TENSION RELATIONSHIPS FOR STEEL CABLE ON NOTCHED STUMPS

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Title: Tension Relationships for Steel Cable on Notched Stumps

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Tension relationships were determined in steel cable passed through a stump notch and anchored to another object. Tensions were measured in the cable coming into and leaving the notch with one full wrap on the stump. Data was collected from two sites with two test stumps (15.7 to 37.5 inches inside notch diameter) per site and two cable sizes (3/4 and 7/16 inch diameter) per stump. Tensions measured in the cable coming into the notch ranged from 4063 to 18701 pounds.

Results show that the coefficient of static friction as determined assuming the V-belt tension equations increases with increased inside notch stump diameter and increased cable site. The coefficient of friction decreases with increased cable tension. A regression equation was developed incorporating these variables. The mean coefficient of friction was 0.1768. This represents a 9.22 to 1 ratio of cable tensions coming into and leaving the notch with a full wrap (360°) on the stump.

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I. INTRODUCTION

Much has been written about the shift in emphasis in the Pacific Northwest from the harvest of old growth timber stands to second growth or young growth stands (Tedder, Nov., 1979) Inherent in this shift is the decreased availability of suitably large stump anchors for logging machinery and skylines. Design of multiple stump anchoring configurations is essential to the feasibility of many settings.

Present design guidelines (Studier, 1974) address multiple stump anchors and specifically stump anchor series. The stated rule-of-thumb is that a third of the cable tension is transmitted to the back line after the cable is passed around the stump one full circle. Measurements recorded in March 1980 by the U.S.D.A. Forest Service Advanced Technical Training Group indicated a lesser tension transfer than the rule-of-thumb. Recorded measurements of the cable tension transfer range from 0.1290 to 0.2375 (n=9, s=0.0286) to the backline. (Data is unpublished and is on file with Donald D. Studier, Civil Engineer, U.S.D.A. Forest Service, Peavy Hall, O.S.U., Corvallis, OR 97331)

A simple force balance on the main stump anchor in a stump anchor series (see Figure 1) illustrates that the stump must resist the difference in load between the active side and the tieback. The sum of the horizontal components of the tension in the tieback and the root system must equal the horizontal component of the tension in the active line.

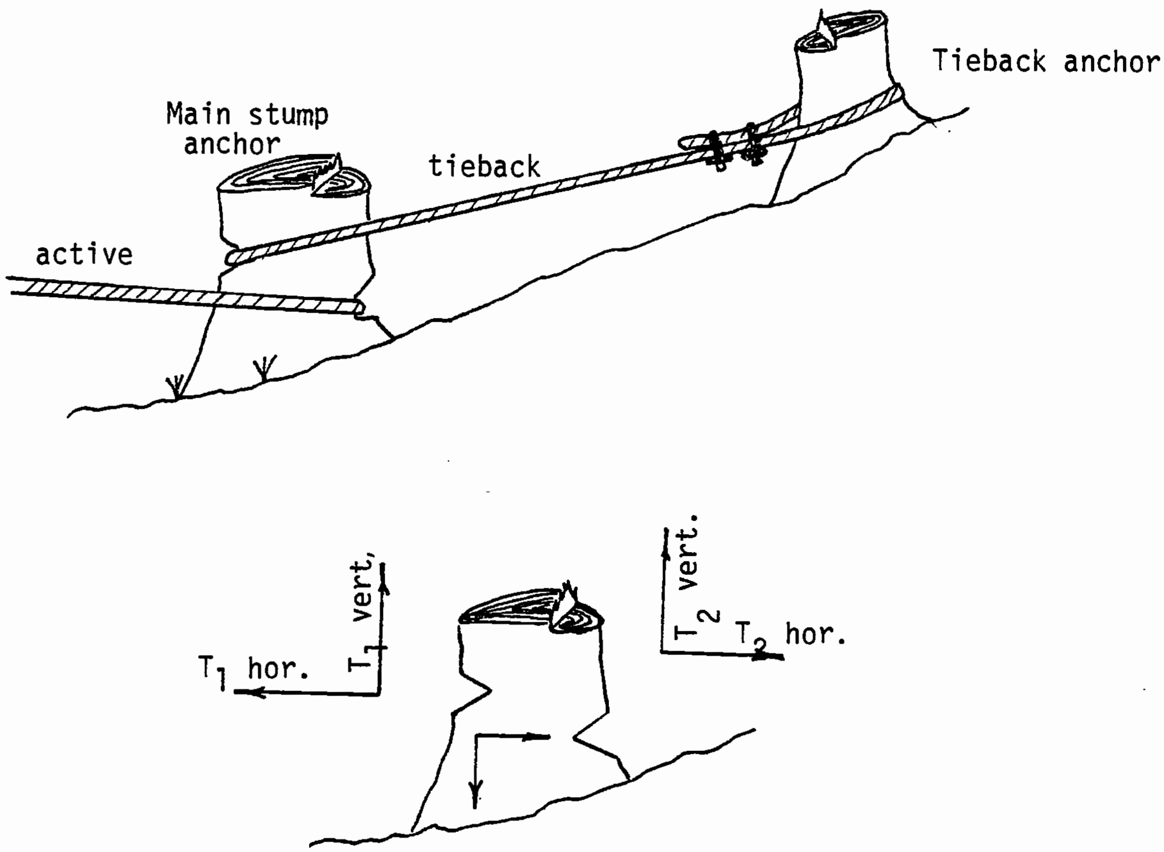


Figure 1. Stump anchor series.

