AN ABSTRACT OF THE THESIS OF

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in Forest Products presented on January 29, 1982

Title: Model for the Prediction of Nail Withdrawal Stiffness

Redacted for Privacy

Abstract approved: Anton Polensek

An important factor affecting the strength and ultimate load of wood structures is the strength, stiffness and durability of its joints. Therefore, the behavior of nailed joints must be given proper consideration when designing and analyzing wood structures. Presently, formulas for determining the strength of nailed joints under withdrawal loads, as outlined in the National Design Specifications and the Uniform Building Code, are based on the statistical regression between maximum withdrawal load (W) and the material properties of the wood and nail.

New models were developed which predict W, withdrawal resistance (WR) and withdrawal stiffness (WK) based on the actual forces responsible for holding the nail in the wood. These include a normal force to the nail due to the elastically compressed wood around the nail and the resulting friction between the wood and nail surfaces. The accuracy of these models were compared to the accepted formulas in the design codes and were found to be superior in predicting W, WR and WK.

Model for the Prediction of Nail Withdrawal Stiffness

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed February 29, 1982

Commencement June 1982

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Date thesis is presentd January 29, 1982

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TABLE OF CONTENTS

		Page
I.	Introduction	1
II.	Literature Review	4
III.	Theoretical Model	11
	3.1 Forces preventing nail withdrawal	11
	3.2 Determining the static coefficient of friction μ_s	14
	3.3 Distribution of stresses in the wood around the nail hole	16
	3.4 Determining the pressure and force on the nail	18
	3.5 The foundation modulus	22
	3.6 Relation between foundation modulus and grain angle	26
IV.	Materials and Methods	27
	4.1 Experimental design	27
	4.2 Materials	28
	4.2.1 Wood selection	28
	4.2.2 Nails	30
	4.3 Testing Procedure	31
	4.3.1 Nail-push and nail withdrawal test	31
	4.3.2 Friction tests	37
	4.3.3 Foundation modulus tests	43
	4.4.4 Evaluation of specific gravity and moisture content	46

		Page
V.	Results and Discussion	48
	5.1 Reduction of experimental data	48
	5.1.1 Nail-push curves	48
	5.1.2 Nail withdrawal curves	48
	5.1.3 Friction test curves	51
	5.1.4 Foundation modulus curves	51
	5.2 Data analysis, results and discussion	54
	5.2.1 Effect of pilot hole size on nail withdrawal resistance	54
	5.2.2 Coefficient of static friction	67
	5.2.3 Correction of foundation modulus for grain angle	67
	5.2.4 Regression	69
	5.2.5 Comparisons between prediction models and empirical formulas	70
VI.	Conclusions and Recommendations	73
	Literature Cited	76
	Appendix A Computer programs	80
	Appendix B Tables	90
	Appendix C Raw data	109

LIST OF FIGURES

Figure		Page
1.1	Types of loading imposed on joints constructed with nails.	2
3.1	The forces resisting withdrawal of a nail embedded in a wood medium.	12
3.2a	Cross-section of a nail embedded in a wood medium showing normal forces acting upon it.	13
3.2b	Differential slice of a nail showing the forces acting upon it.	13
3.3a	Free body diagram showing forces used in evaluating μ_s.	15
3.3b	Free body diagram showing the forces used to evaluate μs in this study.	15
3.4a	Three zones of wood deformation due to nail embeddment in wood.	17
3.4b	Dissipation of normal stresses in the wood medium as a function of the distance from the nail hole.	17
3.5	Pressure exerted by the surrounding wood medium on a single segment i with arc length D_i.	19
3.6a	Cross-section of a nail divided into n segments under the influence of an external pressure per unit length p_i.	21
3.6b	Segment i isolated with the external pressure p_i replaced with an equivalent spring of force $K_i y = N_i$	21
3.7	Dissipation of stresses at 45 degrees to the direction of loading while testing for the foundation modulus.	24
4.1	Flow diagram of testing procedure	29
4.2	Location of predrilled pilot holes on the wide and narrow faces of a test specimen.	32

List of Figures continued

4.3	Machine pushing of nails into the wide faces of a Douglas fir specimen.	33
4.4	Withdrawal of nails from the wide face of a southern-yellow-pine specimen.	35
4.5	Typical withdrawal curve showing maximum withdrawal load and the relative displacement or slip between the nail and wood surface.	36
4.6	Cutting pattern used to expose two wide face and two narrow face half holes for friction tests.	38
4.7	Testing apparatus used to evaluate friction coefficients.	39
4.8	Close-up of apparatus used to apply the H needed in evaluating the friction coefficient.	40
4.9	Schematic of the vise used to apply H when evaluating the static friction coefficients.	41
4.10	Positioning of the steel plate used to evaluate the foundation modulus for end and radial grain directions.	44
4.11	Testing for the end grain foundation modulus for a nail driven into the narrow face of a southern-yellow-pine specimen.	45
5.1	Typical load-penetration curve showing the resistance of the nail moving into the wood at a constant penetration rate.	49
5.2	Due to dense layers of summerwood, the maximum penetration load does not always occur at the maximum depth of penetration.	50
5.3	A typical curve caused by initial normal load of 40 lbs and gradual "withdrawal" of a nail under constant rate.	52
5.4	Typical load-deflection curve generated while testing for the foundation modulus.	53

List of Figures continued

5.5	Tukey pairwise confidence intervals for the effect of pilot hole diameter on the withdrawal resistance of 6-penny nails from the side grain of clear DF stud sections.	57
5.6	Interaction effect of face and pilot hole on the withdrawal resistance of 6-penny nails from the side grain of clear DF stud sections.	59
5.7	Interaction effect of face and pilot hole on the withdrawal resistance of 6-penny nails from the side grain of clear ES stud sections.	60
5.8	Interaction effect of face and pilot hole on the withdrawal resistance of 6-penny nails from the side grain of clear SP stud sections.	61
5.9	Tukey pairwise confidence intervals for the effect of pilot hole diameter on the withdrawal resistance of 6-penny nails from the side grain of clear DF stud sections.	62
5.10	Tukey pairwise confidence intervals for the effect of pilot hole diameter on the withdrawal resistance of 6-penny nails from the side grain of clear ES stud sections.	63
5.11	Tukey pairwise confidence intervals for the 64 effect of pilot hole diameter on the withdrawal resistance of 6-penny nails from the side grain of clear SP stud sections.	64
5.12	Nail cross-section subdivided into 32 slices.	68

LIST OF TABLES

Table		Page
B-1	Analysis of variance table for WR of nails pulled from the wide faces of DF blocks.	90
B-2	Tukey pairwise confidence intervals for the comparison of the WR of the control (PH1) against all other treatment means (PH2, PH3, PH4) of nails pulled from the wide faces of DF blocks using a 90 percent family confidence coefficient.	91
B-3	Paired T-test results (two-tailed test) on the WR for nails without the PH (PH1) pulled from the wide and narrow faces of DF blocks.	92
B-4	Analysis of variance tables for WR of nails pulled from the wide and narrow faces of DF, ES and SP blocks.	93
B-5	Tukey pairwise confidence intervals for the comparison of the WR of the control (PH1) against all other treatment means (PH2, PH3) of nails pulled from the wide and narrow faces of DF, ES and SP blocks.	95
B-6	Confidence intervals for the difference in mean WR between the wide and narrow faces of DF, ES and SP blocks.	97
B-7	Paired T-test results (two-tailed test) on the coefficient of static friction of nails pulled from wide and narrow face half-holes of DF blocks.	98
B-8	Experimental and predicted values of W, WR and WK.	99
B-9	Regression equations relating experimental values of W, WR and WK to the values obtained using the prediction models.	107
B-10	Regression equations relating experimental values of W and WR to the values obtained using the empirical formulas.	108

MODEL FOR THE PREDICTION OF
NAIL WITHDRAWAL STIFFNESS

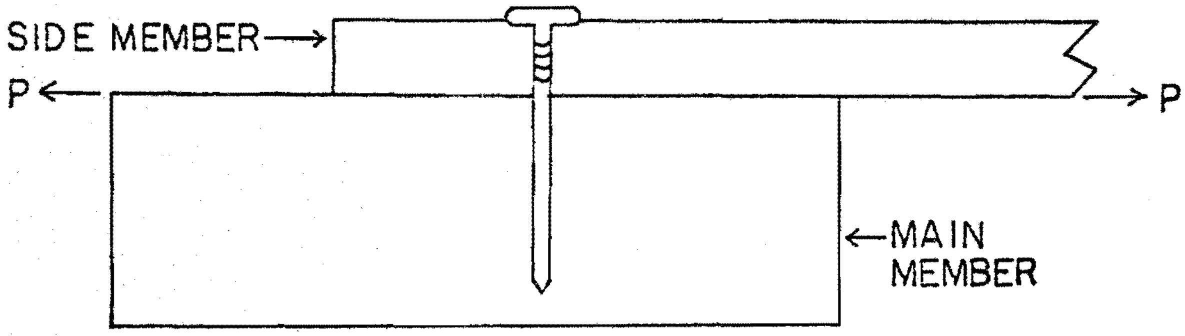
I. INTRODUCTION

Nails probably are the oldest and most common type of mechanical fasteners used to join wood into composite structures. An important factor affecting the strength and ultimate load of wood structures is the strength, stiffness and durability of its joints (4). For instance, a statically determinate wood structure is only as good as its weakest joint. Therefore, the behavior of the nailed joints must be given proper consideration when designing and analyzing wood structures.

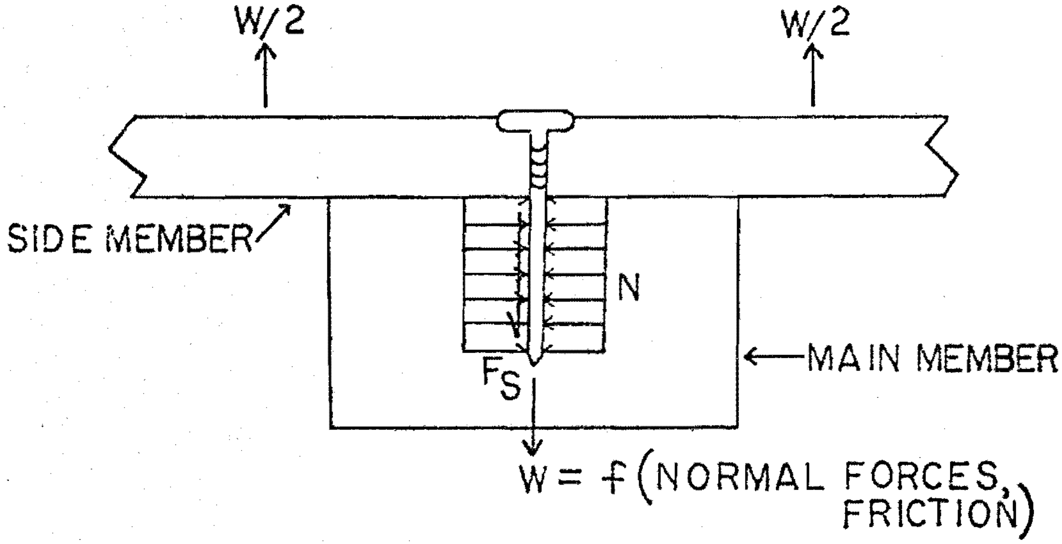
Recently, Polensek (17, 18, 19, 20) has developed a rational design procedure for wood stud walls. The semirigid nailed joints between the studs and wall coverings induce partial composite action, which increases the deflection and ultimate load of the wall under compression-bending loads. The degree of composite action depends on the stiffness of the nailed joints. Withdrawal strength and stiffness of fasteners is sometimes another important design parameter. For instance, the thickness of door jambs depends on the withdrawal strength of the screws between hinges and jambs (21).

In general, nails may undergo two types of loading (5), lateral and withdrawal (Figure 1.1). Although both loading types are important in the design of wood structures, only the latter is considered in this study.

The force holding the nail in a wood member under direct withdrawal is due to friction caused by normal forces at the nail-wood



(a) JOINT UNDER LATERAL LOAD (PURE SHEAR)



(b) JOINT UNDER WITHDRAWAL LOAD

Figure 1.1: Types of loading imposed on joints constructed with nails.

interface (Fig. 1.1 b). Frictional forces are activated when an external force P attempts to move the nail with respect to the wood. Normal forces are exerted to the nail surface by the wood fibers which have been compressed by the nail when driven into the wood medium.

Joint properties are usually evaluated by testing. To reduce testing, which is both expensive and time consuming, it is desirable to develop a theoretical model from which the designer could predict the withdrawal strength and stiffness of a joint made of any commonly used wood species and nails. Equipped with such a model, the designer could theoretically evaluate the effect of joint withdrawal properties on the performance of wood systems. Therefore, the model should be helpful with the structural analysis of wood systems.

The main objective of this study is to develop a model for predicting the withdrawal stiffness of nails. The model is based on several concepts from the mechanics of materials and on structural mechanisms observed by testing specimens made of 6d common nails and Douglas-fir, southern-yellow-pine, and Engelmann-spruce lumber.

II. LITERATURE REVIEW

In the past a large number of studies have been conducted on nail joints subject to direct withdrawal. A wide variety of testing apparatus and conditions were investigated to determine the factors affecting maximum withdrawal loads (PMAX), but almost no attempts were made to evaluate withdrawal stiffness and to develop a model for predicting withdrawal stiffness. This chapter summarizes the models used to predict and the variables that affect PMAX of nail joints.

2.1 Variables Influencing Nail Withdrawal Loads

There are five main variables influencing PMAX: specific gravity (SG) of the wood used for connecting components, moisture content (MC), creep in wood under prolonged loading, nail properties and nail driving method.

Specific gravity of the wood has been recognized as the most important variable (1, 5, 13, 14, 16, 25, 26, 31, 33). The two most common formulas used for predicting PMAX express these loads in terms of SG (5, 33). The formulas indicate that the dense, heavy woods offer greater resistance to nail withdrawal than the lighter, less dense woods. Westman (31) found that the formulas do not predict PMAX equally well for all species; he found that experimentally determined PMAX for Douglas-fir agreed closely with those calculated by one of the formulas (33), but the same formula underestimated PMAX for western hemlock by 55 percent. Westman (31) also observed that for both species SG was a better predictor of PMAX than ring density.

Nail withdrawal loads are greatly affected by the wood MC (1, 5, 8, 9, 14, 16, 24, 28, 29, 33). For most species (5, 24, 28, 33), PMAX for joints with nails driven into seasoned wood which remains seasoned in service is about equal to that of unseasoned wood which remains unseasoned. When nails are driven into unseasoned wood that is allowed to season (8, 28, 33) or into seasoned wood that is subject to repeated wetting and drying cycles (8, 16, 29, 33), the nails will lose a major part of their initial withdrawal resistance and may retain only 25 percent of the values determined by the general formula offered by the Wood Handbook (33). For nails driven into unseasoned wood that is allowed to dry down to 50 percent MC, Tokuda (28) found that the withdrawal resistance gradually increased as the MC decreased. The reason for this increase seemed to be that the coefficient of friction between the nail and wood surfaces increased as the water between the nail and the wood was removed. But when the MC of the wood dropped below 40-50 percent, PMAX decreased due to the micro-cracking of the wood around the nail.

Several researchers (16, 24, 28, 33) observed that PMAX decreased with time. Perkins (16) and Tokuda (28) attributed this decrease to the creep in wood, i.e., the stress relaxation in the wood fibers around the nail. This relaxation decreases the pressure that the wood exerts on the nail, which subsequently decreases the frictional resistance between the nail and wood surfaces. Most relaxation takes place during the first two to three days after assembling the joint.

In unseasoned wood water along the nail shank may produce nail corrosion and wood rot. As the nail begins to corrode (16, 24) the initial PMAX increases. The increase is dependent on the wood species and nail type. However, with time the increase in PMAX tapers off and eventually becomes a decrease; the deterioration or rotting of unseasoned wood (16) decreases the pressure exerted on the nail by the wood.

The nail properties (5, 8, 14, 24, 28, 33) represent the third variable that effects PMAX. During manufacturing the surface of the nail shank is frequently modified to improve PMAX. The modification is usually done by applying various surface coatings, surface roughening or mechanically deforming the nail shank. Senft (24) found that for Douglas-fir joints galvanized or cement coated nails have greater PMAX than smooth nails because of the increased friction between the nail and wood surfaces. The use of coated instead of smooth nails in joints made of wood with lower density species may double PMAX immediately after driving (5), but the effect is only temporary. In about a month PMAX of coated nails becomes equal to that of smooth nails (33). For dense wood species, such as hard maple, birch and oak, coated nails offer little advantage since most of the coating usually peels off during driving. Other coatings such as those of zinc or plastics (33), which have been used to prevent corrosion, increase PMAX considerably less than the cement coatings.

