BRACE RODS FOR CODOMINANT STEMS: INSTALLATION LOCATION AND BREAKING STRENGTH

by E. Thomas Smiley[1], Craig M. Greco[2], and James G. Williams[3]

Abstract. The location at which brace rods should be installed to reduce the risk of breakage in codominant stems traditionally has been below the crotch. In this study, codominant stems were pulled apart with measured force to determine if crotch strength was increased by installing a rod above the crotch rather than in the traditional rod location below the junction. With both red oak *(Quercus rubra)* and red maple *(Acer rubrum)*, the strength of the codominant stem was increased significantly by installing the rod above the crotch a distance equal to the diameter of one of the stems. Brass rods tended to fail more than steel rods in oak but may be useful in small, weaker-wooded trees.

Key Words. Crotch strength; hazard tree; threaded rod; limb breakage.

Brace rods are installed in trees to reduce the potential for codominant stem splitting or to repair splits. The recommended location for brace rods installation varies among authors. Thompson (1959) recommends that a single rod be installed through or just above the crotch. However, in his diagram the rod is installed above the crotch at a height approximately equal to the diameter of a codominant stem. The National Arborist Association standard (1985) specifies single or double rods be installed slightly below the crotch. Mattheck and Breloer (1994) state that if a fork is split, a rod should be inserted 10 cm (4 in.) above the "tip" (lower end) of the crack. However, their diagram shows the location of the rod below the junction. However, their diagram shows the location of the rod just below the junction.

This study was conducted to determine the strength of codominant stems with two rod locations and compare them with the strength of codominant stems without brace rods.

MATERIALS AND METHODS

Twelve red maple (*Acer rubrum* L.) and 12 red oak (*Quercus rubra* L.) trees were harvested in June and July 1999 at the Bartlett Tree Research Laboratories in Charlotte, North Carolina. Codominant stems were removed from the felled trees, leaving at least 46 cm (18 in.) of stem on either side of the crotch. Stem diameter was measured 30 cm (12 in.) below and above the crotch. Diameter varied from 4.9 to 15.6 cm (1.94 to 6.15 in.) below the crotch and from 2.9 to 13.8 cm (1.16 to 5.45 in.) above the crotch

Codominant stems were treated in one of three ways (Table 1). A conventional brace rod was installed approximately 2.2 cm (1/2 in.) below the crotch, or a brace rod was installed above the crotch at a distance approximately equal to the diameter of one of the stems above the crotch. The third treatment was a control with no brace rod installed. Steel or brass 9.5-mm (3/8-in.) diameter machine threaded rods were inserted through 11-mm (7/16-in.) diameter holes. They were fastened with nuts on top of a heavy-duty washer of the same metal with an outside diameter of 25 mm (1 in.) and thickness of 2 mm. Twenty-nine red maple and 34 red oak crotches were tested.

The crotches were fastened to a large tree trunk using nylon straps 30 cm (12 in.) above and below the crotch (Figure 1*). A 1.2-cm (1/2-in.) diameter polyester line was tied to the nonattached stem at 30 cm above the crotch. This line was run through a block and was tied to a Dillion 4,000-lb peak reading mechanical dynamometer (Weight-Tronix, Fairmont, MN). The dynamometer was attached to a tractor (Figure 2). The tractor was driven at a 0.85 m/sec (2 mph) until failure occurred. The peak reading on the dynamometer was recorded.

*Figures for this article begin on page 174.

Table 1. Bracing treatments applied to codominant stems of two tree species. Rods were located above the crotch a distance equal to the diameter of the stem or below the crotch in the conventional location. There were 11 red maple and 10 red oak control crotches had no rod installed.

Species	Rod placement	Brass	Steel
Red maple	above	2	6
	at crotch	3	7
Red oak	above	7	8
	at crotch	6	3

RESULTS

Breaking force varied from 64 to 1,818 kg (140 to 4,000 lb) and was dependent on species, diameter, and rod location. Stem breakage occurred in consistent patterns. When using a conventional brace rod location or when the rod was installed above the crotch, the failure occurred at or directly above the rod (Figures 3 and 4). When no rod was installed, the failure occurred at the junction between the codominant stems (Figure 5).