This paper is an analysis of measurements taken in April, 1981 to determine a coefficient of static friction for a steel cable and a notched stump. The assumption was made that the cable would behave as a V-belt inside the notch (See Fig. 2). The ratio of the tension (Deutschman, et.al., 1975, Levinson; 1978) in the active side of the cable (T_1) to the tension in the tieback is evaluated as:

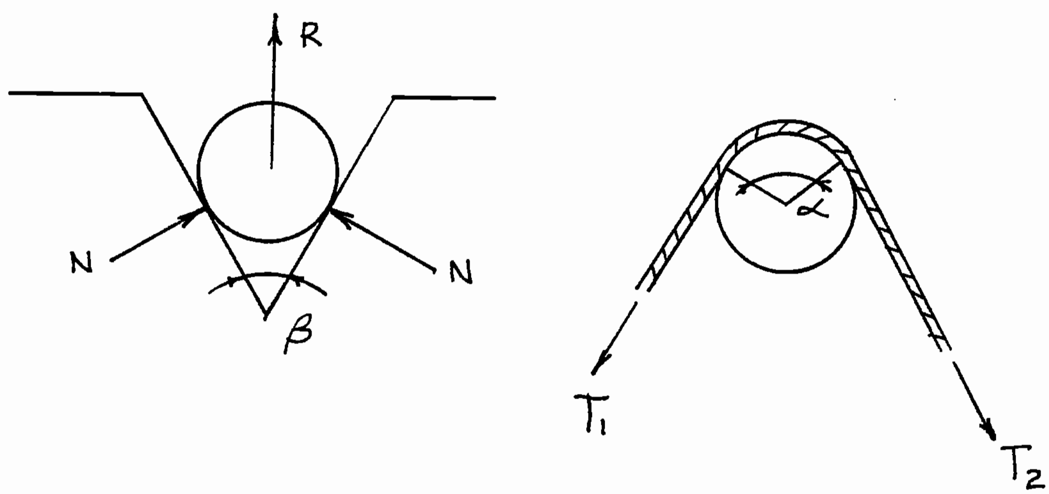
$$\frac{T_1}{T_2} = e^{\left(\frac{\mu \alpha}{\sin (\beta/2)}\right)}$$

where μ = coefficient of friction

α = angle of contact within the groove or notch, in radians

β = groove or notch angle, in degrees

In this equation, μ is dependent on whether or not the belt is allowed to slip. The coefficient of static friction is used when the belt is not allowed to slip. Otherwise, the coefficient of sliding friction is used. In the case of a steel cable in a stump notch, there should be no slippage.



$$R = 2\,(N)\,\sin(\beta/2)$$

$$\frac{T_1}{T_2} = e\left[\frac{\mu\alpha}{\sin(\beta/2)}\right]$$

where R = resultant force

N = normal force

μ = coefficient of friction

Figure 2. V-belt force diagram

Results are for Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), the predominant stand component in the Coast and Cascade Mountain Ranges and are applicable to other species in the forest stand.

II. OBJECTIVES

This study was set up with the following objectives:

1. Determine the coefficient of static friction (μ) for notched, green Douglas-fir (Pseudotsuga menziessi (Mirb.) Franco) stumps and steel cable.

2. Test hypotheses that stump diameter and cable diameter do not effect the tension relationships in a steel cable after it is passed through a stump notch.

III. LITERATURE REVIEW

Limited information on the coefficient of static friction for steel and wood surfaces is available in the literature. The following is a more general review of the literature involving wood as a frictional surface. Leonardo da Vinci observed that the frictional force was one-quarter of the load and constant for all materials (Dowson, 1979). Amontons countered in 1699 that the frictional force was actually closer to one-third of the load in his experiments with wood and friction (Bowden and Tabor, 1973). In more recent times studies have been conducted with metals and wood.

The classical derivation (Deutschman, et.al, 1975 and Levinson, 1978), for the tension relationships in a belt drive incorporates the assumptions that pulley radius and belt size do not affect the relationship and that frictional force is proportional to the normal force. McKenzie and Karpovich, 1968, found the effects of load and nominal contact area to be minor. They found sliding speed to be the most significant determinant of the coefficient of sliding friction. The coefficient exhibited a monotonic reduction, greater in wet wood than in dry wood, with an increase in sliding speed. None of the searches made revealed any past work done to determine coefficients of static or sliding friction between steel cable and wood surfaces.

Bowden and Tabor, 1973, report that study results are erratic due to presence of wood fats. Hydroxyl groups in the cellulose cause appreciable adhesion between the wood and metal which accounts for the greater part of the frictional force. The coefficient of friction for wet wood is approximately 20% lower than the coefficient for dry wood. They also assert that wood acts much like a polymer in the way it deforms. Suh and Turner, 1975, discuss the frictional behavior of polymers and with Bowden and Tabor, 1973, assert that the coefficient of friciton is dependent on the normal stress. As the normal force increases, the coefficient of friction will decrease.

Many values for coefficients of friction are available in the literature. Deutschman, et.al., 1975, and Levinson, 1978, present tables for different surfaces. Wood-on-metal values are from 0.2-0.3. McKenzie and Karpovich, 1968, tested different species at a range of moisture contents and found Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) to have values of 0.11 (10-14% moisture content, slow sliding speed and smooth steel), 0.16 (fibre saturated, slow sliding speed, smooth steel) and 0.57 (fibre saturated, slow sliding speed and rough steel). They defined rough steel as "steel abraded with 60-grit paper".

IV. PROCEDURE

Data was collected in the SE1/4, NW1/4 Section 8 and the NE1/4, SW1/4 Section 16, Township 10 South, Range 5 West, Willamette Meridian. Sites are within Oregon State University's Paul Dunn Forest north of Corvallis, Oregon (Figure 3).

Sites were selected for alignment of stump anchors, accessibility to road system and to include a range of stump diameters. Alignment of the rigging stump, main anchor stump and the tie back anchor was to maintain a nearly uniform angle of cable/stump contact among samples. The range of stump diameters was to test the hypothesis that pulley (or stump) diameter does not affect the tension relationships in the cable. Groundslope on each site was 0-5%.

Experimental design is 2x2 factorial, testing a number of levels of each variable (stump size and cable size) for all possible combinations. Total sample size was calculated using unpublished data from March, 1980 measurements made by Studier, et.al. The assumptions were made that the observations have a normal distribution, desired significance level is 95% and desired confidence interval width is 0.01. For continuous data, sample size, n, can be calculated as:

$$n = \frac{2\,(Z_{\alpha/2})\,\sigma}{w}^{2}$$

where σ = estimate of population standard deviation from subsample

w = width of desired confidence interval

$Z_{/2}$ = probability of normal distribution at level.