Chemical etching and sand blasting the nail (5) results in an increase of PMAX which is less effected by changing MC than that of smooth shank nails. Nails with other than circular cross-section, such as that of the barbed and helically or annulary threaded nails, also produce higher PMAX than common wire nails.

The nail point affects the condition of wood around the nail. Nails with long sharp points, driven into low-density species, normally produce higher PMAX than nails with a diamond point (33). In the high-density species, the sharp point may induce splitting which reduces PMAX. A blunt or flat point without taper reduces splitting, but it destroys the fibers during driving, which reduces the wood pressure on the nails and consequently PMAX.

The method by which the nails are imbedded into the wood member could also affect PMAX. Loferski (10) compared the shear stiffness of machine-pushed nail joints to that of hammered nail joints. Machine pushed nail joints had lower variability than the hammered joints due to the controlled assembly conditions; the machine pushed nails were driven straighter and more perpendicular to the wood surface which produced joints with more uniform lateral stiffness than that of the hammered joints. Therefore, it is reasonable to expect that PMAX of machine-pushed nails should also be more uniform than that of hammered nails.

2.2 Present Design Procedure

The strength of nailed joints under withdrawal loads is outlined in specifications and codes such as the National Design Specifications (NDS) (14), the Timber Construction Manual (TCM) (1) and the Uniform Building Code (6). Both the NDS (14) and the TCM (1) recommend that the joints designed to transfer loads should not act in withdrawal. When this becomes unavoidable and nails transfer shear and withdrawal forces, the NDS and TCM provide graphs (14) or tables (1) to determine the allowable PMAX. For nail sizes and wood species not listed in the graphs or tables, these specifications give an alternative; the allowable PMAX of a nail or spike driven into the side grain under normal duration of load can be calculated by the empirical formula (1, 5, 14):

$$PALL = 1380\ G^{5/2}\ D \qquad (2.1)$$

where

PALL = allowable PMAX per inch of penetration into the member holding the nail point (lbs/in.);

G = specific gravity based on oven-dry weight and volume; and

D = diameter of the nail shank (inches).

Nail diameters are available in tables (1, 14) which classify common and box wire nails and spikes according to pennyweight or length. The same information (1, 14) is provided for anularly or helically threaded, hardened steel nails and spikes made of high-carbon steel wire, and for heat treated and tempered nails. These nails normally have smaller diameters than the corresponding common wire nails of the same pennyweight.

Equation 2.1 has limitations. The PALL's are valid only if the nails are driven into the side grain perpendicularly to the fibers of seasoned wood which remains seasoned or unseasoned wood which remains unseasoned (1, 14). If the nail is driven into unseasoned wood which will season in service, a 75-percent decrease in the tabulated values is required except for treated, hardened steel nails (1, 14). In addition, correction factors are given (1, 14) for duration of load and MC.

If more than one nail is used in a joint, the total PALL for that joint is the sum of the allowable loads for the individual nails (1, 14). When three or more nails are used on one face of a joint member, the spacing between the nails must be considered since this spacing controls the shearing area which develops the nail load (1, 14). Tables are available (1, 14) to determine recommended spacings of the nails. These spacings are affected by the angle of load to the grain and the angle of the axis of the nail to the grain (1, 14).

2.3 Empirical Formula for PMAX

For bright, common wire nails driven perpendicular to the fibers of seasoned wood which remains seasoned or unseasoned wood which remains unseasoned, the empirical formula for PMAX equals (33):

$$PMAX = 7{,}850\ G^{5/2}\ DL \qquad (2.2)$$

where

PMAX = the average maximum withdrawal load per nail (pounds);

G = the specific gravity of the wood based on oven-dry weight and volume at 12 percent MC;

D = the diameter of the nail (inches); and

L = the length of the nail in the member holding the nail point (inches).

Actually, equation 2.2 is basically the same as equation 2.1. PALL is based on one-fifth of PMAX. If we multiply the constant of 1380 in equation 2.1 by five we get 6900 which is very close to 7850, the constant used in formula 2.2 The difference between 7850 and 6900 is attributed to the fact that in equation 2.2 G is based on volume at 12 percent MC rather than oven-dry volume used by equation 2.1.

Hoyle (5) points out an important consideration in using equation 2.1: "This general equation for PALL appears to give the advantage in joint strength to the higher density species. The allowable loads are predicted on the assumption that nail spacing is great enough that splitting of the wood will not occur. As a rule the lower density species do not split so easily as the higher ones. This permits closer nail spacing in the lower density species, often permitting the design of joints equal to those in species of higher density via the use of more and larger nails per joint."

III. Theoretical Model

3.1 Forces Preventing Nail Withdrawal

A free body diagram (FBD) showing the forces holding a nail in a wood block is shown in Figure 3.1. The wood exerts pressure on the nail due to its elastic nature, which results in a frictional force at the wood-nail interface when a withdrawal load W is applied. Figures 3.2a and 3.2b illustrate a differential slice of the nail shank, which is defined by angle $d\theta$ and differential length dL. The differential normal force on the slice can be obtained by multiplying the wood pressure exerted on the nail, p, by the differential area dA:

$$dN = p\,dA \tag{3.1}$$

Because dA equals:

$$dA = R\,d\theta\,dL$$

dN may be written:

$$dN = pR\,d\theta\,dL \tag{3.2}$$

where

R = radius of the nail (inches)

The total normal force N exerted on the nail can then be found by integrating equation 3.2 around the circumference of the nail and along its penetration depth:

$$N = pR \int_{o}^{2\pi} \int_{o}^{L} d\theta\,dL \tag{3.3}$$

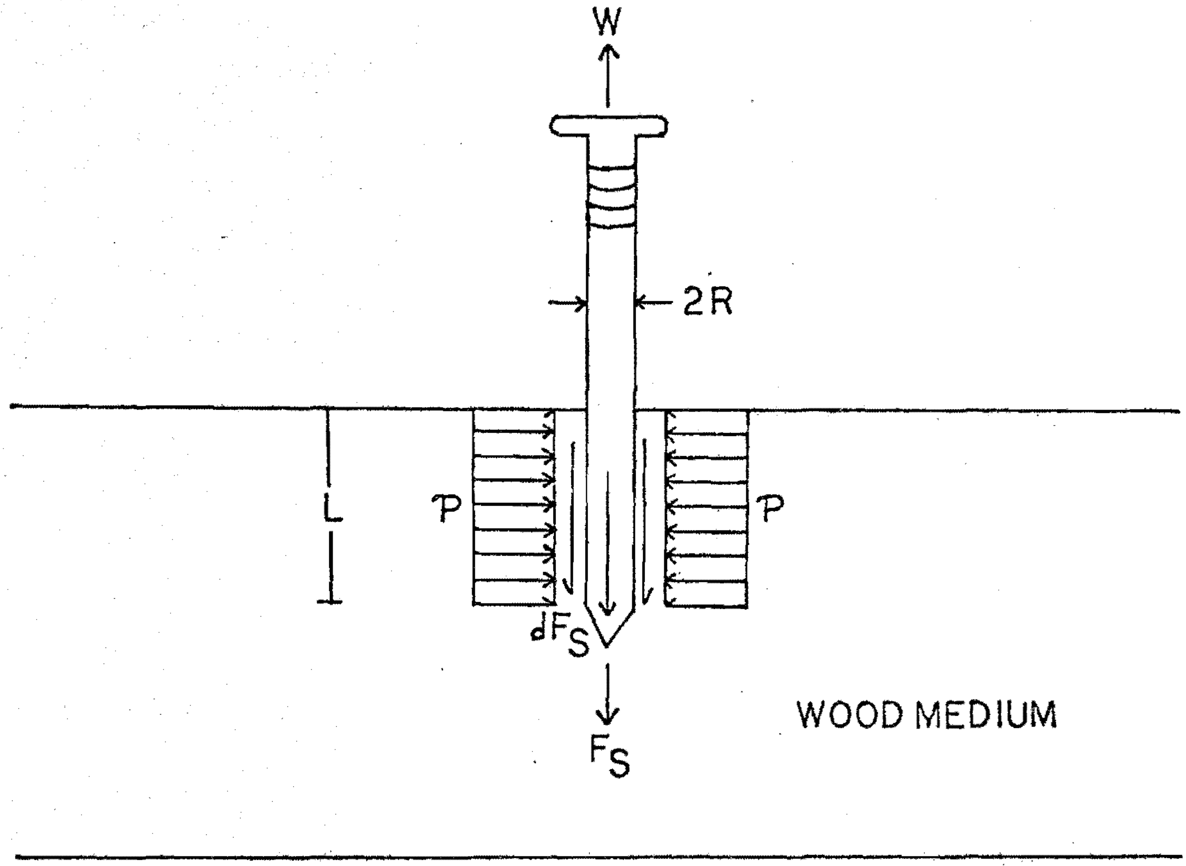


Figure 3.1: The forces resisting withdrawal of a nail embedded in a wood medium.

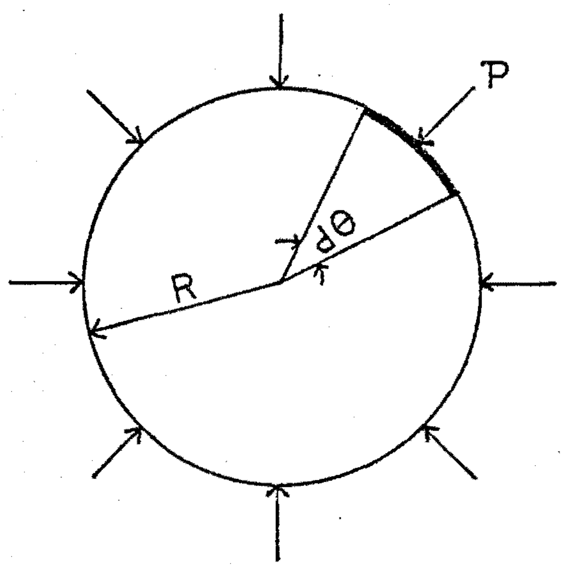


Figure 3.2a: Cross-section of a nail embedded in a wood medium showing normal forces acting upon it.

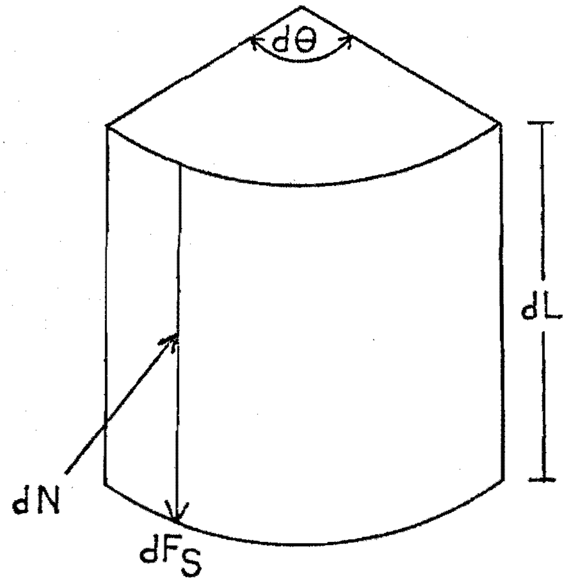


Figure 3.2b: Differential slice of a nail showing the forces acting upon it.

where

L = penetration depth of the nail shank (inches)

Knowing N and the coefficient of static friction between the nail and wood surfaces we can calculate the frictional load preventing withdrawal of the nail when a load W is applied:

$$Fs = \mu_s N \quad (3.4)$$

where

μ_s = coefficient of static friction (dimensionless); and

$Fs = W$

Because of equilibrium Fs is equal to the maximum withdrawal load necessary to initiate slip between wood and nail (Fig. 3.1).

PMAX is related to static friction only. Sliding friction, which is activated after the nail begins to move relative to the wood fibers, is therefore associated with a withdrawal load less than PMAX. Thus, the force necessary to initiate withdrawal is more than enough to continue the extraction process of the nail.

3.2 Determining the Static Coefficient of Friction μ_s

When a load P is applied to two bodies in contact as shown in Figure 3.3a, the bodies will not slip until angle α is of certain magnitude (11). This magnitude is a function of the surface characteristics of the two bodies in contact.

In Figure 3.3a the resultant force R lies along the line of action of the applied load P. It is resolved into its two rectangular

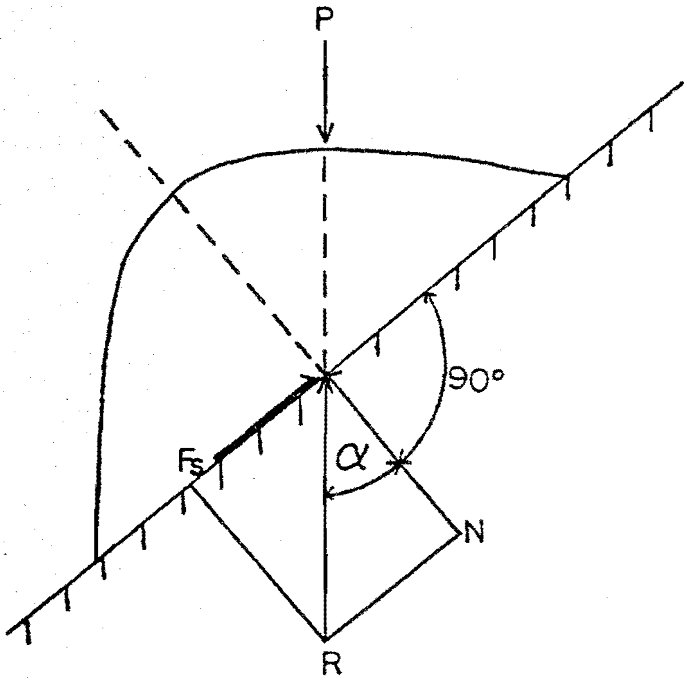


Figure 3.3a: Free body diagram showing forces used in evaluating μ_s

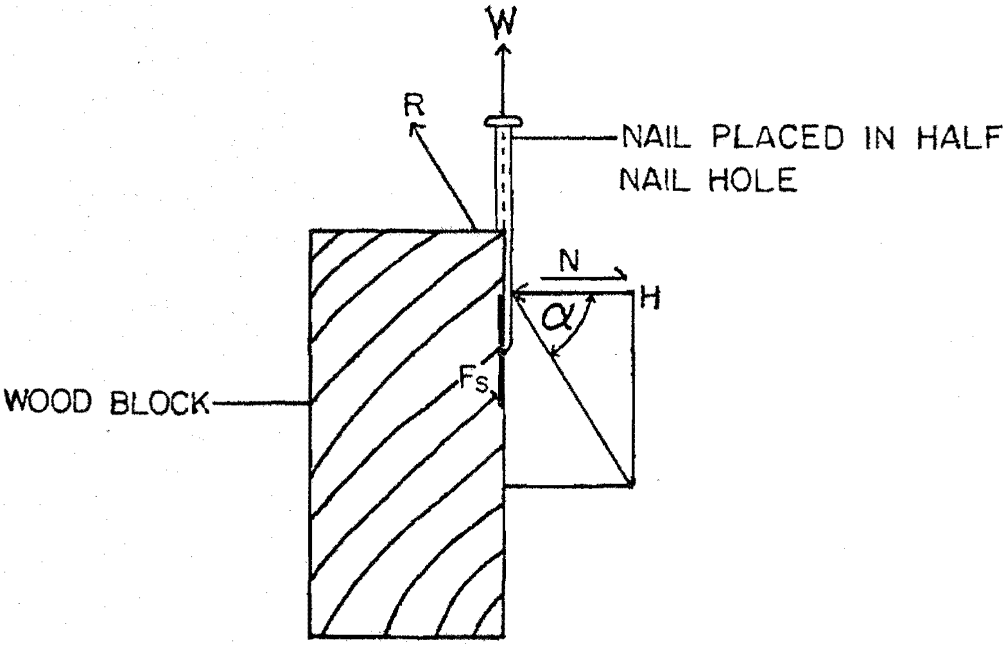


Figure 3.3b: Free body diagram showing the forces used to evaluate μ_s in this study.

components: N, a normal force and Fs, the static frictional force. Fs acts in the plane of the contacting surfaces. The sliding starts when (12):

$$Fs = N\tan\alpha \tag{3.5}$$

Since Fs also equals $\mu_s N$

$$\mu_s = \tan\alpha \tag{3.6}$$

No motion will result as long as Fs is less than $\mu_s N$. A state of impending motion is reached as Fs approaches the value of $\mu_s N$.