Four control-treatment red-maple crotches were discovered to have included bark. The number of samples was too low to analyze statistically; however, the force required to break the crotch was considerably less than expected for a crotch of equal size without included bark. Because the rod treatments broke at a point above the junction, the number with included bark was unknown. All data were included in the regression analysis.

Hardware failure occurred in red oak when 4 of 13 (30%) brass rods broke at the same time or after the wood failure occurred. No rod failures occurred with red maple. Steel rods bent, but none broke. Nuts pulled through the washers twice, one brass and one steel, one oak and one maple. A slightly misdrilled, oversized hole in one limb and a small area of decay near the hole in the other may account for a weakness below the washer that allowed the bending of the washer and eventual pull through.

Linear regression analysis was conducted on the combined steel and brass rod data for each species (Figures 6 and 7). The regression line formula and r^2 values are presented in Table 2. Regression lines were compared for slope and Y-intercept using the general linear test approach (Neter and Wasserman 1974). While Y-intercept was used for statistical purposes, negative values are not found in nature and it is assumed that the actual regression line is not linear in the diameters range less than 5 cm (2 in.) that were not tested.

Table 2. Regression equations and r^2 values for red oak and red maple to determine the force required to break a codominant stem with one of two rod placement locations or nonrodded controls. Diameter (dia) was measured 30 cm (12 in.) below the crotch; it ranged from 4.9 to 15.6 cm (1.94 to 6.15 in.)

Species	N	Rod placement	Equation to determine force in lb	r^2
Red maple	10	at-crotch	447 (dia) – 526	0.64
	8	above	859 (dia) – 1,722	0.89
	11	control	546 (dia) – 1,051	0.79
Red oak	9	at-crotch	820 (dia) – 2,024	0.89
	15	above	1,541 (dia) – 3,975	0.72
	10	control	603 (dia) – 1,337	0.94

For red maple, there were no significant differences in Y–intercept. Slopes were significantly different between above-crotch rods and control ($P \leq 0$ .058), and between above-crotch rods and at-crotch rods ($P \leq 0.03$). There was no difference between slope of the at-crotch rods and the control.

For red oak, there were significant ($P \leq 0.05$) differences in regression line slope and Y-intercept between the rod-above treatment and controls, and the slope between rod-above and at-crotch treatments. There were no differences between the at-crotch rods and the control treatments.

As an example of the regression with red maple, a crotch 10 cm (4 in.) in diameter breaks at 1,100, 1,300, and 1,700 lb for the control, conventional, and above-crotch rod treatments, respectively. For 15-cm (6-in.) diameter crotches, the control and conventional are nearly the same strength, about 2,200 lb, while the above-crotch rod increases the strength to about 3,400 lb.

As examples of red oak, a crotch measuring 10 cm (4 in.) in diameter typically breaks with about 1,000 lb of force with either the conventional rod location or with no rod. Moving the rod about 10 cm upward increases the breaking strength to 2,200 lb. With a 15-cm (6-in.) diameter crotch, the differences among treatments becomes larger. Without a rod, the crotch splits at 2,300 lb. With a conventional rod, the split occurs at 2,900 lb, and with the rod 15 cm higher, the limb breaks at 5,300 lb.

These examples point out that nonrodded crotches of red maple and red oak have virtually the same strength when they are pulled apart; however, red oak branch wood has more strength than red maple, as is reflected in the above-crotch rod treatments. The smaller r^2 values indicate a greater variability among red maple crotches than red oak.

DISCUSSION

When a single brace rod is installed above a crotch in a 9-cm (3.5-in.) diameter or larger codominant stem, there is a significant increase in strength of the system as compared to the system without a brace or with a brace rod below the crotch. With no brace rod, the V-shaped codominant stem junction is weaker than the stem directly above the crotch, so the break that occurs when force is applied is at the junction. A rod installed in the traditional location below the crotch reduces the amount of junction that splits; however, because the wood shape and thickness make this area weaker than that farther up on the stem, the break still occurs at the crotch. Another factor at work is the redirection of forces within the junction area (Figure 8). When a rod is installed above the junction, general rules of mechanics imply that there is a compressive force in the crotch area that may actually increase the strength of the crotch. This redirection of forces makes the limb the weakest portion of the system rather than the junction.