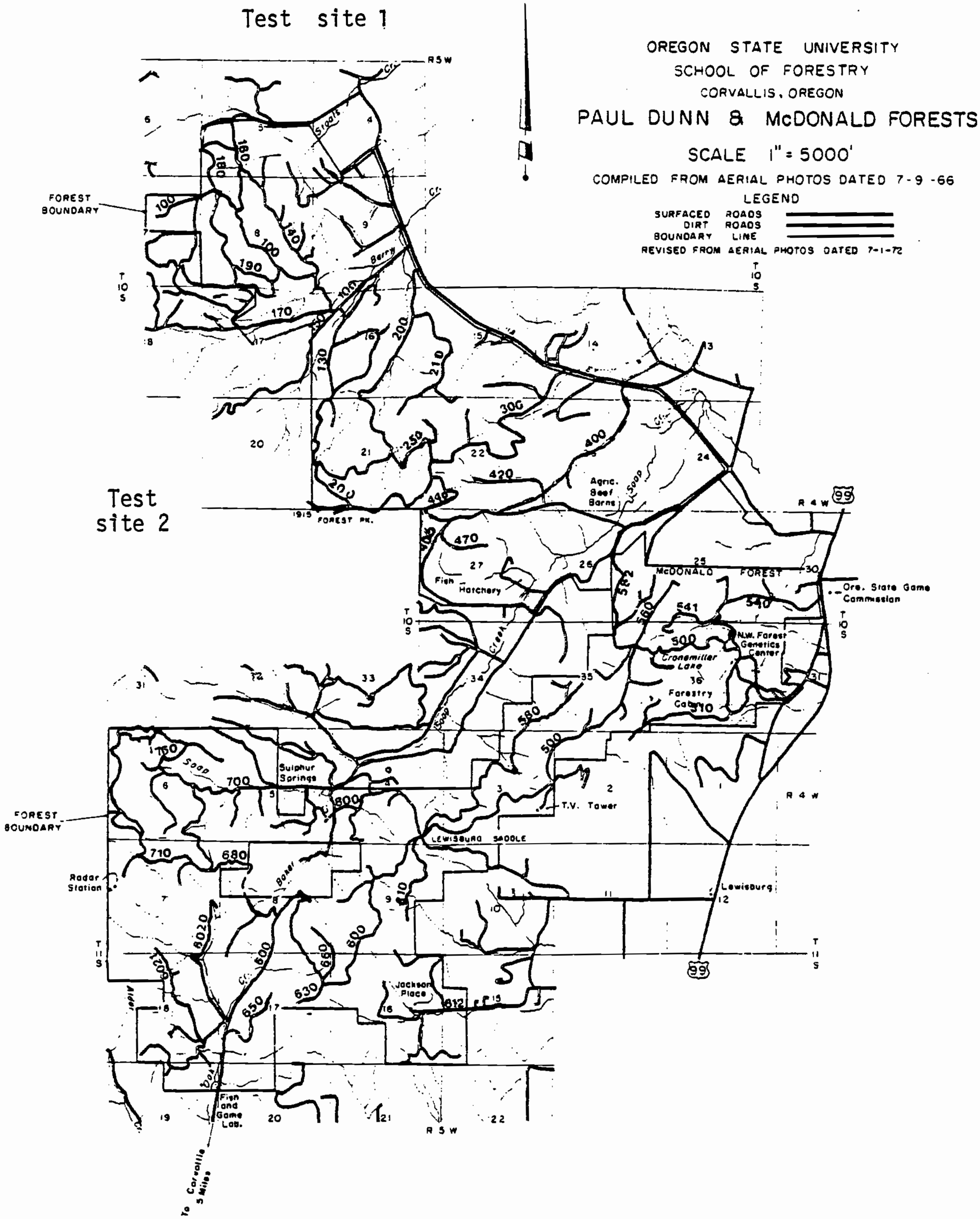


Figure 3. Project location

Applying subsample data:

$$n = \frac{2(1.96)\ (0.0286)^2}{0.01}$$

$$= 126 \text{ samples}$$

Site preparation required felling three Douglas-firs on site 1 and two on site 2. On site 1 (Figure 4) stumps one and two were notched at heights of 13 inches and 18 inches (respectively) to accommodate the cable wrap. Measurements of the notch angle, β, were taken at 6 points (60° apart) and averaged. Stump A was wrapped with a 3/4 inch diameter cable choker to anchor the block configuration. On site 2 (Figure 5) stumps three and four were notched at a height of 13 inches and the notches were measured as above. The block configuration was anchored to a bigleaf maple (*Acer macrophyllum* Pursh). Table 1 is a summary of the measurements made on the main stump anchors.

TABLE 1: Summary of test site measurements

Site	Stump	Notch angle (degrees)	Inside Notch Stump Diameter (inches)	Wrap angle (radians)
1	1	65	22.2	2π
	2	73	37.5	2.0833π
2	3	70	18.1	2π
	4	74	15.7	2π