Evaluation of μ_s between the nail and wood surfaces can be experimentally accomplished in the following manner. A force H with known magnitude can be applied normal to the nail and wood surfaces (Fig. 3.3b) and then the nail can be extracted with a known vertical force W. The magnitude of W is the maximum load that occurs just before the nail starts to slip on the wood. μ_s may then be evaluated by:

$$\mu_s = \tan\alpha = \frac{W}{H} \tag{3.7}$$

3.3 Distribution of Stresses in the Wood Around the Nail Hole

Wood is composed of fibers held together by lignin. When a nail penetrates this material three distinct zones of deflection are recognized (Fig. 3.4a). The first zone is composed of collapsed fibers that provide no resistance to nail withdrawal but serve as a

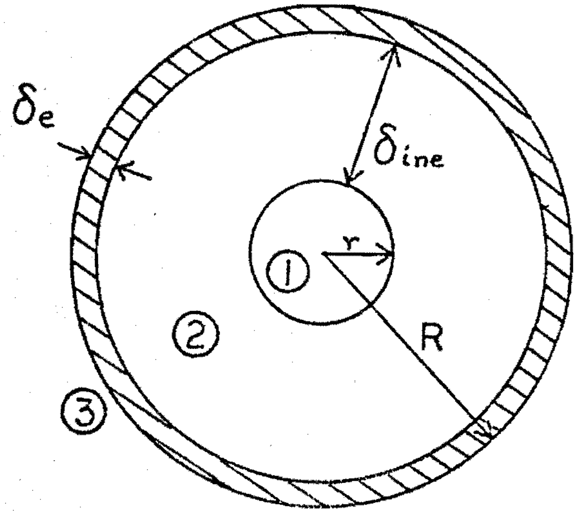


Figure 3.4a: Three zones of wood deformation due to nail embeddment in wood.

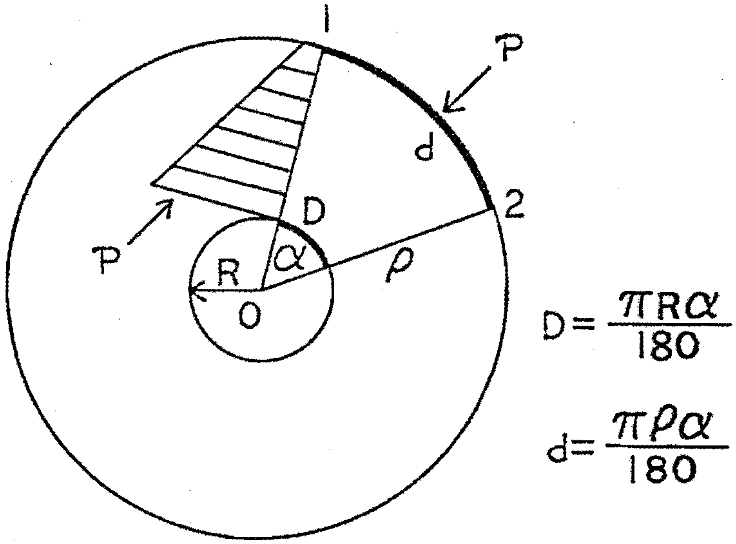


Figure 3.4b: Dissipation of normal stresses in the wood medium as a function of the distance from the nail hole.

packing around the nail. As the nail penetrates into the wood, the point rips the fibers as it clears a path for the nail shank. The resemblance of this zone to pilot holes (PH) drilled in the wood will be developed in the experimental procedure.

In the second zone the fibers are pushed beyond their elastic range resulting in permanent set. This set is the result of nonlinear behavior of the wood medium in which the deformation is only partially restored after the load is removed. These fibers provide some of the pressure and packing around the nail.

The remaining fibers within the nail diameter, zone three, are elastically compressed and are the most important in providing the normal pressure on the nail.

Exact stress distribution in the wood around the nail is difficult to predict, but the assumption of a linear variation of stresses and strains with respect to the distance from the nail center, ρ, is considered reasonable. Close inspection of Figure 3.4b reveals that the area supporting the total pressure p in segment 0-1-2 keeps increasing proportionately to ρ. Therefore, as ρ gets larger and the area increases, the stress decreases until a point is reached when the stresses become negligible.

3.4 Determining the Pressure and Force on the Nail

Figure 3.5 shows a length of nail and the pressure exerted by the wood medium on a single segment. The pressure on the nail equals:

$$p = k_o y \tag{3.8}$$

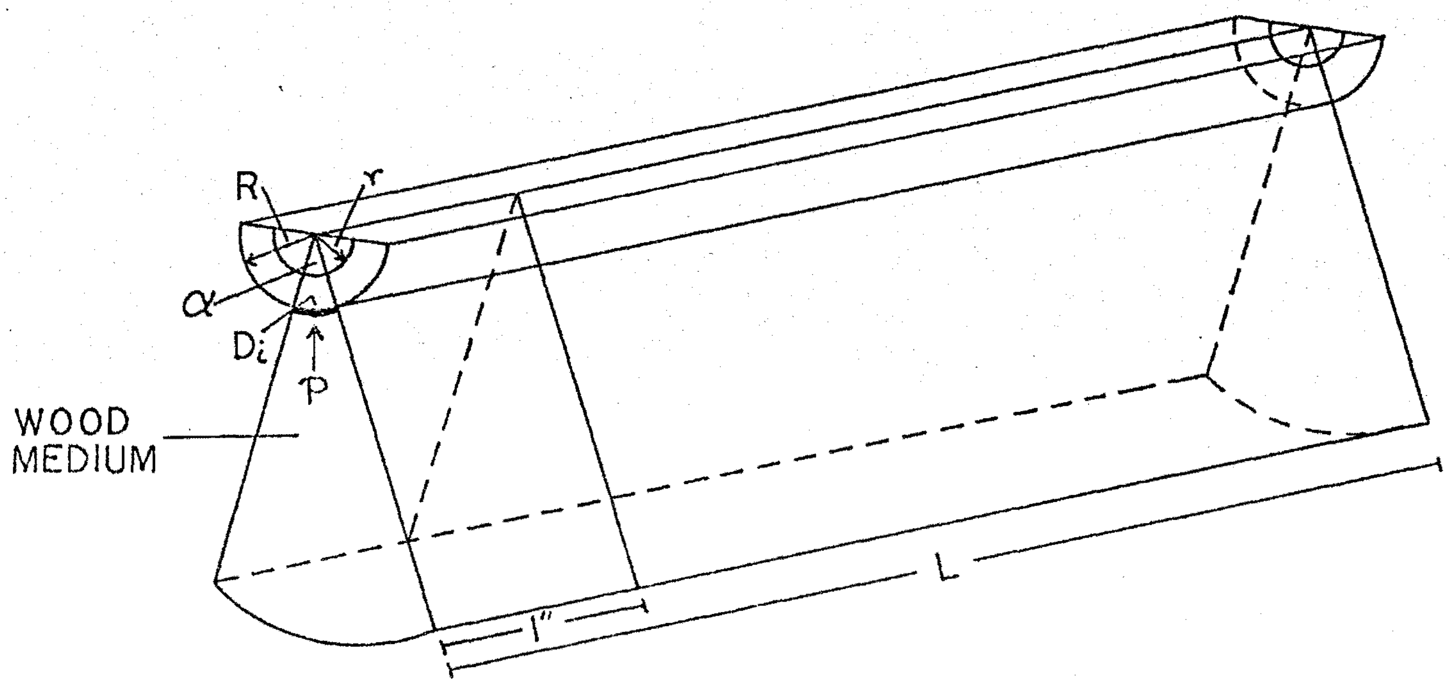


Figure 3.5: Pressure exerted by the surrounding wood medium on a single segment i with arc length D_i

where

k_o = foundation modulus (psi per inch of penetration); and

y = deformation which may be expressed as the difference between the nail radius R, and the radius of a predrilled PH, r (in).

An analogy can be made between the pressure exerted on the nail by the wood medium and a spring. Figure 3.6a shows the cross-section of a nail divided into n equal segments, each segment subject to an external pressure p_i. The external pressure on segment i can be replaced by an equivalent spring which exerts a normal force N_i on the nail (Fig 3.6b):

$$N_i = K_i y \tag{3.9}$$

where

K_i = spring constant on segment i (lbs/in).

The spring constant, K, can then be expressed in terms of the foundation modulus, k_o:

$$K_i = k_{oi}A = k_{oi}D_iL \tag{3.10}$$

where

A = area over which k_{oi} acts (in^2); and

D_i = arc length of segment i (in)

The total normal force on the nail can then be found by summing all the equivalent spring forces over the n segments along the entire penetration depth (L) of the nail:

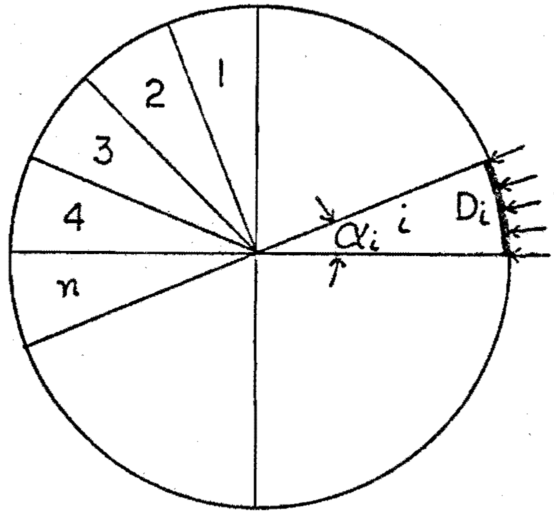


Figure 3.6a: Cross-section of a nail divided into n segments under the influence of an external pressure per unit length p_i

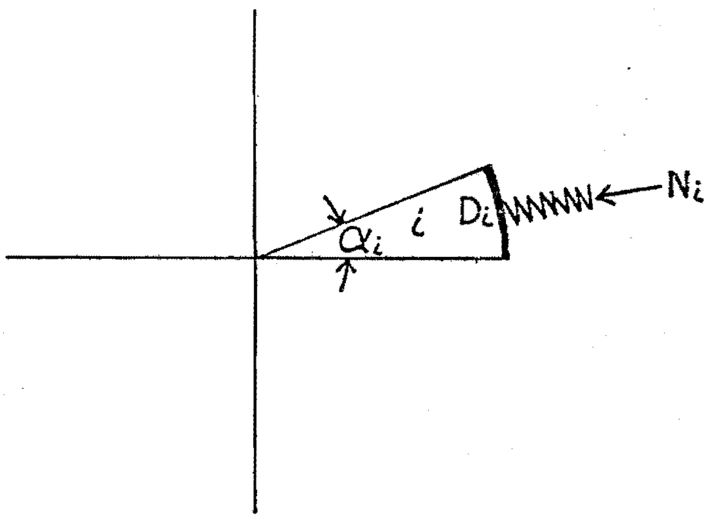


Figure 3.6b: Segment i isolated with the external pressure p_i replaced with an equivalent spring of force $K_i y = N_i$

$$N = L \sum_{i=1}^{n} N_i = Ly \sum_{i=1}^{n} D_i k_{oi} \qquad (3.11)$$

With n equal to 32 segments, the maximum withdrawal load (W) can therefore be predicted according to the following model:

$$W = \mu_s Ly \sum_{i=1}^{32} D_i k_{oi} \qquad (3.12)$$

where all terms are as previously defined.

The maximum withdrawal resistance (WR) is then given by the following model where each side of equation 3.12 is divided by L:

$$WR = \mu_s y \sum_{i=1}^{32} D_i k_{oi} \qquad (3.13)$$

The maximum withdrawal stiffness (WK) is found by dividing equation 3.12 by the withdrawal deformation (WD):

$$WK = \frac{\mu_s Ly}{WD} \sum_{i=1}^{32} D_i k_{oi} \qquad (3.14)$$

WK has units of pounds per inch. The withdrawal deformation is explained in more detail in chapter 5.1.2.

3.5 The Foundation Modulus

The foundation modulus (k_o) is the force exterted by a unit deflection of wood medium, expressed in pounds per square inch per inch of deflection. It is evaluated for wood by testing, by applying a known load over a bearing surface (Fig. 3.7) and then measuring the deformation of the bearing surface into the wood medium. The ratio of the deformation and force is the spring modulus k. When k is divided by the bearing area it is identical to the foundation modulus of the wood medium.

Figure 3.7 shows a possible testing arrangement for determining k_o. The stresses under the test block dissipate at angle β, which in similar conditions is usually assumed to be 45 degrees. Thus, k_o is a function of the deformation of wood columns HIJK (Fig. 3.7). The modulus of elasticity (E) of a short column, based on the conventional expression for column deformation, is (27):

$$E = \frac{PL}{\Delta A} \tag{3.15}$$

where

P = axial load (lbs);

L = column length (in);

Δ = column deformation (in); and

A = cross-sectional area of the column (in^2)

Equation 3.15 applies to the column in Figure 3.7 if A is assumed to vary along the column length. Bearing area at depth Z is (Fig. 3.7):

$$A_Z = (\frac{2bZ}{L} + a)\ w$$

E for the column in Figure 3.7 is then obtained by substituting A_Z into equation 3.15 and integrating over L:

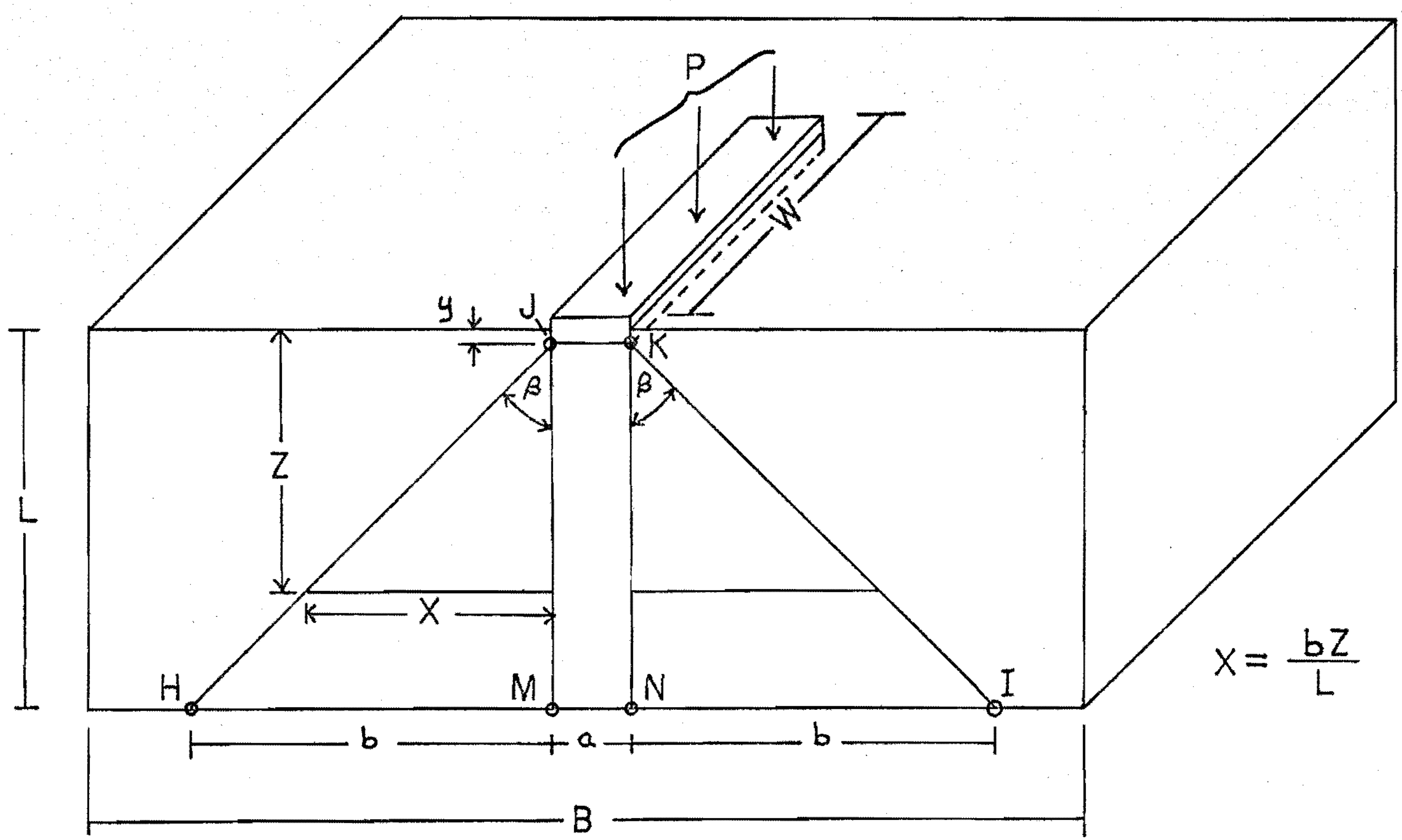


Figure 3.7: Dissipation of stresses at 45 degrees to the direction of loading while testing for the foundation modulus.

$$E = \frac{P}{\Delta} \int_{o}^{L} \frac{dZ}{(\frac{2bZ}{L} + a)\ w} \qquad (3.16)$$

Solving equation 3.16 gives:

$$E = \frac{PL}{2\Delta wb} \ [\ln(2b + a) - \ln a] \qquad (3.17)$$

The definition for the spring modulus under the loading block is:

$$k = \frac{P}{\Delta}$$

which for the column JKMN in Figure 3.7 equals (according to equation 3.15):

$$k = \frac{EA}{L} \qquad (3.18)$$

where

A = area under the bearing plate (A=aw)

Substituting equation 3.17 into equation 3.18 gives:

$$k = \frac{Pa}{2\Delta b}[\ln(2b + a) - \ln a] \qquad (3.19)$$

The conventional foundation modulus corresponding to k equals:

$$k_o = \frac{k}{A} = \frac{P}{2\Delta wb} \ [\ln(2b + a) - \ln a] \qquad (3.20)$$

3.6 Relation Between Foundation Modulus and Grain Angle

The effective modulus of elasticity at angle θ to the grain direction of the wood medium may be obtained from the following equation[1]:

$$\frac{1}{E} = \frac{\cos^4\theta}{E_1} + \frac{\sin^4\theta}{E_2} - \left(\frac{1}{G_{12}} - \frac{2V_{12}}{E_1}\right) \sin^2\theta\cos^2\theta \qquad (3.21)$$

where

E_1 = modulus of elasticity in the longitudinal direction;

E_2 = modulus of elasticity in the radial direction;

G_{12} = modulus of rigidity in the longitudinal-radial plane; and

V_{12} = Poisson's ratio in the longitudinal-radial plane

and since k_o equals a constant multiplied by E (32), k_o in any grain direction may be expressed in terms of k_o in two perpendicular directions:

$$\frac{1}{k_o} = \frac{\cos^4\theta}{k_{o1}} + \frac{\sin^4\theta}{k_{o2}} + \left(\frac{1}{G_{12}} - \frac{2V_{12}}{k_{o1}}\right) \sin^2\theta\cos^2\theta \qquad (3.22)$$

where

k_{o1} = foundation modulus in the longitudinal direction; and

k_{o2} = foundation modulus in the radial direction.