Brass rods were evaluated in this trial because of the large number of small trees, such as Callery pears, redbuds, and flowering cherries, that have numerous weak crotches that may need to be braced. When these trees eventually are removed, it is inevitable that some of the crotch wood with grown-over rods will be fed through a chipper. Tests conducted in conjunction with Mike Morey Jr. (personal communication) indicate that there is far less damage to a chipper when brass rods are chipped than when steel rods are chipped. Therefore, there is less chance for personal injury with brass rods. The brass rods that failed in this trial usually failed at the same time as the limb or after the limb had failed. Brass rod failure occurred only in the stronger oak wood, so the 30% failure rate may be of less consequence than it appears. More research on brass or other more "chippable" rods is necessary to determine where they can be used most effectively. Brass rods should be considered when a lower level of security is needed in a small tree or with weaker-wooded trees. Removing major limb crotches before chipping is recommended where the possibility of rods exists. No type of rods should ever intentionally be fed into a chipper.

Washer failure was rare; however, it occurred twice. In both cases, the nut pulled through washer. The washer never pulled though the limb. These failures point to the necessity of using heavy-duty washers that are larger in diameter and thickness than standard washers. When thicker or heat-treated washers are available, they should be used. At least one distributor is already supplying hardened, galvanized washers (Tobe Sherrill, Sherrill Arborist Supply, Greensboro, NC; personal communication).

Whenever possible, cables should be used in conjunction with brace rods to reduce movement in the crotch. When a single brace rod is used, it should be installed above the crotch union. More research is required to define the exact location above the crotch to install the rods. For larger trees or trees with existing splits, multiple rods will be required, and at least one rod should be installed above the crotch.

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Résumé. Des tiges filetées sont installées dans les arbres pour réduire les bris potentiels de branches codominantes ou pour réparer des branches fendues. la localisation recommandée pour installer les tiges filetées a varié au cours des dernières décennies et selon les auteurs. Thompson (1959) recommandait qu'une tige simple soit installée au travers ou juste au-dessus de la fourche. Cependant, dans son schéma, la tige était installée distinctement au-dessus de la fourche à une distance approximativement égale au diamètre des branches codominantes. Le norme du *National Arborist Association* (1985) spécifie d'installer une simple ou une double tige filetée sous la fourche. Mattheck et Breloer (1994) ont déterminé que si une branche était fendue, une tige devait alors être insérée 10 cm au-dessus de l'extrémité de la fissure. Leur schéma montre la localisation de la tige filetée sous la fourche. cette revue de littérature révèle qu'il n'y a aucune recherche qui justifie chacune de ces recommandations.

Zusammenfassung. Stahlstangen werden in Bäume eingebaut, um das Potential des Ausbruchs von Stämmlingen zu reduzieren oder um schon vorhandene Risse zu reparieren. Die Empfehlungen, wo die Stahlstangen einzubauen sind, variieren über die Zeit und auch mit den Authoren. Thompson (1959) empfiel eine einfache Stange, die durch oder gerade oberhalb der Spalte bzw. Vergabelung eingebaut wird. Dennoch ist in seinen Diagrammen die Stange deutlich höher ,etwa gleich dem Durchmesser der beiden Stämmlinge, eingebaut. Der Standard der nationalen Baumpflegeorganisation (1985) spezifiziert eine einfache oder doppelte Stange, die unterhalb des Risses eingebaut wird. Mattheck und Breloer (1994) führen aus, daß, wenn die Gabel einen Riß aufweist, eine Stange 10 cm über dem unteren Ende desselben einzubauen ist.. Ihr Diagramm zeigt die Plazierung der Stange unterhalb der Vergabelung. Dieser Literaturüberblick enthüllt keine Forschung, die irgendeine der Empfehlungen rechtfertigt.