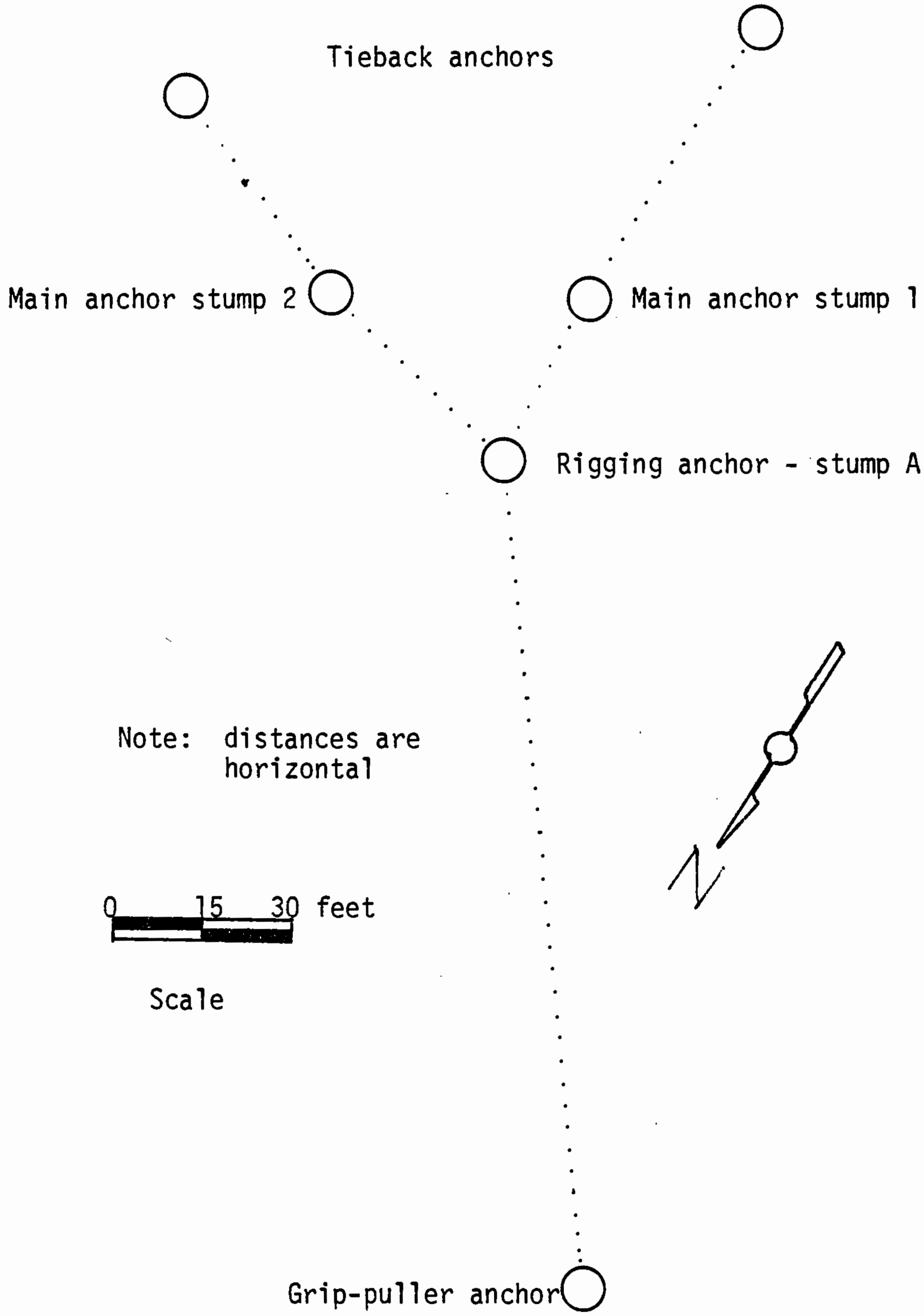


Figure 4. Test Site 1

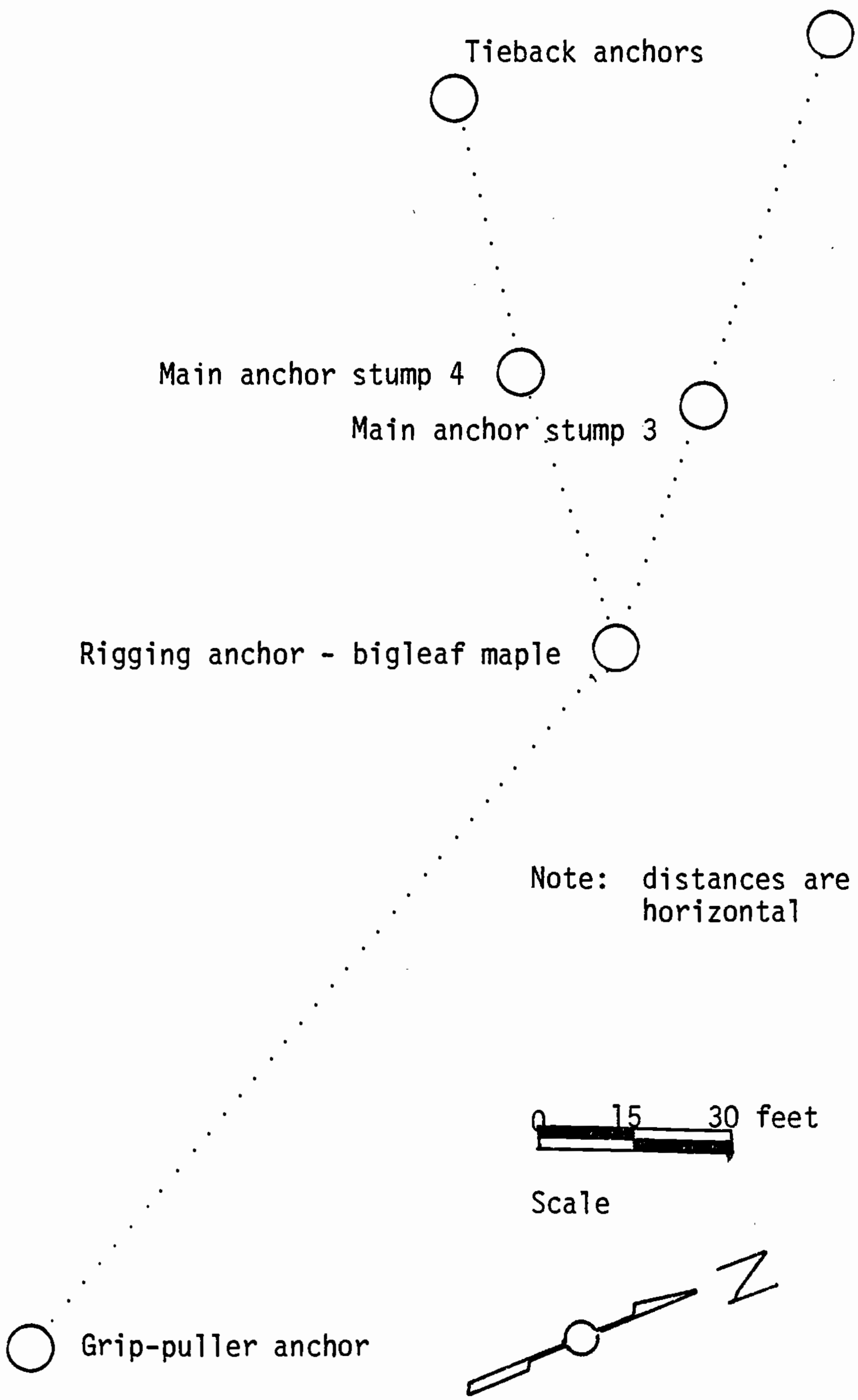


Figure 5. Test site 2

Tensioning of the test cable was achieved with use of a 6,000 pound capacity JET Grip-Puller. The tensioning line was passed through six blocks (see Figure 6) to increase possible system loads. The test cable was shackled to the purchase configuration and was then wrapped around the main stump anchor and tied back to standing live trees. Two cables, 7/16 and 3/4 inch diameter, were tested on each of the four main stump anchors. Both test cables were in good condition with no discernable fraying or cracking.

For each test a bar tensiometer (Tri Coastal Industries, Inc., Seattle, Washington, Model SLT-4-1593, Serial 112) was clamped to the cable between the main stump anchor and the block configuration. It was attached to a guage (Tri Coastal Industries, Model 12, Serial 5556). A Dillon Dynamometer (W.C. Dillon & Co., Inc., Van Nuys, California, 1500 pound capacity, Serial 27703) was shackled to the 7/16 inch diameter cable between the main stump anchor and the tie back anchor. When