[1]Polensek, Anton. April 1979. Class Lecture: Advanced Wood Physics. Forest Products Dept., School of Forestry, Oregon State University, Corvallis.

IV. Materials and Methods

The research techniques used in this study somewhat deviate from those of other investigators. While studies in the past have been confined mainly to the statistical regression between PMAX and the material properties of the wood and nail, the actual forces responsible for holding the nail in the wood member and the associated material mechanics have been ignored. A design procedure based on accepted formulations from mechanics of materials should include a normal force to the nail due to the elastically compressed wood around the nail and the resulting friction between the wood and nail surfaces. This chapter covers the experimental procedures needed to apply and verify the theoretical procedure outlined in chapter III.

4.1 Experimental Design

Four types of tests were conducted to evaluate the forces holding the nail in a wooden member. Specimens consisted of clear stud sections of nominal size 2 x 4 inch. Each section had six testing sites for nails. The first two tests were a nail-push test and nail withdrawal test which were conducted to determine the withdrawal stiffness and the amount of collapsed wood fibers due to nail penetration. The third test was a friction test aimed at determining the coefficient of static friction between the nail and wood surfaces. The fourth test, a foundation modulus test, enabled the evaluation of the pressure exerted on the nail by the wood medium. A flow diagram of the complete testing procedure complete with objectives of each step is shown in Figure 4.1. After the completion of testing, specimens were cut into small pieces which were tested to determine the material properties of wood.

4.2 Materials

4.2.1 Wood Selection

Thirty Douglas-fir (DF) studs of 2- by 4- inch nominal size were selected from a sample coming from several local mills in the Willamette Valley. Before testing the studs had been stored for six months at an equilibrium moisture content (EMC) of approximately nine percent. A resistance-type electric meter was used to determine the initial MC.

Thirty Engelmann-spruce (ES) studs, also of 2- by 4-inch nominal size, were obtained from an unused portion of samples left from a recent research project (17). The studs had been kiln-dried and stored in a covered shed for six years at an EMC of about 12 percent. The same resistance-type electric meter was used to determine their initial MC.

One specimen, twelve-inch in length, was cut from each DF and ES stud. Cut sections were free of any visual defects including knots, splits, checks, and pitch pockets. Next the specimens were conditioned in a kiln at 150°F for five days until an approximate 12 percent MC was reached. After conditioning the samples were stickered and allowed to equalize for two months in a conditioning room at 70°F

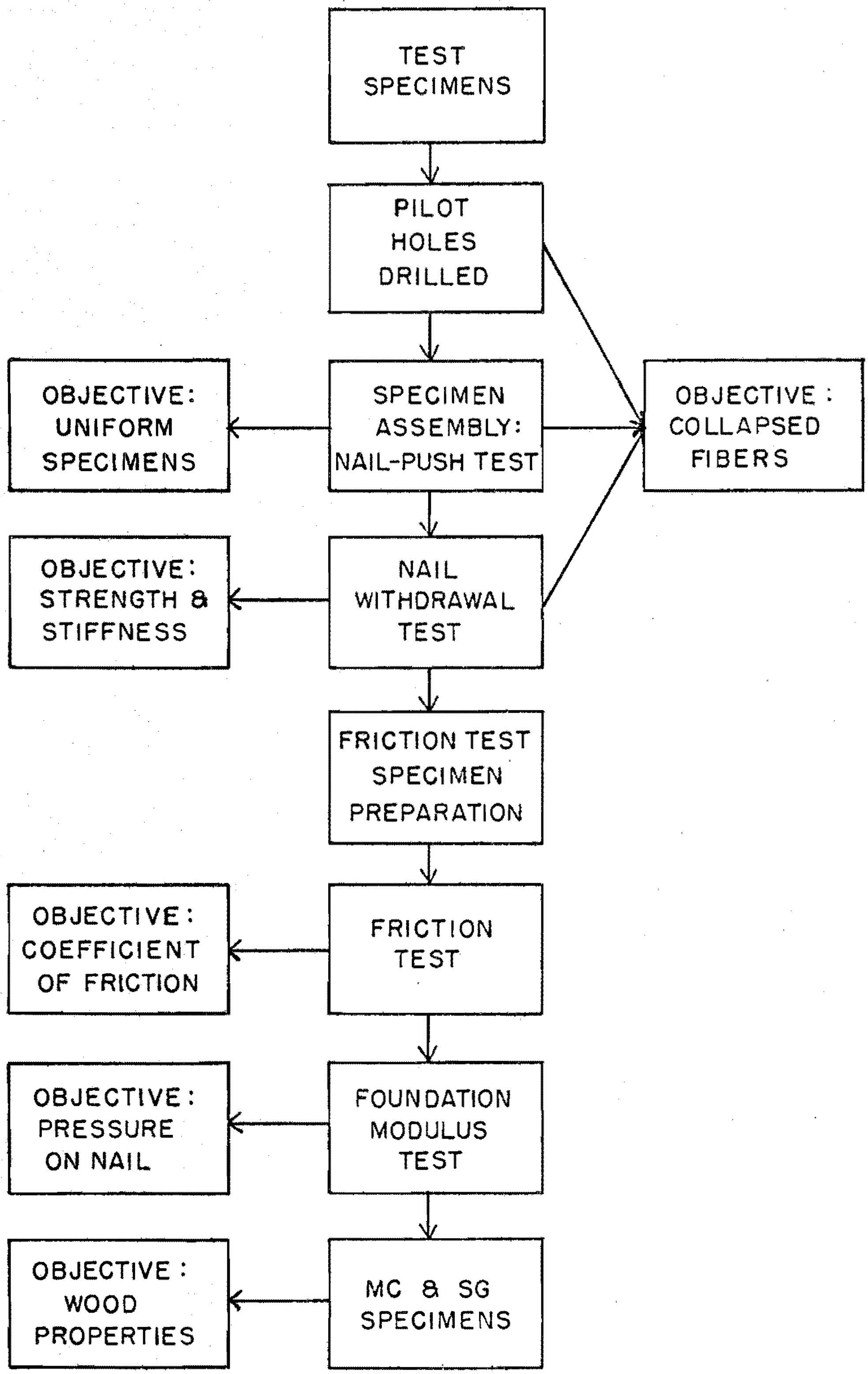


Figure 4.1: Flow diagram of testing procedure

and 65 percent relative humidity. Finally, the samples were cut to the cross-sections of 1.5 by 3 inches of 6-inch lengths.

Thirty southern-yellow-pine (SP) stud sections twelve inches in length and of 2- by 4-inch nominal size were cut from an unused portion of samples left over from a previous project (10). They had originally been obtained from the Forest Products Laboratory in Madison, Wisconsin at a MC of about eight percent. They were conditioned in a kiln for two weeks at 150°F and then allowed to equalize to 12 percent in a conditioning room where they remained for about 16 months. Before testing they were cut to cross sections of 1.5 by 3 inches of 6-inch lengths.

All tests were conducted on a machine in another conditioning room maintained at a constant temperature of 73°F and constant 50 percent relative humidity. These conditions correspond to an EMC of approximately nine percent. Since the specimens were predrilled and tested within a few hours after being taken from the first conditioning room it is assumed that the EMC of the specimens had experienced a negligible change.

4.2.2. Nails

Two nail factors, length and diameter of shank, are incorporated in the model for predicting nail withdrawal load and stiffness. Therefore, to fully establish the accuracy of the theoretical model a wide variety of nail sizes would have been chosen for this study. However, to keep the testing to a manageable scope, only one nail type was chosen, i.e. 6d common bright nail obtained from local shops. They had an average shank diameter of 0.113 inches and an overall length of two inches. Before testing all nails were wiped clean with a dry cloth and inspected for uniformity and smoothness of surface. Each nail was used only once.

4.3 Testing Procedure

4.3.1. Nail-Push and Nail-Withdrawal Test

The objective of these two tests was to determine the amount of collapsed wood fibers caused by the nail as it was driven into the wood member.

Four pilot holes (treatments) were predrilled to a depth of approximately 0.80 inches into the wide face of DF specimens before nailing (Fig. 4.2). The pilot hole sizes included diameters of zero (control), 0.0700, 0.0465 and 0.0400 inches.

Nails were machine driven into four pilot holes on the wide face of each specimen (Fig. 4.3) to a depth of approximately 0.75 inches at a constant rate of penetration of five centimeters per minute. The chosen speed was the fastest speed available on the testing machine, which more closely simulated hammer driving than the lower available speeds. A steel guide was used to assist in pushing the nails perpendicularly to the specimen faces. Machine driving was employed to reduce the variability associated with conventional hammering and to enhance the statistical reliability of the results.

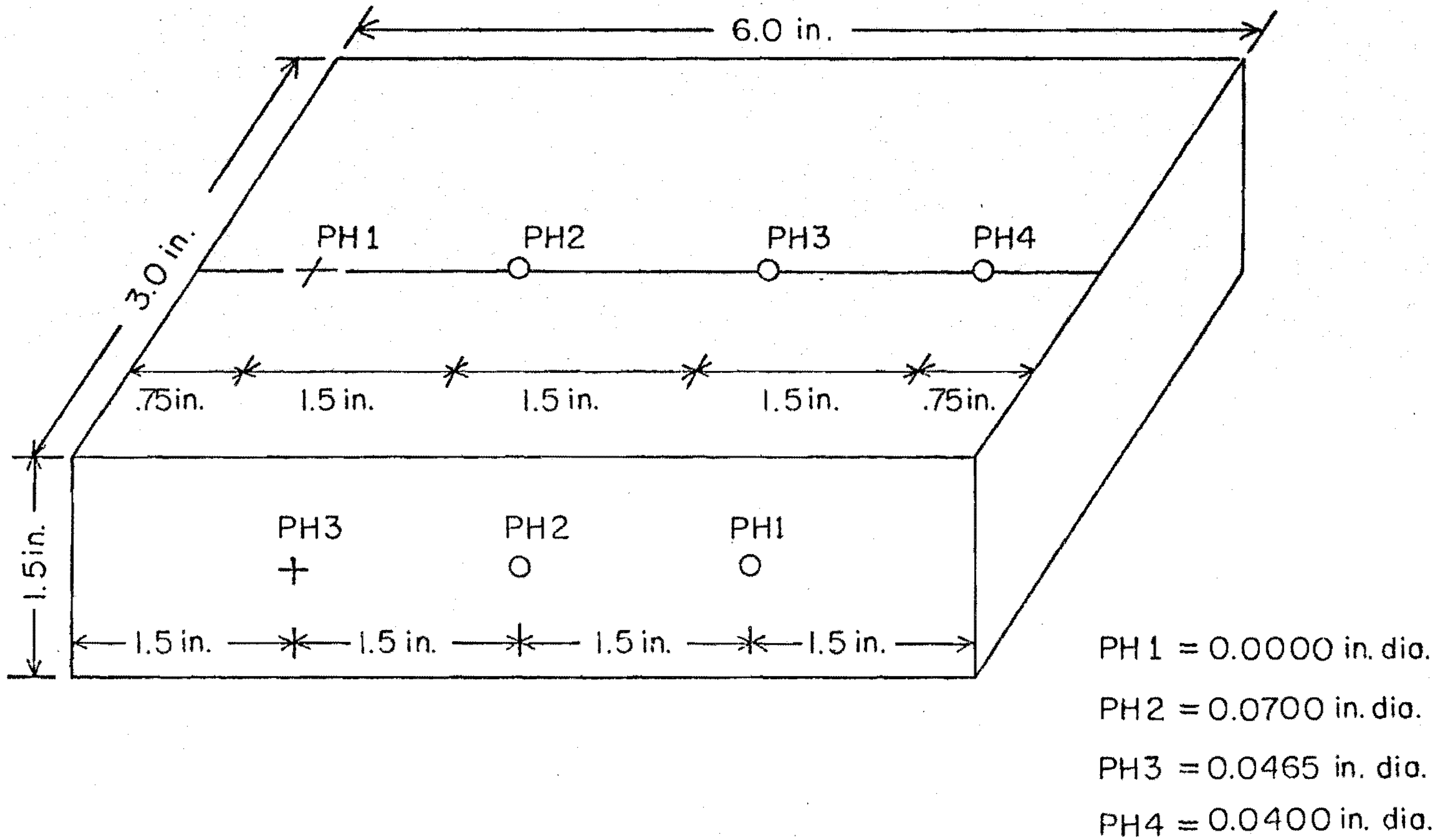


Figure 4.2: Location of predrilled pilot holes on the wide and narrow faces of a test specimen

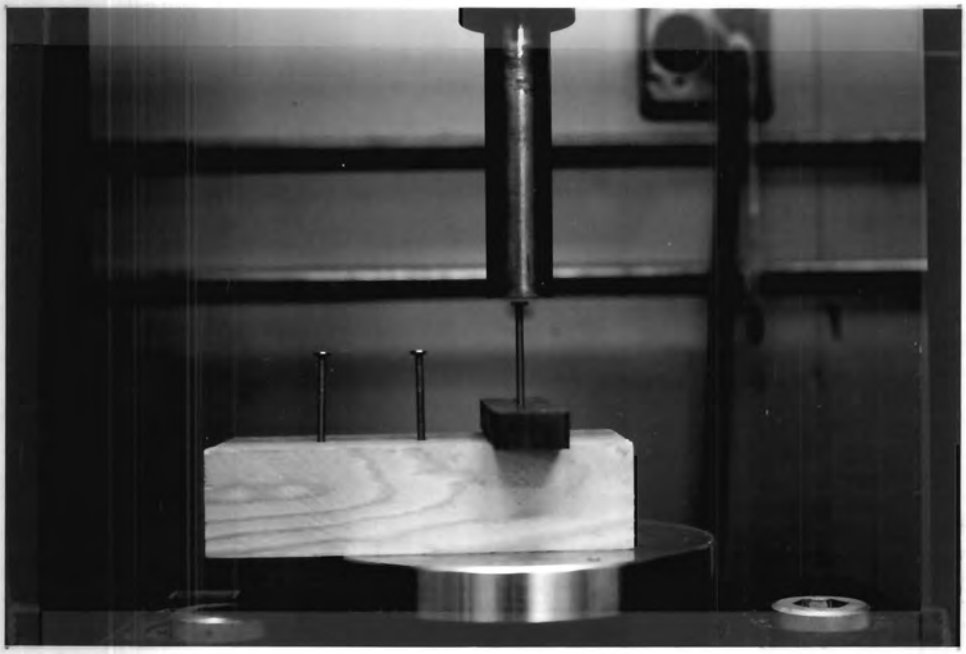


Figure 4.3: Machine pushing of nails into the wide face of a Douglas-fir specimen.

After assembly, the nails were withdrawn (Fig. 4.4) at a constant rate of 0.2 centimeters per minute which approximately complies with the rate of 0.075 inches per minute specified by Standard D143 of the American Society of Testing and Materials (ASTM) (2). The nails were considered withdrawn when a small relative displacement or slip between the nail and wood surface was realized and the withdrawal load decreased sharply (Fig. 4.5). Preliminary testing showed that for additional withdrawal the load decreased because the nail penetration depth also decreased. The objective of this investigation was maximum withdrawal load which occurred at the initial point of slip. The force needed to initiate slip, PMAX, which is associated with the static friction, is larger than that of sliding friction which is present during the withdrawal process of the nail.