Resumen. Los pernos pasadores son instalados en los árboles para reducir el potencial de fractura de los tallos codominantes o para reparación de fracturas, que hayan ocurrido recientemente. La ubicación recomendada para instalar los pasadores ha variado con el tiempo y entre autores. Thompson (1959) recomienda que sea instalada una sola varilla a través o casi arriba de la horquilla. Sin embargo en su diagrama la varilla aparece distintivamente arriba de la horcadura a una altura aproximadamente igual al diámetro de las extremidades codominantes. Los estándares de la National Arborist Association (1985) especifican que una o dos varillas sean instaladas debajo de la horquilla. Mattheck y Breloer (1994) establecen que si una horquilla está fracturada, se debe insertar una varilla 10 cm (4 pulg) arriba de la extremidad (extremo menor) de la grieta. Su diagrama muestra la ubicación de la varilla debajo de la horquilla. Esta literatura sólo efectúa una revisión, no hace una investigación que justifique cualquiera de las recomendaciones.

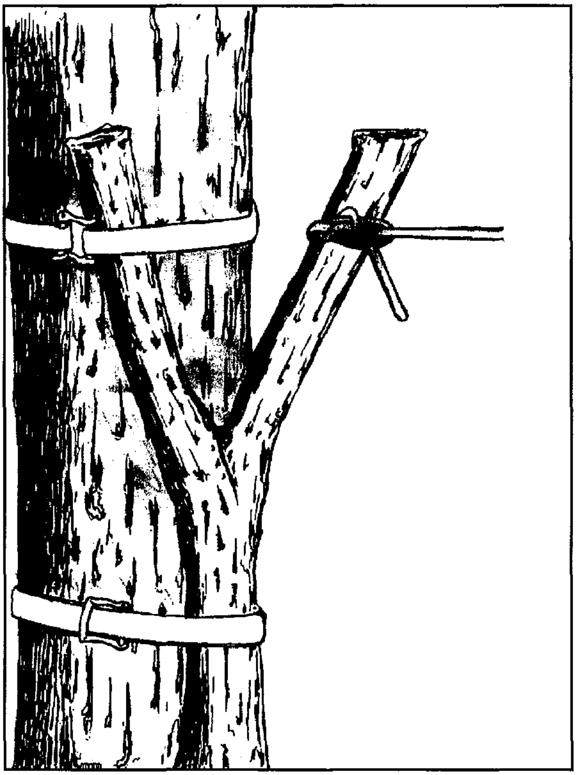

Figure 1. Sample crotches were attached to a large tree at points 30 cm (12 in.) above and below the crotch.

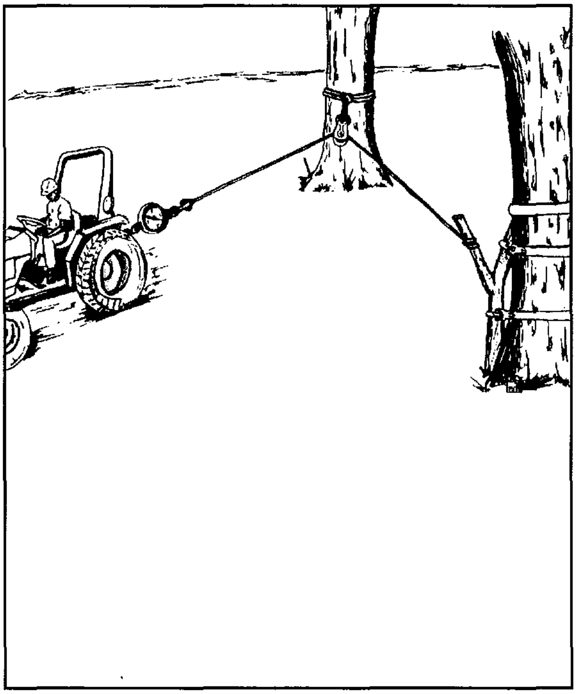

Figure 2. The experimental setup consisted of a half-inch line attached to the free side of the codominant stem and run through a block to a dynamometer attached to a tractor.