the 3/4 inch diameter cable was being tested a Martin Decker Tension Indicator (Martin Decker Co., Santa Ana, California, Model UAI-100, 20,000 pound capacity) was clamped to the cable between the main stump anchor and the tie back anchor.

The bar tensiometer was calibrated in Oregon State University's Civil Engineering Laboratories. The Martin Decker Tension Indicator and the Dillon Dynamometer were calibrated at O.S.U.'s Forest Research Laboratory.

Tensions in the test cable on both sides of the main anchor stumps were recorded using the Grip-Puller, the system was tightened in intervals of 100-1500 pounds. Intervals were difficult to regulate due to some slippage in the notch and tightening of the whole system. Readings were taken when movement ceased.

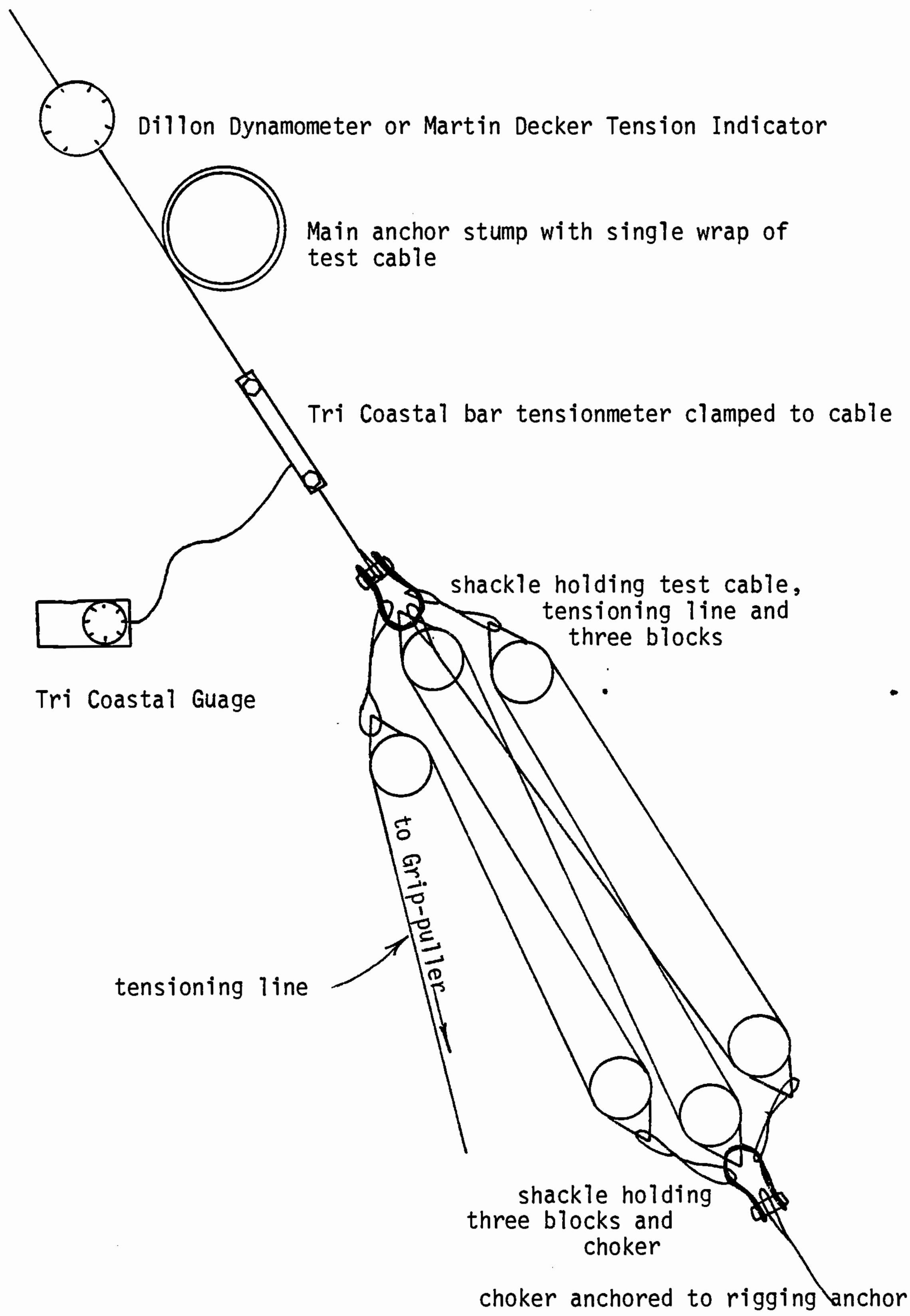


Figure 6. Block rigging configuration

V. DATA ANALYSIS AND DISCUSSION

Eight tests were run in all. Data for the tensions in the test cable on both sides of the main anchor stump were fitted into the equation presented in the Introduction to this paper. β and α are from Table 1. Table 2 is a summary of the test data:

Table 2: Data summary

Inside Notch Stump Diameter (in)	Cable diameter (in)	Range of T_1 (pounds)	Sample size (n)	Mean Coefficient ($\bar{\mu}$)	Standard Deviation
22.2	7/16	4115-11215	18	.1694	.0175
37.5	7/16	4482-11955	14	.2133	.0071
37.5	3/4	4246-15831	17	.1991	.0063
22.2	3/4	4063-15831	18	.1774	.0165
18.1	3/4	4706-18701	18	.1549	.0157
18.1	7/16	4942-11770	10	.1374	.0066
15.7	3/4	4798-15634	14	.1970	.0384
15.7	7/16	4115-9183	7	.1274	.0079

The variation in the range of values for T_1 was due, in part, to the cable size being tested. The safe working load for 7/16 inch extra-improved plow steel (EIPS) is 6800 pounds and for 3/4 inch EIPS is 19,600 pounds. When testing the 7/16 inch line on stump 4 (15.7 inch inside notch diameter) the cable cut into the notch more than 1/2 inch in places and the system tensioning was halted at T_1= 9183 pounds.

An analysis of variance was performed to test the null-hypotheses that the mean coefficients of friction for the four stumps were equal, the means for the line sizes were equal and that there was no interaction between these variables. The Fixed Effects Model was utilized because of the nonrandom selection of stumps and cables. The computed F value (2439.58) for the interaction effects exceeds the critical value (2.08) at the $\alpha = .05$ significance level. Therefore the hypothesis that there is no interaction must be rejected. (Bowker and Lieberman, 1959; Neter and Wasserman, 1974; Steel and Torrie, 1980). A one-way analysis of variance was performed on the data by cable diameter. For both cables, the calculated F values (2027.00 for the 7/16 inch cable and 16.00 for the 3/4 inch cable) exceed the critical value at the $\alpha = .05$ significance level (3.01). The null hypotheses that variance in values for the coefficient of static friction can be explained by cable size alone is therefore rejected.

All test data pairs from each stump were tested for equal variances and only one pair (on stump No. 1) was not rejected at the 95% level. Using a Student's t-test, tests on stump No. 1 were found to have equal mean coefficients of friction. The null hypothesis in the modified t-test (for unequal variances) tests the means of the two samples and equality was rejected for all other pairs (stumps 2, 3, and 4).

All data was put into the Statistical Interactive Programming System on Oregon State University's Control Data Corporation-3300 computer (Cyber Operating System). The calculated values for the coefficient of friction were regressed against six variables in stepwise regression procedure to determine regression coefficients and the coefficients of multiple determination (R^2). Three interaction terms were introduced to reflect the results of the analyses of variance. Partial results are presented to illustrate the relative changes in the R^2 value with the addition of variables.

In the following discussion and equations:

DIAM = Inside notch stump diameter, inches

CABL = Diameter of cable, inches

TENS = Tension in cable, T_1, kips

DICA = (DIAM) X (CABL)

DITE = (DIAM) X (TENS)

CATE = (CABL) X (TENS)

COEF = Coefficient of friction

* = Indicates the regression coefficient is significantly different from 0 at the 0.005 probability level.

** = Indicates the regression coefficient is significantly different from 0 at the 0.01 level but not at the 0.005 level.

*** = Indicates the regression coefficient is significantly different from 0 at the 0.05 level but not at the 0.01 level.

1) COEF = -0.035779
+0.007584 (DIAM) *
+0.257547 (CABL) *
-0.008736 (DICA) *

R^2 = 0.5043

2) COEF = -0.026848
+0.007731 (DIAM) *
+0.281307 (CABL) *
-0.002902 (TENS) *
-0.008806 (DICA) *

R^2 = 0.5869

3) COEF = -0.00440
+0.006768 (DIAM) *
+0.321073 (CABL) *
-0.007993 (TENS) *
-0.010465 (DICA) *
+0.000213 (DITE) **

R^2 = 0.6190

4) COEF = -0.003065
+0.006774 (DIAM) *
+0.319153 (CABL) *
-0.008194 (TENS) ***
-0.010479 (DICA) *
+0.000213 (DITE) **
+0.000278 (CATE)

R^2 = 0.6190

A discussion of the order in which variables entered the stepwise regression is noteworthy. The first to enter was DIAM with a corresponding R^2 of 0.3216. The second variable was CABL ($R^2 = 0.3724$) and addition of the interaction term, DICA, increased the R^2 to 0.5043, thus reflecting the results of the analyses of variance. The order of incoming variables illustrated further in the models presented above.

The most representative model for the data is Model 3 due to the comparison of R^2 values with adjacent models. Four of the six regression coefficients (DIAM, CABL, TENS, and DICA) are significantly different from zero at the = 0.005 level. The regression coefficient for tension (T_1) is negatively correlated with the coefficient of static friction as discussed by Suh and Turner, 1975, and Bowden and Tabor, 1973. Model 3 also illustrates a positive correlation with inside notch stump diameter and cable diameter though the literature (Deutschman, et. al., 1975 and Levinson, 1978) indicated these parameters would have no effect on the tension relationships. However, Model 3 explains 61.9% of the variability in the coefficient of static friction as calculated under the aforestated assumptions.