After completion of tests on the wide face of the DF specimens the process was repeated on the narrow face, but with only three pilot holes. The largest pilot hole was omitted on the narrow face because the results from the tests on the wide face indicated that, for the 30 DF specimens the volume of collapsed wood fibers was approximated more closely by one of the two smaller pilot holes. Thus, the total number of tests on DF specimens was 210.

Specimens with ES and SP had only three pilot holes on each face, which called for 180 tests for each species. The remaining construction features and testing procedure were the same as those of DF specimens.

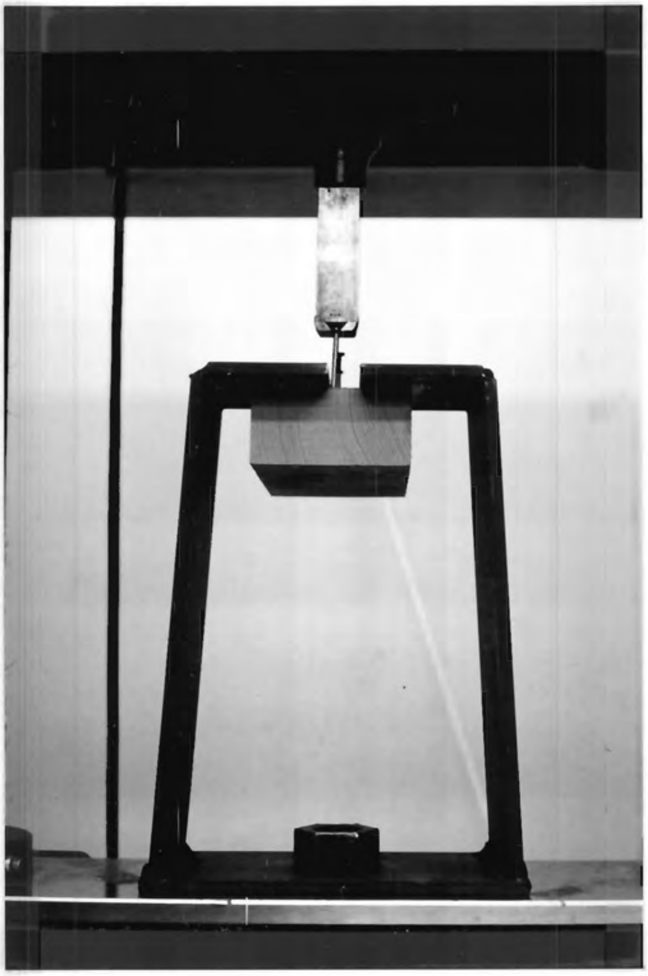


Figure 4.4: Withdrawal of nails from the wide face of a southern-yellow-pine specimen.

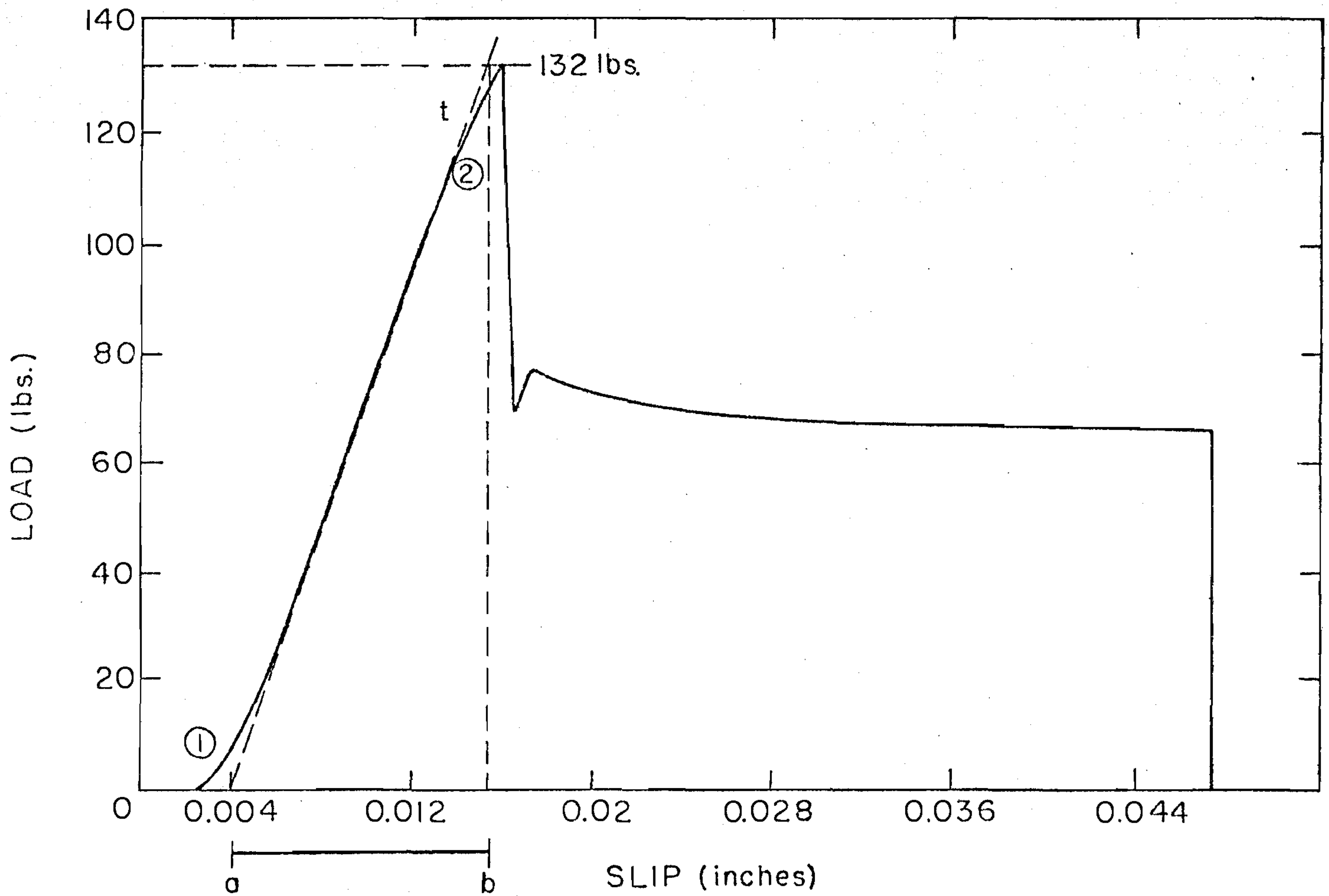


Figure 4.5: Typical withdrawal curve showing maximum withdrawal load and the relative displacement or slip between the nail and wood surface. The Zone between a & b is the withdrawal deformation.

4.3.2. Friction Tests

The objective of this test was to determine the static coefficient of friction between the nail and the wood surface in the nail hole. As demonstrated in chapter III two loads are needed to evaluate the friction coefficient: horizontal load (H) pushing evenly over the length of the nail that is supported by the wood and withdrawal load (W) acting perpendicularly to H.

After withdrawal tests the nails were fully withdrawn and each specimen was cut into five pieces as shown in Figure 4.6. The saw cuts were made through nail holes of two wide and two narrow face sites. The cuts exposed one half the original nail hole along its entire length. The surface in the exposed nail holes were assumed to be almost the same as that introducing frictional forces during withdrawal tests. Therefore this surface should represent actual conditions more closely than the wood surface manufactured by other means such as sawing and planing.

A vise, constructed out of metals, provided H by closing the vise. This pushed the nail into the half-hole left on the wood blocks (Figs. 4.7 and 4.8). A load cell was inserted into the vise to continuously monitor the change in H. Two steel plates, separated by rollers, bore against the load cell and the full embedded length of the nail (Fig. 4.9). The rollers reduced the friction between the outer steel plate and the nail to a negligible level.

Before testing, the wood blocks containing the half-holes were clamped securely into the vise. Nails were placed back into the

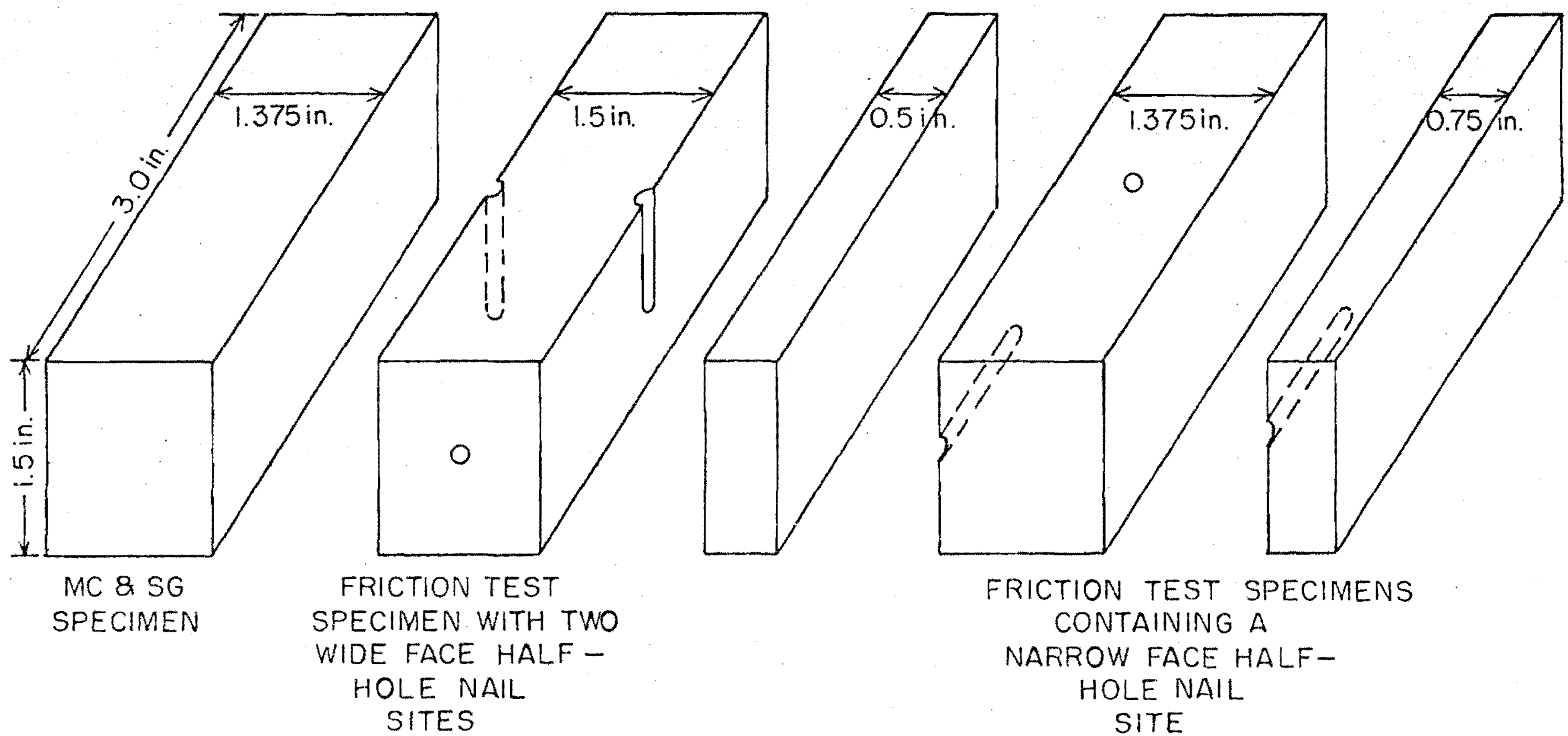


Figure 4.6: Cutting pattern used to expose two wide face and two narrow face half holes for friction tests.

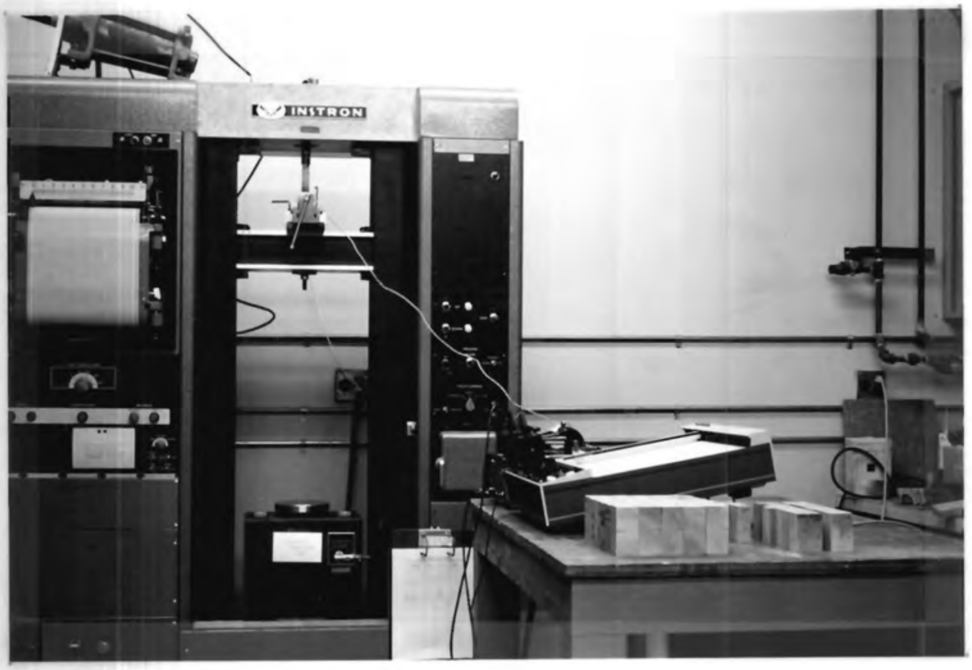


Figure 4.7: Testing apparatus used to evaluate friction coefficients.

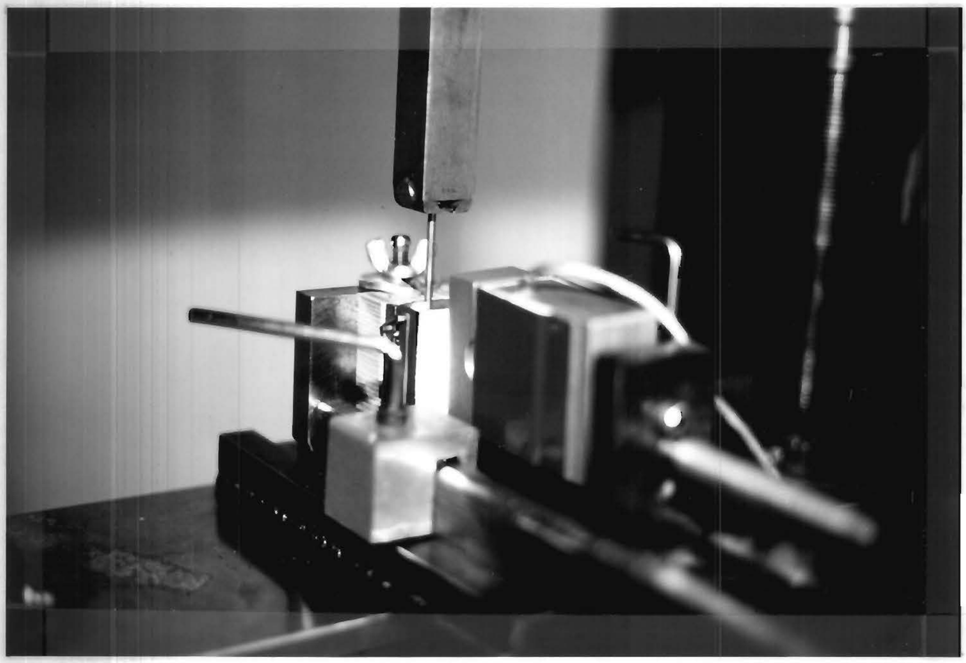


Figure 4.8: Close-up of apparatus used to apply the H needed in evaluating the friction coefficients.