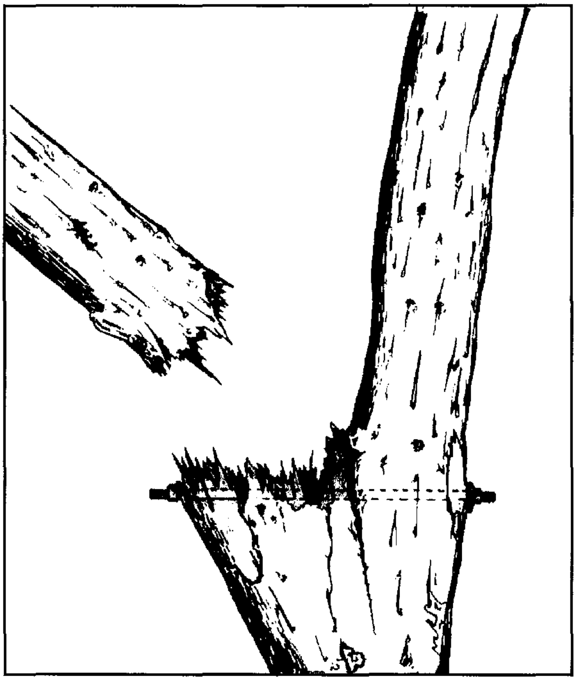

Figure 3. Breakage pattern when a rod is installed in the conventional location below the crotch.

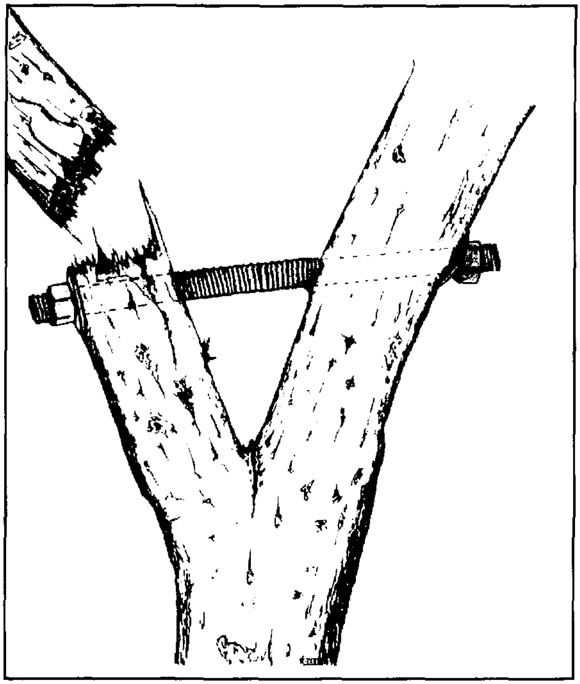

Figure 4. Breakage pattern when a rod is above the crotch.

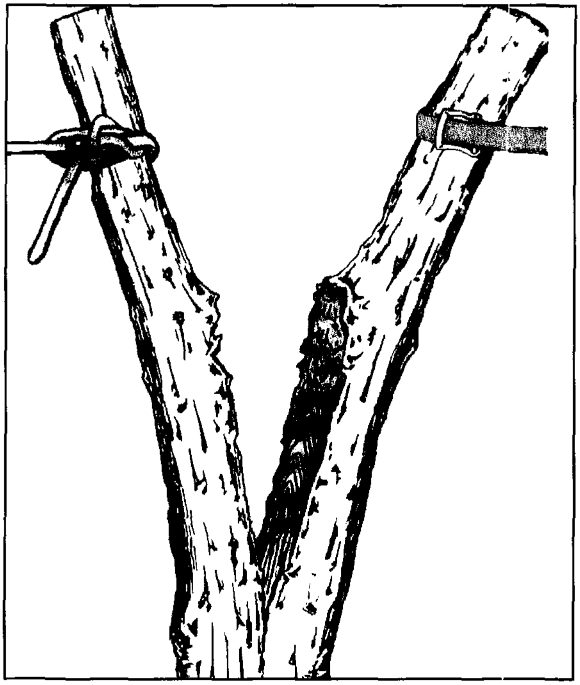

Figure 5. Pattern of breakage when no rod is installed.