Relative values of the regression coefficients may be evaluated in a graphical method. Assuming an inside notch stump diameter of 24" and varying cable diameter, the coefficient of static friction is graphed against cable tension (T_1) in Figure 7. An increase of 0.25 inches in cable diameter will increase the coefficient of static friction by approximately 0.0144. In Figure 8 cable diameter is held constant at 5/8 inch and various inside notch stump diameters are examined with the coefficient of static friction graphed against cable tension (T_1). Increasing the inside notch stump diameter utilized by six inches will increase the coefficient of static friction by 0.0269 at 20,000 pounds tension and 0.0460 at 35,000 pounds tension.

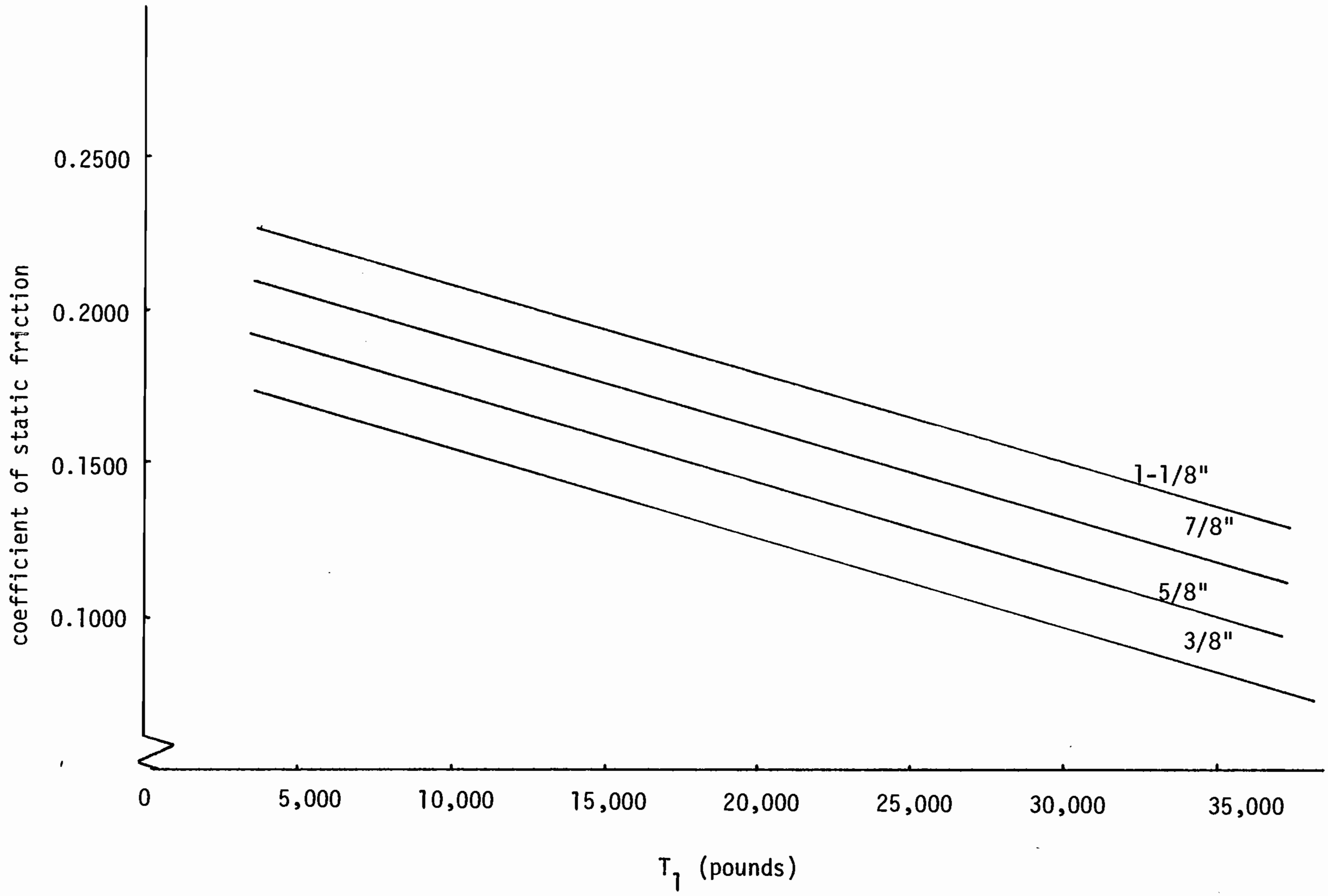


Figure 7. Coefficient of static friction vs. T_1
(cable diameter variable, stump diameter = 24")