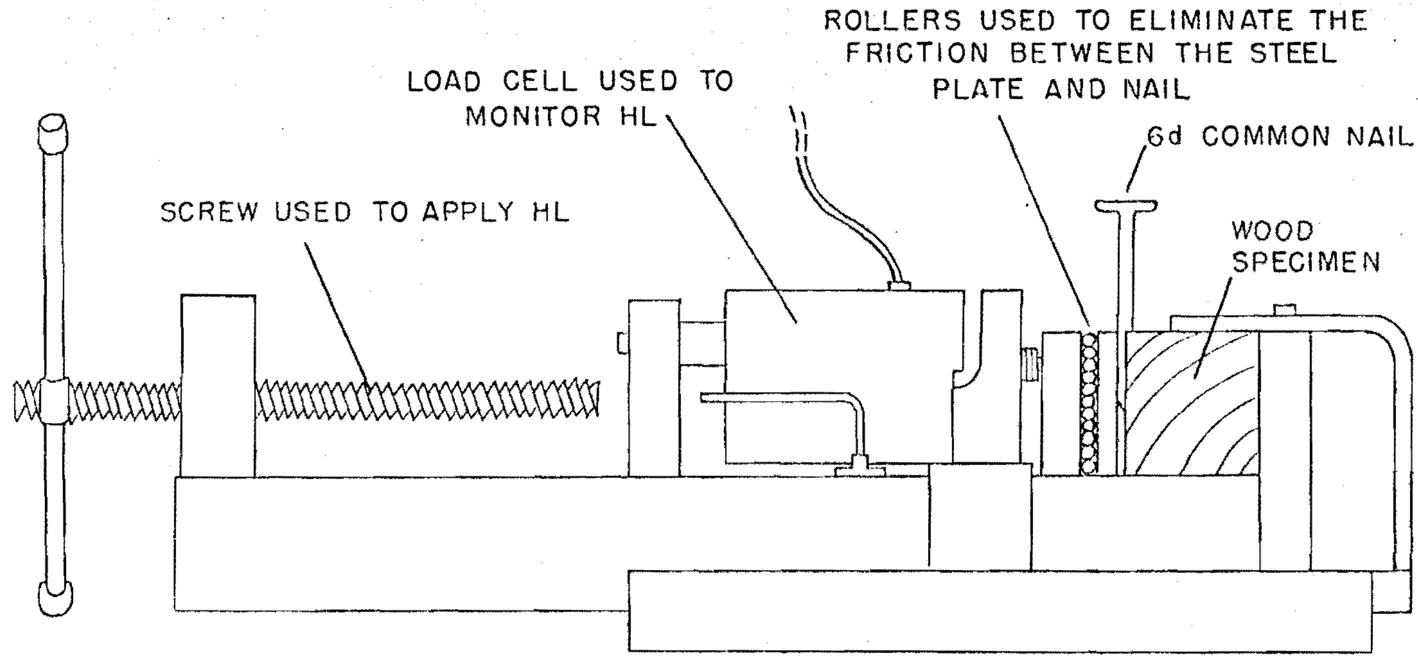


Figure 4.9: Schematic of the vise used to apply H when evaluating the static friction coefficients.

half-holes with their ends 0.75 inches deep in the half-holes. The vise was closed until H reached 40 pounds and then the base of the vise was fastened to the cross-beam of the testing machine. The nail head was connected to the machine head which applied W at the rate of 0.2 cm per minute as in the original withdrawal tests. The nails were withdrawn until a slip occurred between the nail and the wood surface and the W exceeded the force of the static friction. For design purposes, only the maximum coefficient of static friction is needed, because if W continues to pull on the nail a complete withdrawal occurs.

To test the minimum but adequate number of specimens, testing was conducted as follows. Initially, 56 tests were run on 14 DF specimens, two tests on the wide face and two on the narrow face. Two half-hole sites were selected at random from each face on which the tests were to be run. A paired t-test was then performed on the 14 pairs of wide face friction coefficients to determine if they were statistically equal. The same test was then performed on the 14 pairs of narrow face friction coefficients. Results (Chpt. 5.2.2) indicated that the maximum static friction coefficients on both faces were statistically the same. Next, one friction coefficient value was selected, at random, from the wide face and one from the narrow face. A paired t-test was then run to determine if the wide face friction coefficients differed from the narrow face friction coefficients. Again, the results (Chpt. 5.2.2) indicated that the wide and narrow face friction coefficients were statistically the same. Therefore, only one half-hole on the wide face of each of the 16 remaining DF specimens and one half-hole on each of the 30 ES and 30 SP specimens needed to be tested. Thus, the number of tests for the remaining specimens was reduced to 76.

4.3.3. Foundation Modulus Tests

The objective of this test was to determine the pressure and normal force exerted on the nail shanks due to the elastic nature of the wood. Because the values for the modulus of elasticity indicated that the foundation modulus (k_o) for the end grain of wood is considerably greater than that for the radial direction, test data was obtained to evaluate k_o for both directions.

After the completion of all friction tests, one specimen was selected from each of the 30 specimens in each of the three species groups, providing 90 samples for the evaluation of k_o. The testing apparatus used was based on Figure 3.7. A 1/4-inch thick steel plate measuring 1.320 in. x 0.182 in. was first placed on the end grain with its length parallel to the direction of penetration of the wide-face nail site (Fig. 4.10). The specimen was then loaded in compression (Fig. 4.11) by lowering the machine cross-head at the rate of 0.2 centimeters per minute, the identical rate used for both withdrawal and friction tests. This machine cross-head motion indicated compression deformation under the metal plate. Load vs. compression deformation curves were recorded continuously throughout the load application. The test was conducted on four locations, on each specimen, identified in Figure 4.10.

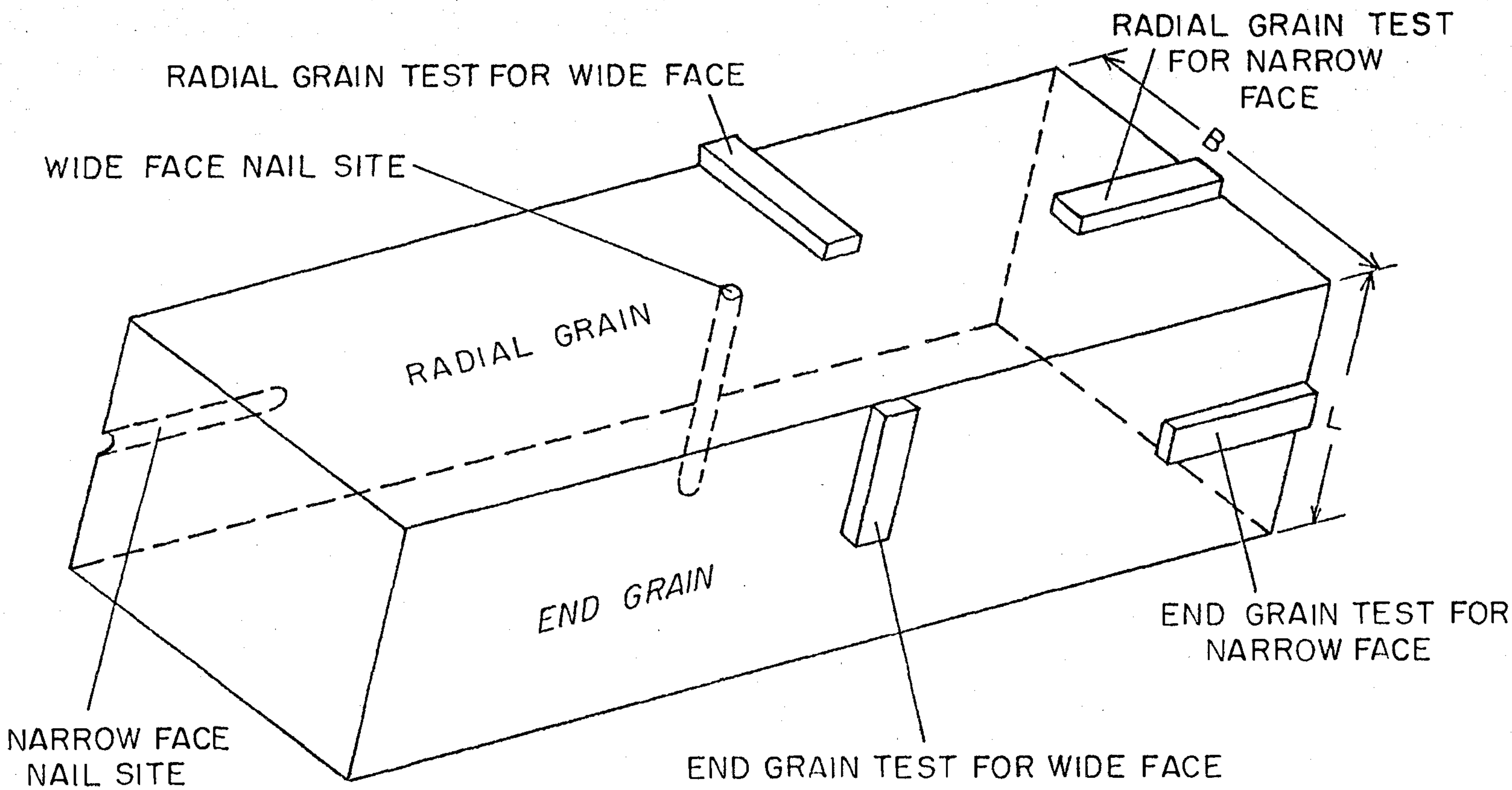


Figure 4.10: Positionings of the steel plate used to evaluate the foundation modulus for end and radial grain directions.

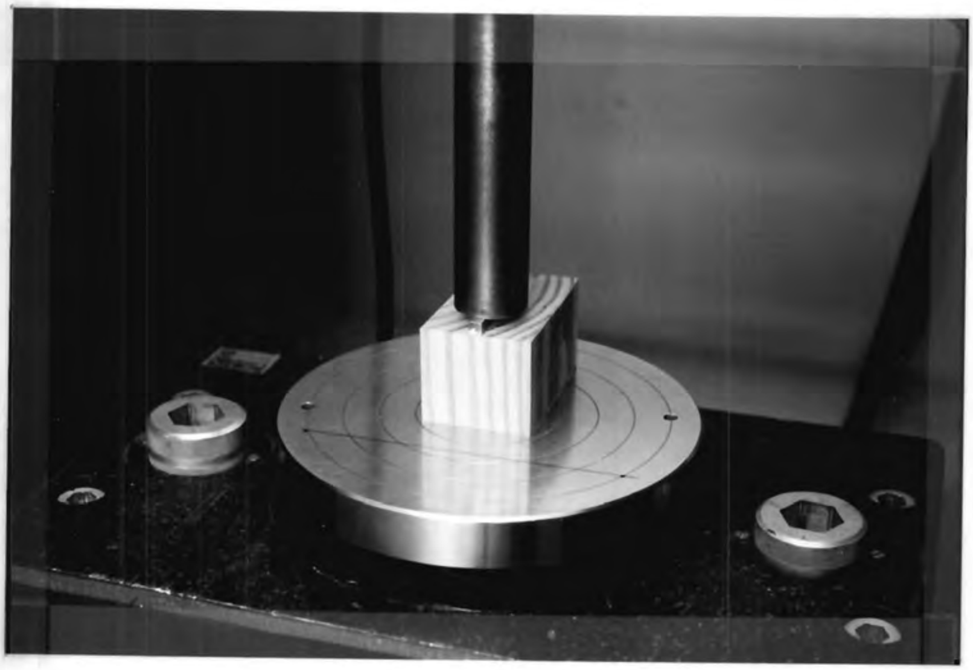


Figure 4.11: Testing for the end grain foundation modulus for a nail driven into the narrow face of a southern-yellow-pine specimen.

After testing, B and L (Figure 4.10) were recorded for each specimen in order to have them available for later analyses.

4.4.4. Evaluation of Specific Gravity and Moisture Content

The SG and MC of each specimen was determined by ASTM Standard D 2395 (2). Sections of wood left after cutting specimens for friction tests (Figure 4.6) were cut into 1- by 1- by 2-inch blocks. Each block was weighed to the nearest hundredth of a gram to determine its initial or green-weight (GW). A measuring device equipped with two linear variable differential tranducers (LVDT) was used to determine the green dimensions of the blocks. After measuring, the blocks were dried in an oven for 48 hours and reweighed to obtain the oven-dry weight (ODW). MC and SG were calculated by the well-known formulas (2):

$$MC(\%) = 100 \; \frac{(GW - ODW)}{ODW}$$

$$SG = \frac{27.68\ (ODW)}{1+(\frac{MC\%}{100})\ LWH}$$

4.4.5. Measuring of the Angle between Nail and Growth Rings

This angle was measured to determine its potential effect on the nail withdrawal stiffness. For each specimen, a xerox copy of one nail site on the wide face and narrow face was made. The angles were then measured from the copies to within one degree of accuracy with a protractor.

V. Results and Discussion

This chapter covers the data analysis procedure, presents the reduced data, and discusses the test results.

5.1 Reduction of Experimental Data

5.1.1 Nail-Push Curves

A typical curve is shown in Figure 5.1. Obtained from these curves were the maximum penetration depth of the nail shank and point, and the maximum load necessary to drive the nail to its maximum depth. The peaks on the curve indicate where the nail shank passes through the dense summerwood while the valleys indicate where the nail shank passes through the less dense springwood. Due to irregular widths of the denser summerwood cell layers, the maximum load did not always occur at the maximum penetration depth, as illustrated in Figure 5.2.

Nails were not always pushed to the same depths of penetration, since the block depths varied slightly. The pushing action could not always be stopped exactly at the target depth.

5.1.2 Nail Withdrawal Curves

A typical curve is shown in Figure 4.5. The results obtained from these curves were the maximum withdrawal load and withdrawal deformation (WD). Because of slippage in the testing apparatus at ini-

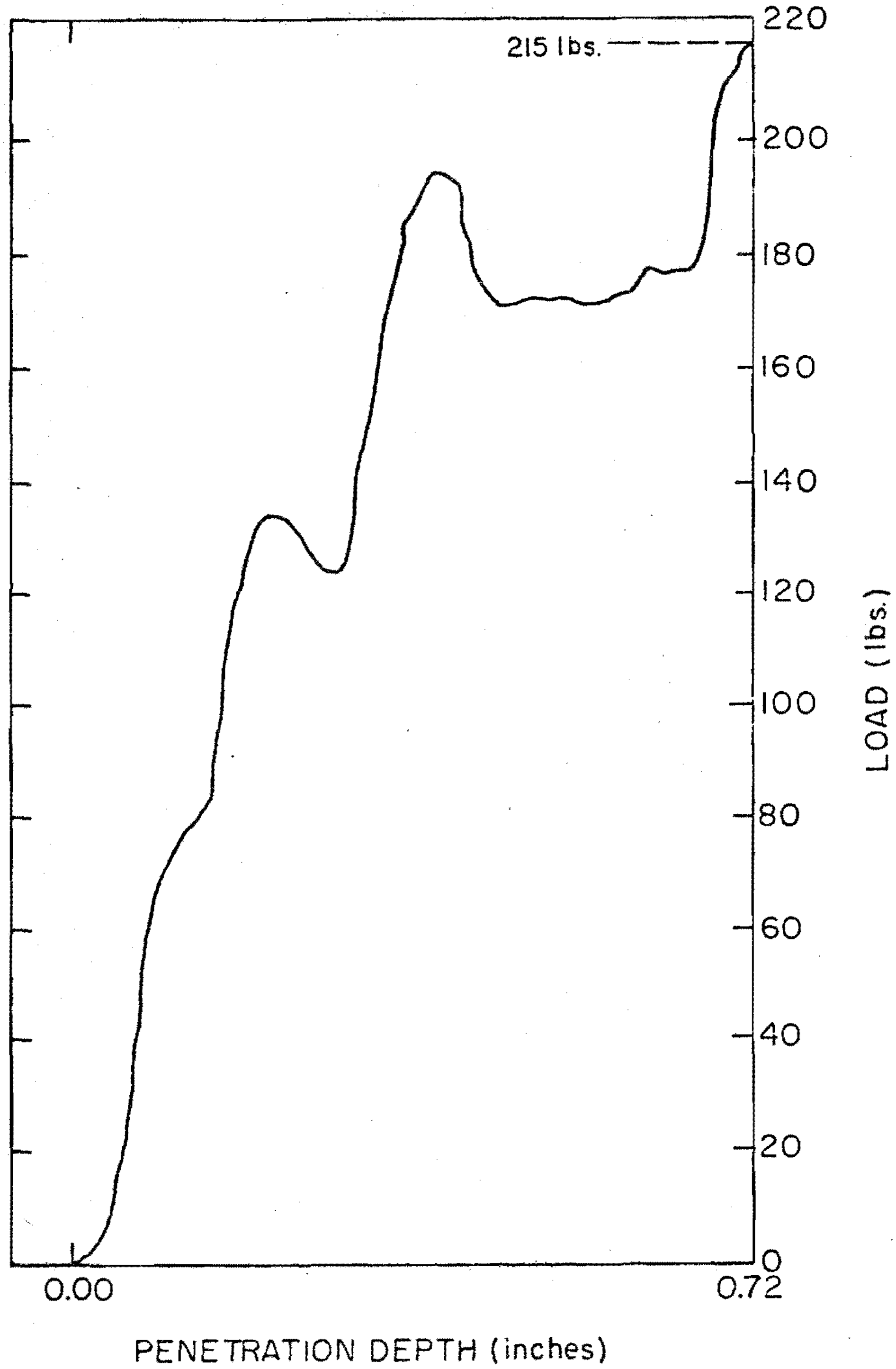


Figure 5.1: Typical load-penetration curve showing the resistance of the nail moving into the wood at a constant penetration rate.