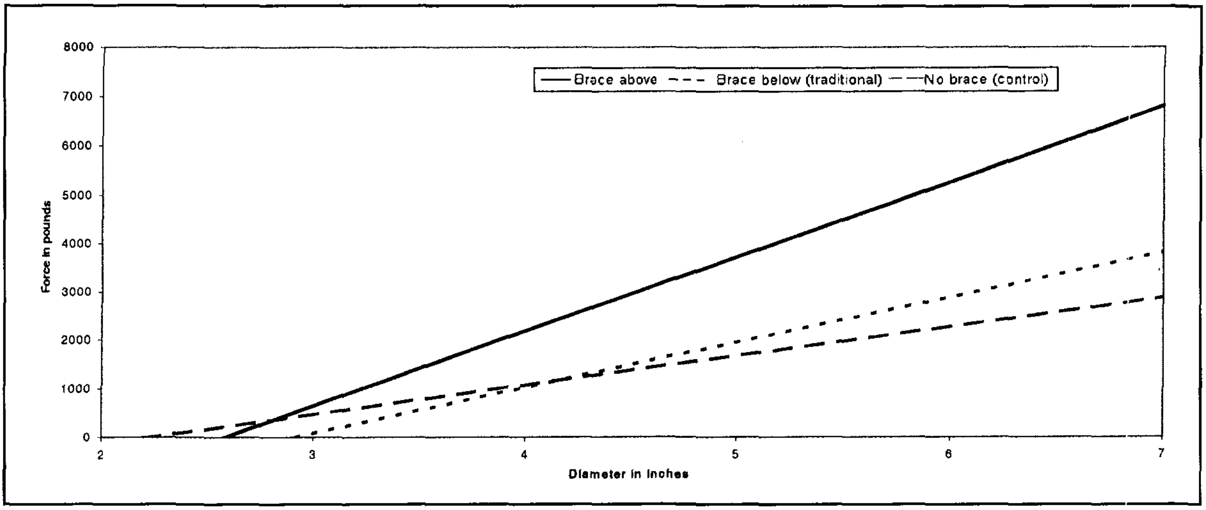

Figure 6. Comparison of breaking strengths on red oak crotch systems with no bracing (control), traditional rod placement at the crotch, and rod located above the crotch.

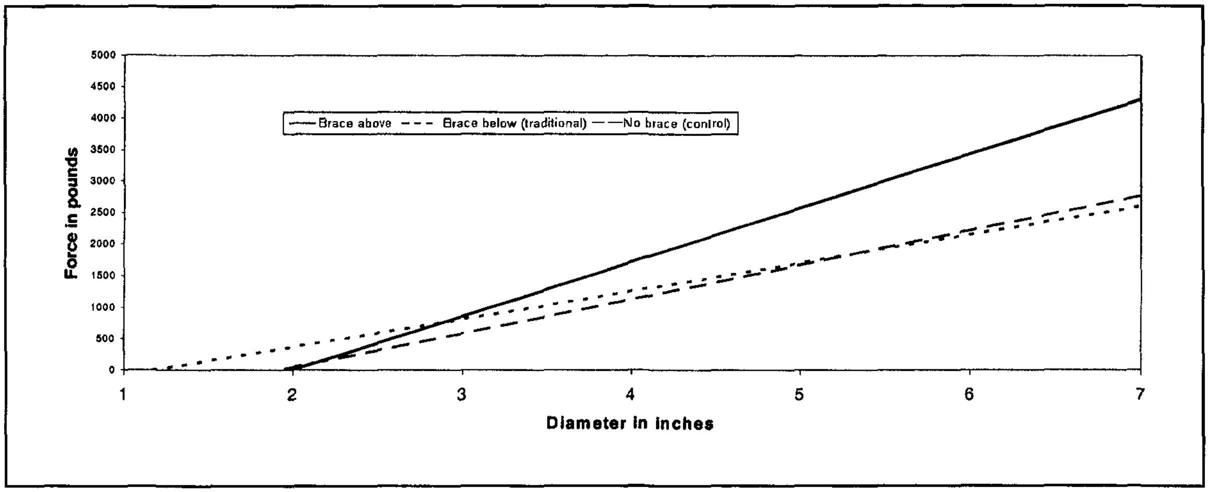

Figure 7. Comparison of breaking strengths on red maple crotch systems with no bracing (control), traditional rod placement at the crotch, and rod located above the crotch.