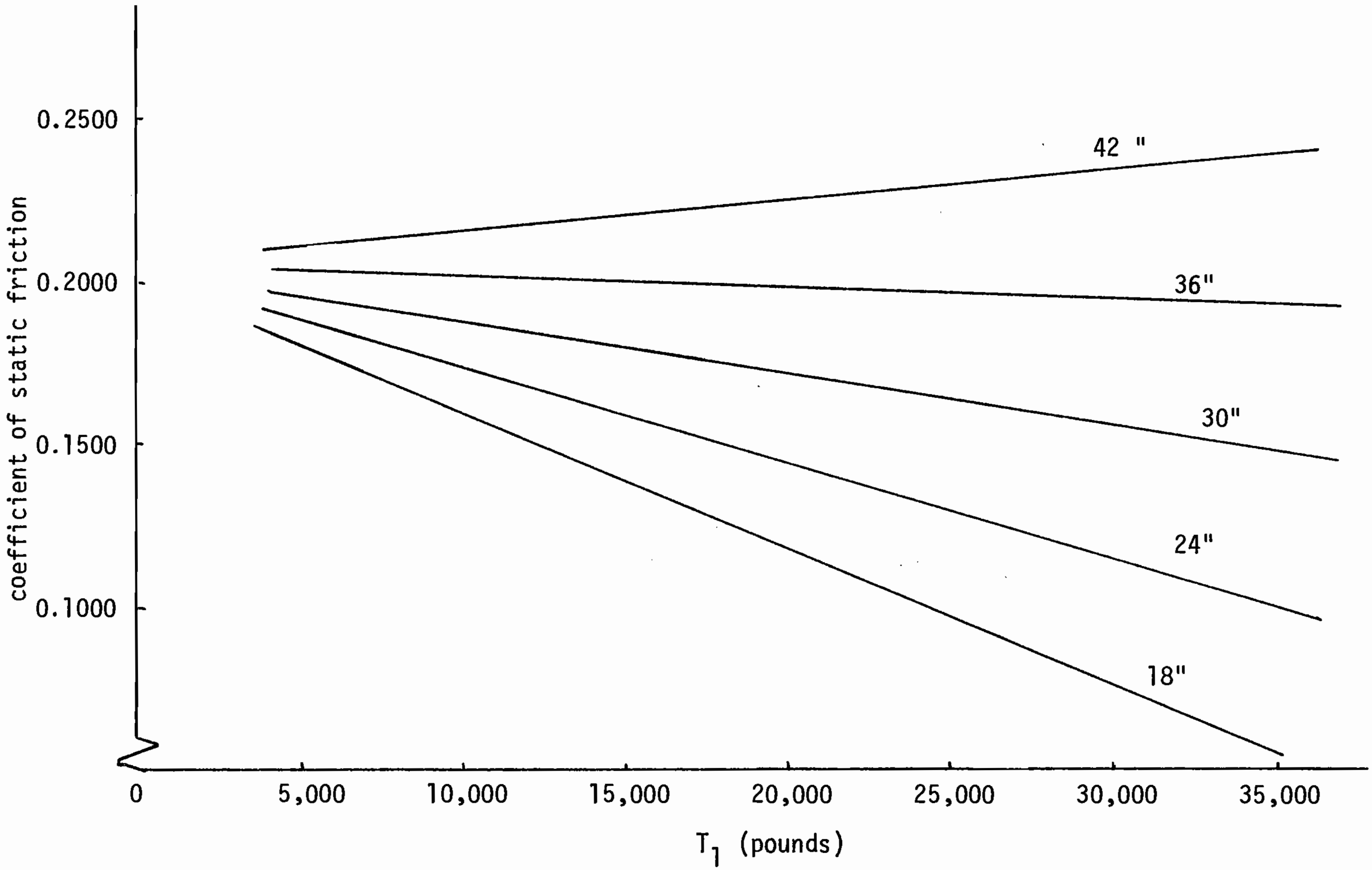


Figure 8. Coefficient of static friction vs. T_1
(stump diameter variable, cable diameter = 5/8")

Possible sources of variability in the data were considered during the data collection period besides those identified by Bowden and Tabor, 1973. The main anchor stump notches had corners or edges where the cutter moved to another angle. Test cables "dug" into the wood on these corners during tensioning and assumption of the V-belt equation at these points may be erroneous. Another source may have been inability to discern cessation of movement of the test cable in the notch. Values obtained more nearly correlate with those observed by McKenzie and Karpovich, 1968, for the coefficient of sliding friction than with those presented in Levinson, 1978, and Deutschman, et.al., 1975, for the coefficient of static friction. These factors or possible sources were not measured or examined in the experiment procedure.

VI. SUMMARY AND APPLICATION OF RESULTS

The coefficient of static friction can be predicted for use in the standard V-belt equation presented in the introduction to this paper. Two of the variables measured in this study (cable diameter and inside notch stump diameter. Explain 50.4% of the variability in the data collected. Cable tension, considered with cable diameter and inside notch stump diameter explain 61.9% of the variability.

Caution should be exercised in use of the multiple regression equations presented. The user should recognize the range of tensions over which the data was collected (4063-18701 lbs) and the cable sizes tested (7/16 and 3/4 inch diameter). Results show that the tension relationships for steel cable in a notched stump are not a pure mechanical system.

The sample mean for the entire data base for the coefficient of static friction is 0.1768. When inserted in the V-belt equation assuming a wrap angle of 2π radians and a notch angle of $60°$, the ratio of T_1 (active tension) to T_2 (tieback tension) is 9.22:1. This is in contrast to present design guideline of 3:1 (Studier, 1974). To examine further the relationship of T_1 to T_2, values from Figures 7 and 8 were input into the V-belt equation (again assuming a wrap angle of 2π radians and a notch angle of $60°$), and are presented in Table 3. (Note that the ranges of active tension (T_1) and cable diameter are beyond the scope of collected data. They illustrate, however, a range of ratios of tension.)

Table 3: Sample comparison of T_1/T_2 using results of multiple regression and V-belt equation.

T_1 (lbs)	Inside Notch Stump Diameter (in)	Cable Diameter (in)	Coefficient of Static Friction	T_1/T_2
5000	16	0.6250	0.1769	9.23
15000 *			0.1311	5.19
25000 *			0.0852	2.92
35000 *			0.0394	1.64
5000	20	0.6250	0.1821	9.86
15000 *			0.1448	6.17
25000 *			0.1075	3.86
35000 *			0.0701	2.41
5000	24	0.6250	0.1873	10.52
15000 *			0.1585	7.33
25000 *			0.1297	5.10
35000 *			0.1009	3.55
5000	24	0.75	0.1960	11.74
15000			0.1672	8.18
25000 *			0.1384	5.69
35000 *			0.1096	3.96
5000	24	1.00	0.2135	14.63
15000			0.1847	10.19
25000			0.1559	7.09
35000 *			0.1271	4.94

* Exceeds safe working load (EIPS)

This exhibited range in ratios of tensions should be recognized by the logging engineer designing a stump anchor series. The main anchor stump holds far more of the active tension than was previously understood. Possibilities for decreasing the coefficient of static friction to effect a greater tension transfer may be considered (eg. lubrication of the notch or a smoother notch with fewer edges). As relatively small anchors become the only alternative, this tension relationship will be increasingly important in design.

Further research on tension relationships in the use of multiple stump anchors is needed. The use of wrap angles less than 360° (2π radians) should be looked at as well as a wider range of notch angles than was analyzed in this study. The use of various lubricants in the stump notch is yet another area. This study could be expanded to examine a broader range of tensions and cable diameters and effect a more reliable equation for estimating the coefficient of static friction and ultimately, the size of the stump required to anchor a cable.

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