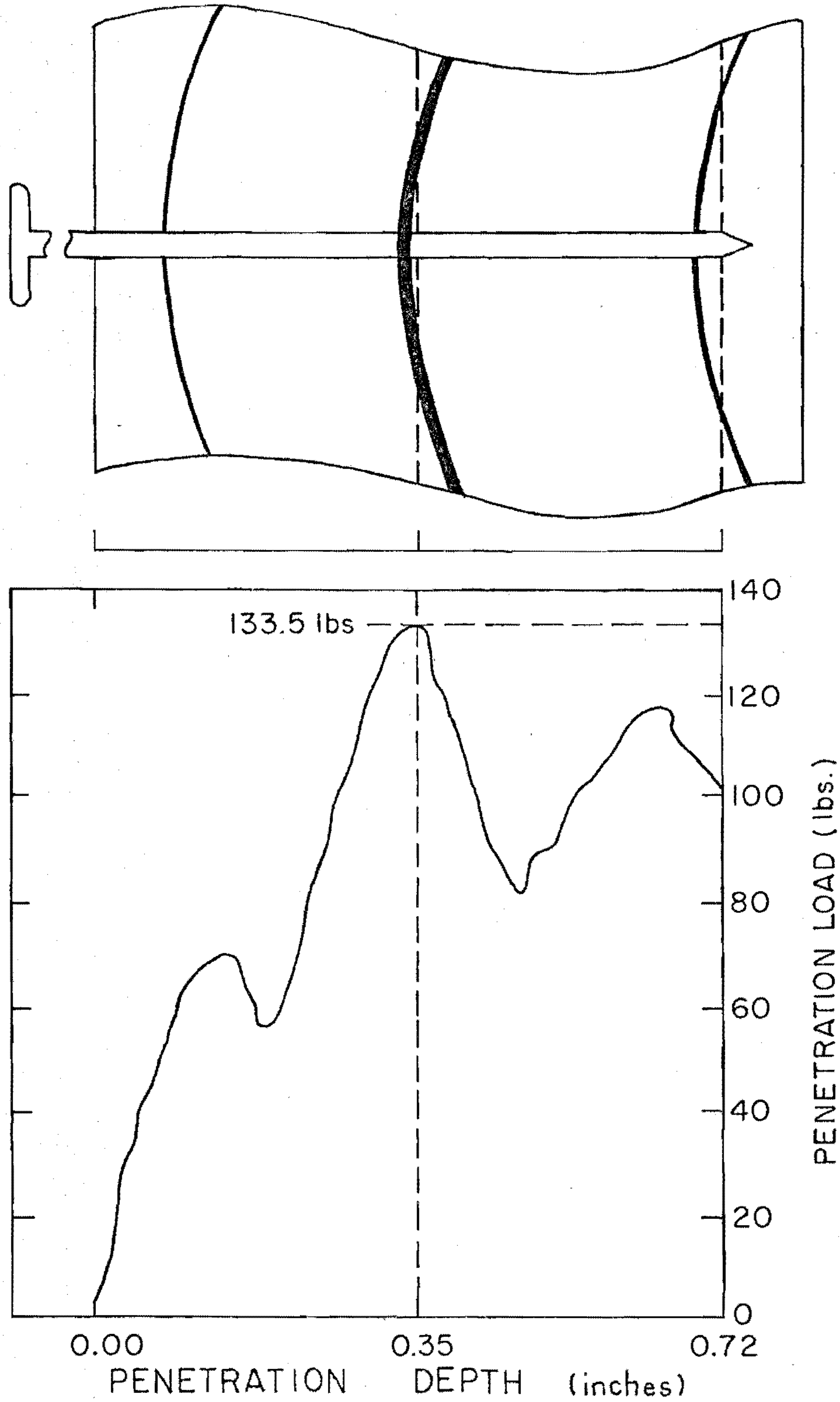


Figure 5.2: Due to dense layers of summerwood the maximum penetration load does not always occur at the maximum depth of penetration.

tial loads (point 1) and possibly at points where the force of static friction between wood and nail was broken (point 2), the curves were corrected as shown in Figure 4.5: A tangent was drawn to the linear portion of the curve so that a straight line represents the load-to-slip relation between zero load and the first peak on the curve. The projection of the tangent line on the x-axis is the WD prior to nail slip and the load needed to initiate this is the maximum withdrawal load. The actual withdrawal slip of the nail begins to the right of the vertical line. The WD prior to slip is caused by wood deformation around the nail.

5.1.3. Friction Test Curves

In order to evaluate the coefficient of static friction, two loads were needed: 1) a normal, and 2) a withdrawal which as noted before has to be large enough to overcome the initial slip between the nail and wood surfaces. These loads were scaled from friction test curves such as the one shown in Figure 5.3.

5.1.4. Foundation Modulus Curves

These curves look much like a conventional stress-strain curve (Fig. 5.4). Because some minimum load is needed before a close contact is reached between bearing plate and wood, the curves initially display an increasing rate of stiffness. Therefore, correction was made by drawing a tangent from the linear portion of the curve to the

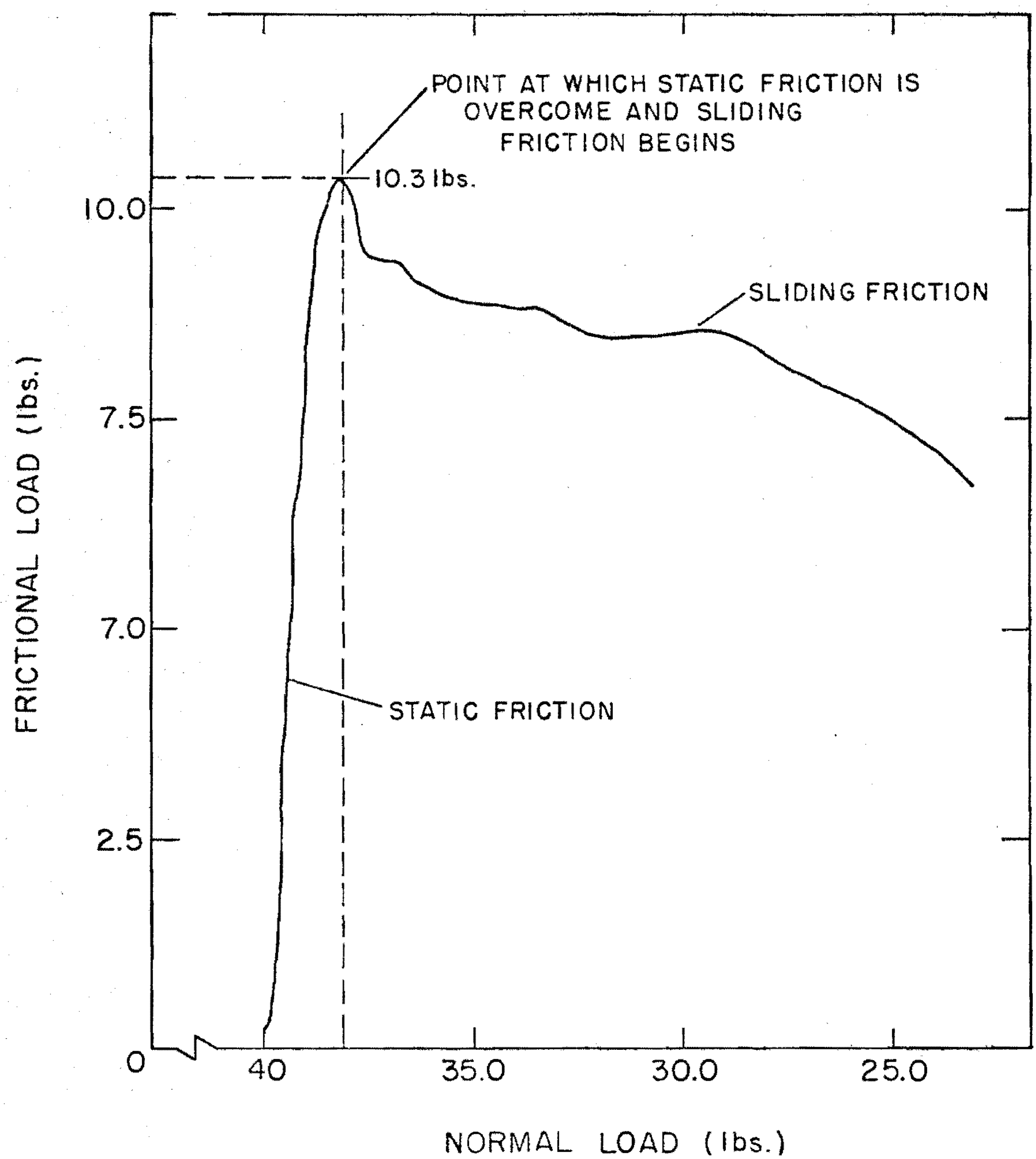


Figure 5.3: A typical curve caused by initial normal load of 40 lbs and gradual "withdrawal" of a nail under constant rate.

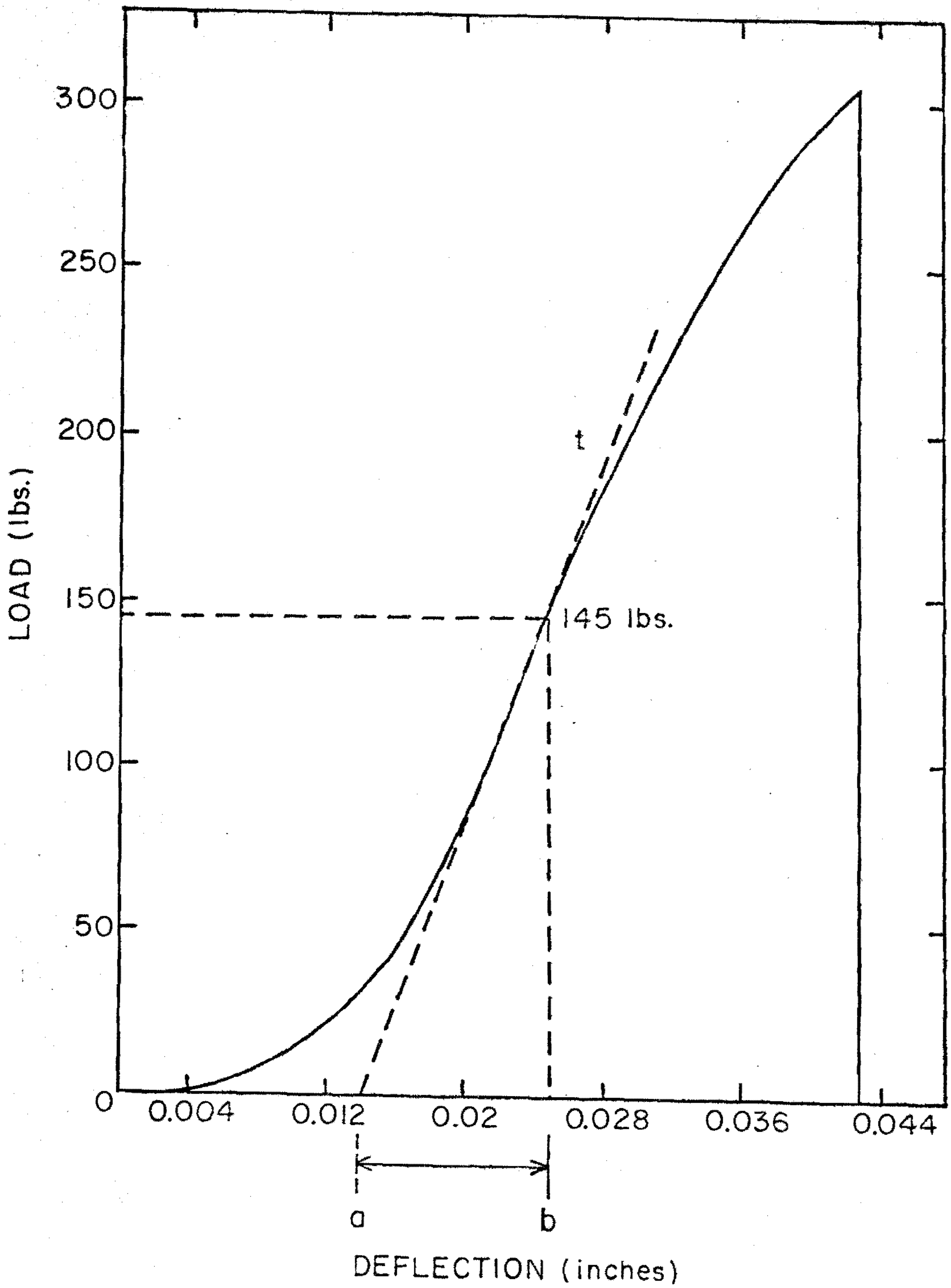


Figure 5.4: Typical load-deflection curve generated while testing for the foundation modulus. The slope of the tangent line t was used to evaluate the foundation modulus. Total deflection is measured between a & b.

X-axis. The slope of this line was then used to evaluate the foundation modulus. The deflection of the bearing plate into the wood is measured between a & b (Fig. 5.4).

5.2 Data Analysis, Results and Discussion

5.2.1. Effect of Pilot Hole Size on Nail Withdrawal Resistance

The maximum penetration depth and maximum withdrawal load were the input variables for the Fortran IV program "WR" (Appendix A) in order to evaluate the withdrawal resistance (WR) for each nail site. Withdrawal resistance is the force per unit length needed to withdraw the nail. Then the WR data were analysed by a computer library package known as the Statistical Interactive Programming System (SIPS) (22). The objective of predrilling pilot holes (PH) and the nail withdrawal test was to determine the amount of collapsed wood fibers. This information was used to evaluate the deflection y (equation 3.8). Since comparisons were being made within groups of similar experimental units, the technique statistically known as blocking was used. Blocking removes a source of variation which tends to inflate the variance (12, 15).

Since nail pushing and the nail withdrawal test were both tedious and time consuming, an initial study using a randomized block design (task file "A" in Appendix A) was performed on the wide face WR results of the DF specimens with the hope of eliminating at least one of the PH's used. The resulting analysis of variance table (AVTABLE) is shown in Table B-1 (Appendix B).

To determine if the mean WR for the four PH's (treatments) are equal, the variability due to differences among the sample (treatment) means (MST) was compared with the variability due to within-sample differences among the experimental units (MSE) using the F-statistic (12, 15). To test if differences exist among the block means a comparison was made between the variation among blocks (MSBL) to the variation due to error (MSE) using another F-statistic (12, 15). This test determined whether blocking was an effective means in reducing the experimental error. Thus, the randomized block design allowed the removal of the variation between blocks from the within-sample variation which decreases the MSE. The smaller the value of the MSE, which appears in the denominator of the F-statistic, the more likely a difference between treatment means is detected, if such a difference exists.

Table B-1 shows that the mean WR values differ among the 30 blocks at the five percent significance level, therefore the use of a randomized block design was helpful in reducing the MSE and increasing the amount of information in the experiment. The treatment differences were also significant at the five percent level. To examine the nature of the differences between the control, case of nailing with no hole (PH1 in Figure 4.2), with the predrilled holes (PH2, PH3, PH4), the Tukey method of multiple comparisons was employed (15). Table B-2 (Appendix B) summarizes the Tukey procedure and the three pairwise comparisons.

The pairwise comparisons indicated that all but one of the differences (PH1 and PH2) were statistically significant (confidence interval did not include zero). A graphical interpretation of the results is shown in Figure 5.5. Since the mean of the control nailing (PH1) is contained within the Tukey pairwise confidence interval of PH1 and PH2, there is no clear evidence to indicate that there is a difference between these two mean WR values. The multiple comparison procedure allows the inference, with a 90 percent family confidence coefficient, that the mean WR of PH3 (0.0400 inch diameter) is closest to that of the control (PH1) followed by PH3, and then PH4.

With the knowledge of the preceeding results, the PH with the largest diameter, PH4 (0.0700 inch diameter), was not included in testing narrow faces of DF specimens. Since the SP specimens had a higher average SG than the DF specimens, the largest diameter pilot hole was eliminated when testing SP specimens. The ES specimens, however, had a lower SG than the DF specimens. Therefore, the smallest PH (0.0400 inch diameter) was eliminated from testing ES specimens.

At the conclusion of all nail-push and nail withdrawal testing, a paired t-test (12) (taskfile "B" in Appendix A) was conducted between the wide face and narrow face for the nails without the PH (PH1). This test was to determine if the mean WR between the controls (PH1), or more specifically, if the change in angle between the axis of the nail and the growth rings within a species, was significant or not. Table B-3 (Appendix B) summarizes the results.

The results in Table B-3 indicate that, on the average, there is no difference in WR whether the nail is withdrawn from the wide face or the narrow face of the specimens. In other words the average angle between the axis of the nail and the growth rings has no effect on WR.

