When this additional safety factor is required, it is supplied by the installation of an additional length of rod from 1 to 3 feet above the parallels in a position which is parallel to, and approximately equidistant from, each rod (fig. 21, pl. II). The same requirements for hole diameter apply to safety bolts as have been discussed for parallels, except that nuts and washers should always be used on safety bolts as an additional factor of safety.

Lip bolting. The term "lip bolts" may be applied to rods which are used to "sew up" a long split in a limb or trunk (fig. 22, pl. II). Lip bolts are often used in cavity bracing but are also very useful in providing mechanical support even though no cavity treatment is accorded the split area. The same rules for hole size apply to lip bolts as were previously mentioned for parallels. Lip bolts usually should be placed approximately 12 to 16 inches apart, and care should be taken that consecutive holes are not in the same direct line of sap flow but are staggered. When lip bolts are installed in thin-walled wood, it is sometimes necessary to use nuts and washers on each side of the wood wall to provide rigidity and to assure that the walls will not be drawn together.

It must not be inferred by the foregoing paragraphs that bolting is necessarily limited to the types described. While the use of parallels, safety bolts, and lip bolts will usually provide sufficient rigid bracing, it is often necessary to add to these bolts by supplementary rods. These may be installed as the necessity arises and in such quantities as experience and good judgment dictate. A tightly fitting pipe covering placed over exposed rods will increase their rigidity to a considerable degree as well as protect them from the weather.

Bracing Rubbing Limbs

When two limbs develop so that they rub together, it is usually desirable to remove one of the offenders. This practice would often destroy a very desirable limb, however, and it is frequently considered better judgment to resort to bracing. Rubbing limbs may be either held tightly together or braced apart.

If limbs are to be held together and encouraged to form a graft (fig. 25, pl. II), the cambium should be traced away from the points of contact, and the resulting wounds should be given necessary treatment; then a hole should be drilled directly through the two limbs for the bolt. Usually it is necessary to provide nuts and washers to augment the holding power of the thread in the wood and, of course, countersinks should be provided for nuts and washers when used.

If limbs are to be held apart, they should be blocked apart temporarily while a hole is drilled in a direct line through the two limbs. As the rod is inserted, either two nuts and two washers or a pipe covering should be placed on the rod between the two limbs in order to provide a permanent separated position (fig. 26, pl. II). The ends of the bolt should, of course, be provided with nuts and washers in the usual manner.

Cavity Bracing

Regardless of the type of treatment to be accorded a major tree wound, a certain amount of bracing is usually required in an attempt to replace artificially the inherent strength of the decayed or removed woody tissue and to hold the cavity walls in position. Much of the previous discussion concerning crotch bracing, lip bolts, etc., may be applied to cavity bracing, but additional strengthening is sometimes indicated. This work may be classed as internal bracing. This may take the form of cross bracing or backbone bracing.

Cross bracing involves alternate placing of screw rods diagonally across a deep cavity so that in plan the rods form an X shape. Such bracing will keep the side walls from spreading and will tend to minimize the twisting strains that do so much damage to filling materials (fig. 23, pl. II).

Backbone bracing is sometimes used in an attempt to reduce longitudinal wind sway, but the stresses set up in a large wound and the leverage exerted by a tree in a heavy wind are so great as to preclude any major benefits from this type of bracing. Its use is rarely recommended. Indeed, if a tree is in such a bad condition as to indicate the need of extensive internal bracing of any kind, it is usually better judgment to replace the tree with a healthy one.

Rodding Standards

1. Standard screw rods should be cadmium-plated lag-threaded rods in ⅝-, ¾-, and 1-inch diameters. Cadmium-plated hexagonal nuts and diamond-shaped cadmium-plated washers should be provided for these sizes of rods.
2. Holes for all rods should be drilled one-sixteenth of an inch smaller in diameter than the rods except where it is necessary to draw limbs or split trunks together, in which case holes of the same diameter as the rods are to be used.
3. Washers should invariably be countersunk not less than one-eighth of an inch below the cambium, in holes of exact shape and size of the washers. The floor of such countersinks must be so cut that the washers will lay perfectly flat and exactly at right angles to the rod.
4. All rod holes except countersinks should be reamed below the cambium so as to avoid springing of cambium and bark.
5. All rods should be covered with a mastic or tree-wound dressing as they are being inserted, and all countersinks and reamed holes should be painted with approved wound dressing after nuts and washers are covered with a metal-preservative paint.
6. All exposed rods should be covered with tightly fitting pipe which should extend the full length of the exposed area so as to provide protection and extra stiffness.

7. All exposed rods, pipe nuts, and washers should be painted with a metal-preservative paint.

8. When rods and nuts are to be used for drawing split crotches together, it is often necessary to provide two or more washers under each nut for additional stiffness. A round washer between the diamond washer and the nut will help to keep the diamond washer from twisting.

9. When a rod is to be broken off below the cambium, the rod should be cut nearly through before it is inserted in the hole. This cut should be approximately 1½ inches from the rod end so as to allow purchase for a stillson wrench. Care must be taken when inserting rod so that wrench marks do not damage threads that have to engage wood or nuts.

10. In drilling for screw rods, it is important to have holes in opposite limbs exactly lined up. A long extension bit is very useful for this purpose. If such a bit is not available, observers from at least two angles should direct the drilling to make sure that the holes will be in alinement.

11. Care must be exercised in tightening nuts on screw rods so that the bark and cambium are not injured. A socket wrench should be used for this purpose. One end of the thread on the rod should be left exposed after tightening the nut, and the rod rounded off with a ball peen hammer to prevent the nut from working loose.

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