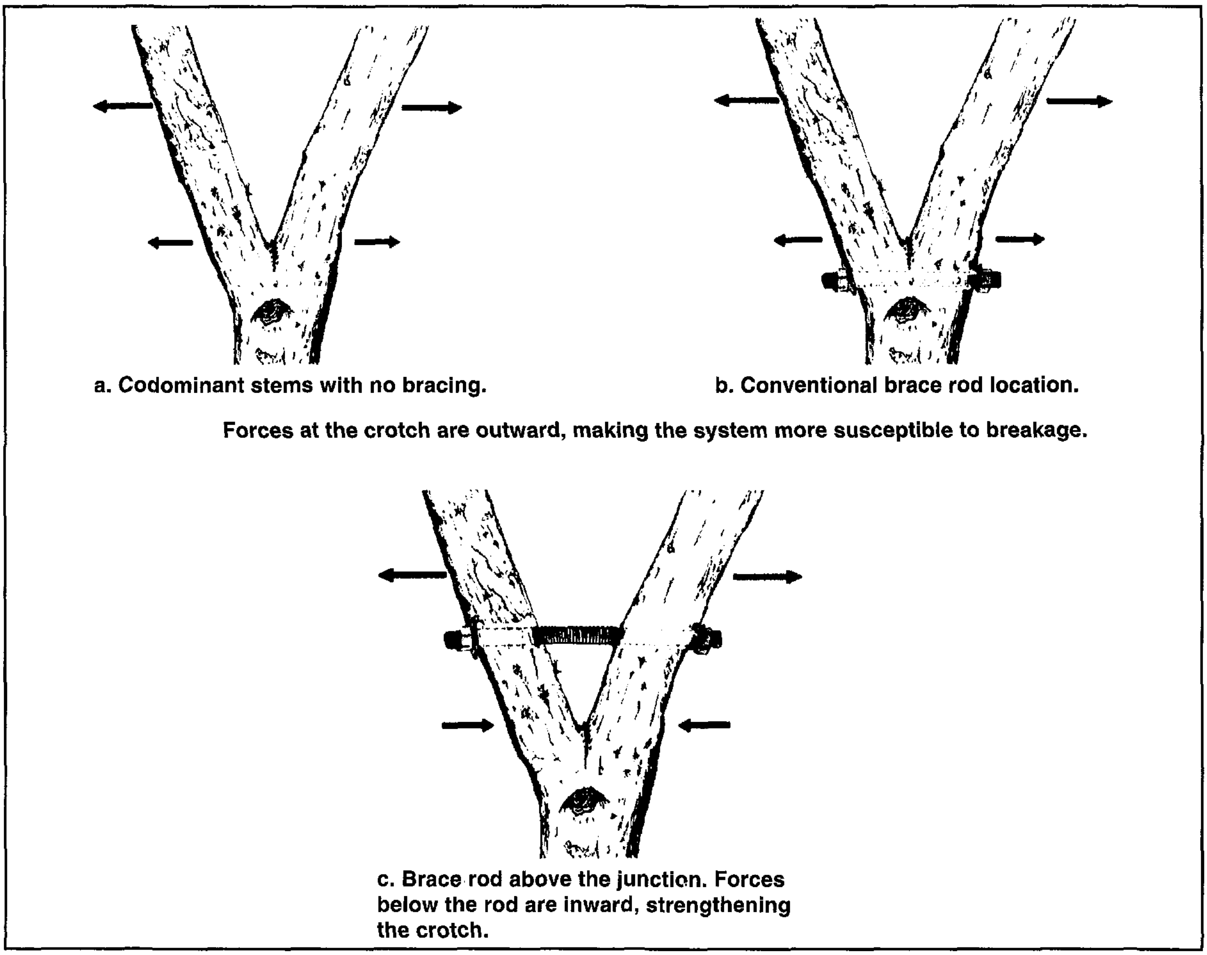

Figure 8. Forces involved in different brace rod locations.