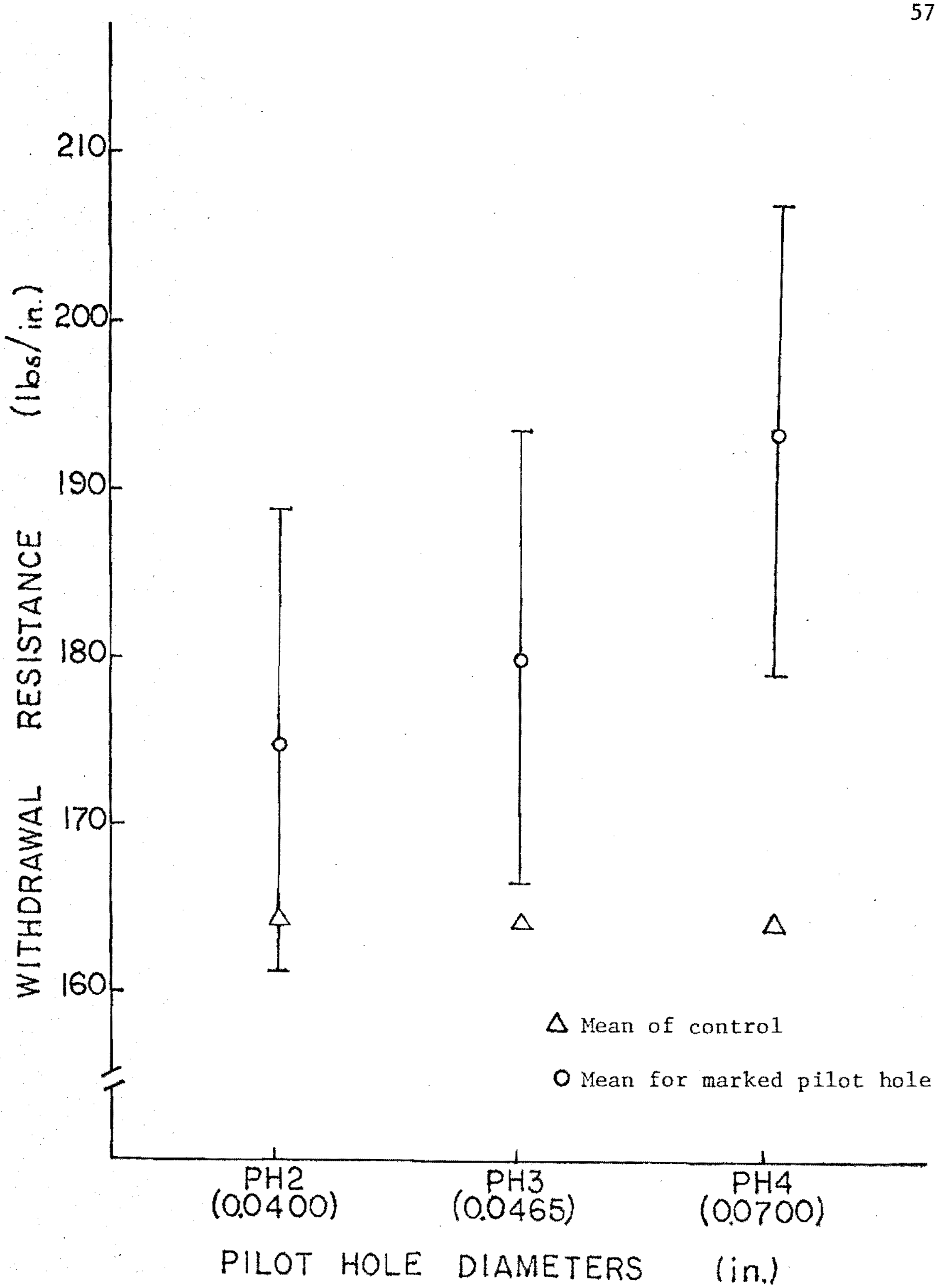


Figure 5.5: Tukey pairwise confidence intervals for the effect of pilot hole diameter on the withdrawal resistance of 6-penny nails from the side grain of clear DF stud sections. Intervals are formed by adding the mean pilot hole withdrawal resistance to the Tukey pairwise confidence intervals found in Table B-2.

However, differences may exist among individual observations, which is of lesser importance because the application of WR calls for using the means and not individual values.

Next, a two-factor randomized complete block design (15) (taskfile "C" in Appendix A) was employed to evaluate the amount of collapsed fibers due to nail penetration. The resulting AVTABLES for each species are shown in Table B-4 (Appendix B).

Table B-4 illustrates that the mean WR values of the three species differ among the 30 blocks at the five percent level of significance. Therefore, use of the randomized block design did reduce the MSE thereby increasing the amount of information in the experiment. A test for interaction effects was made using an F-statistic (15) which reflects the variability of the estimated interactions (MSAB) to the variability due to error (MSE). Table B-4 indicates that at the five percent level PH and face do not interact in their effects on WR, which is also shown graphically in Figures 5.6, 5.7, and 5.8.

The differences in WR between the control nail (no PH) and nails driven into the other two PH sizes used (factor A main effects) are significant at the five percent level for DF and ES specimens, and at the 10 percent level for SP specimens. The Tukey procedure (15) was again used to examine the pairwise differences between the control, case of nailing with no hole, (PH1) and PH2, and PH1 and PH3 for DF, ES, and SP specimens. Table B-5 (Appendix B) and Figures 5.9, 5.10 and 5.11 summarize the Tukey procedure and all pairwise comparisons for the three species.

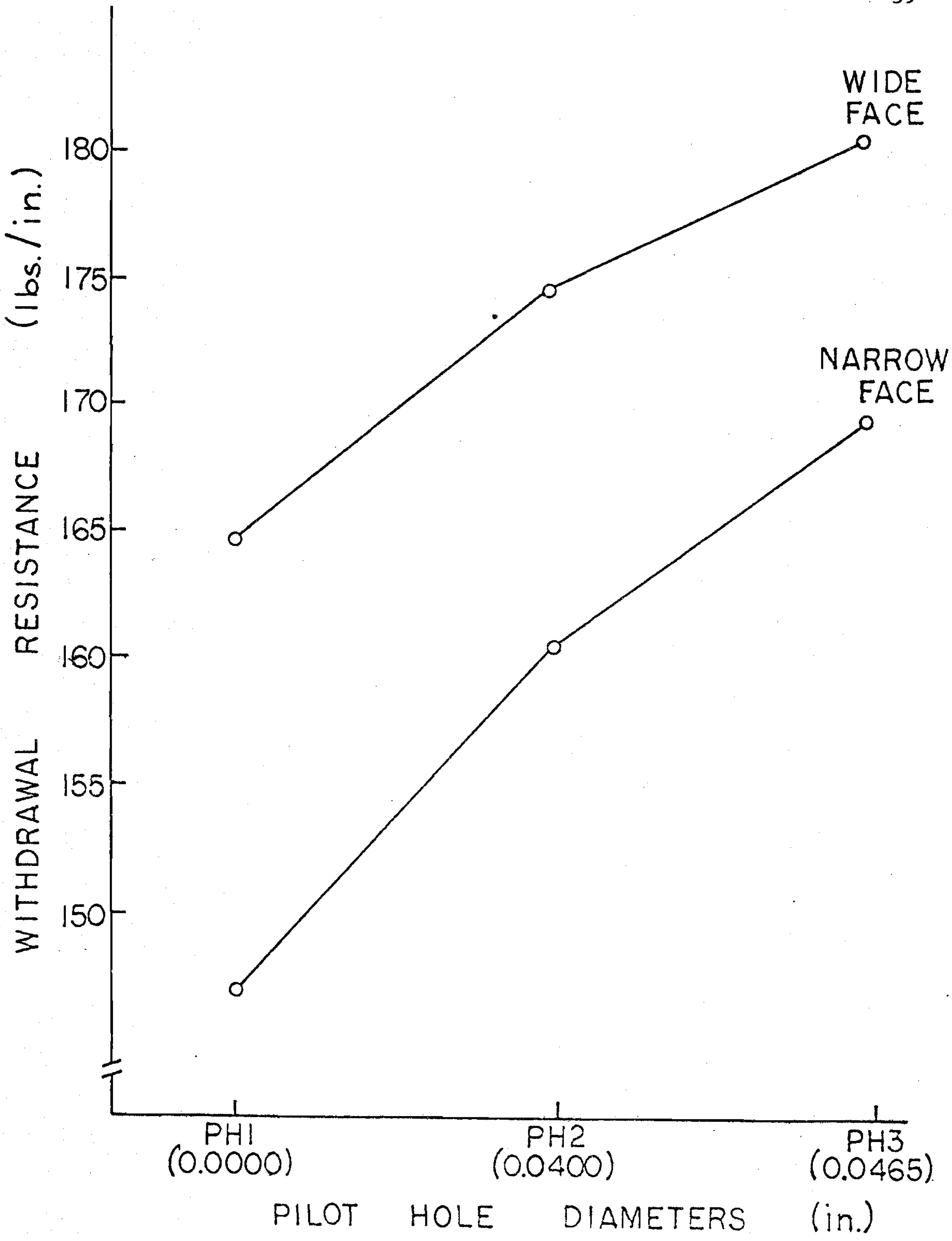


Figure 5.6: Interaction effect of face and pilot hole on the withdrawal resistance of 6-penny nails from the side grain of clear DF stud sections. Each point is an average of 60 observations.

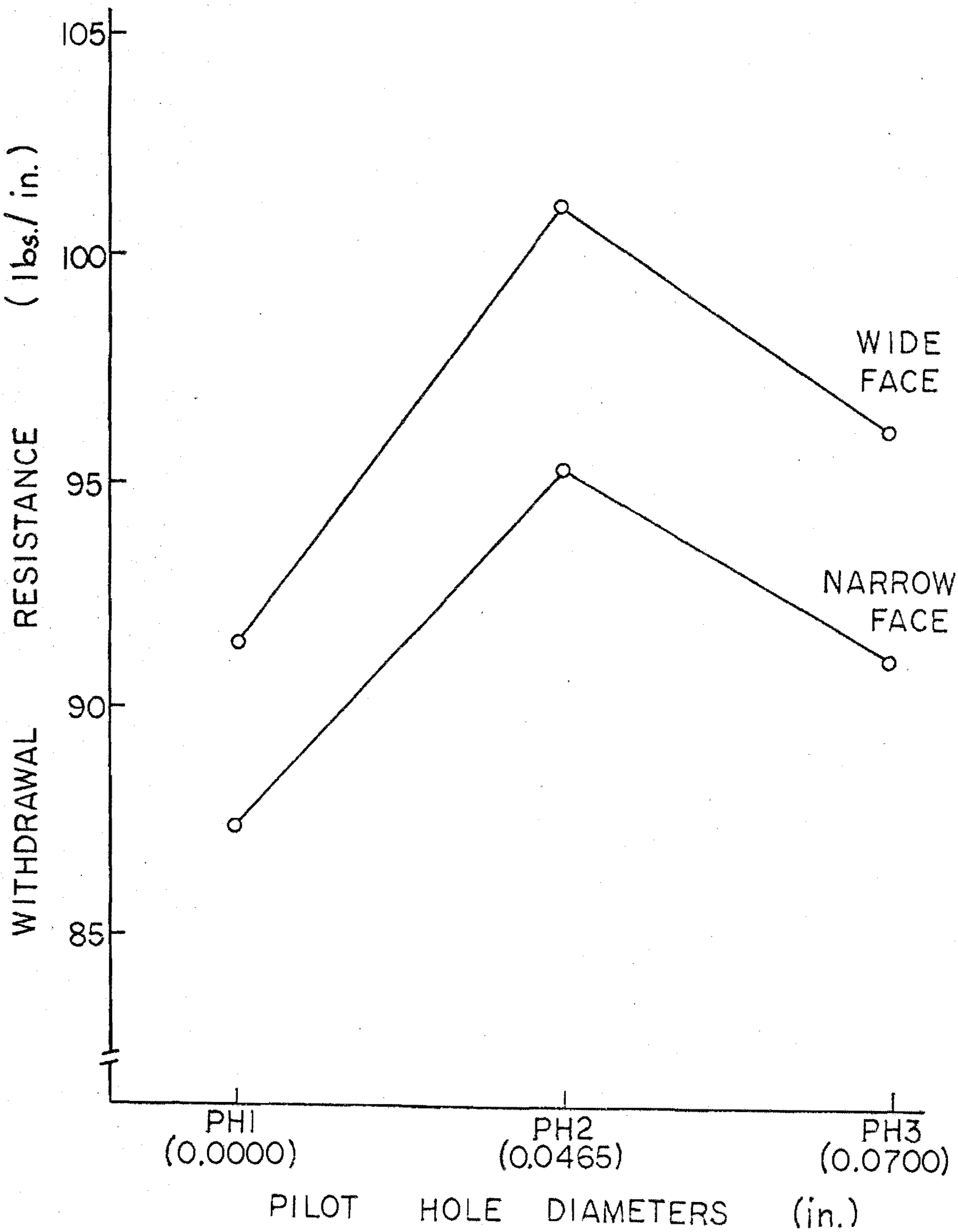


Figure 5.7: Interaction effect of face and pilot hole on the withdrawal resistance of 6-penny nails from the side grain of clear ES stud sections. Each point is an average of 60 observations.

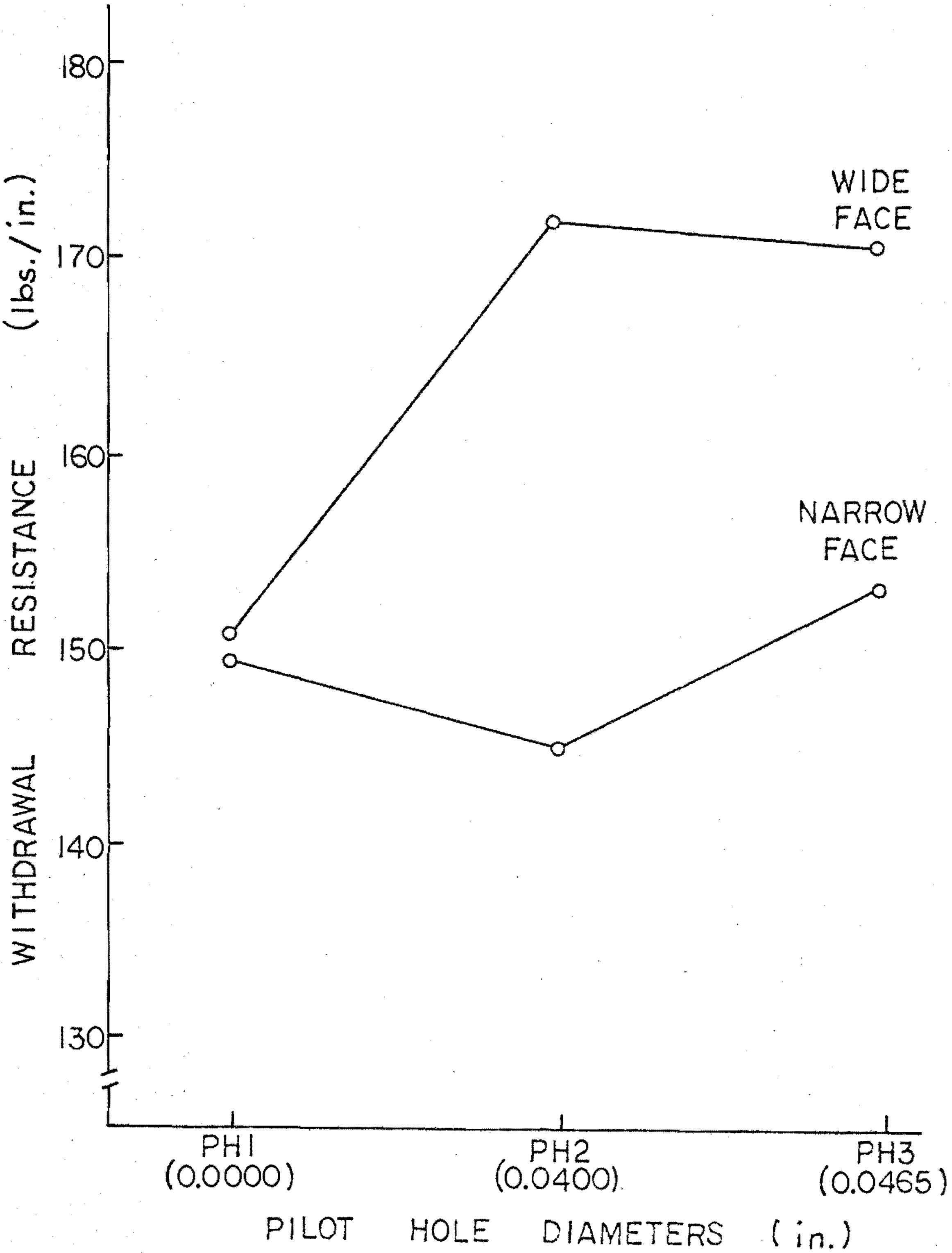


Figure 5.8: Interaction effect of face and pilot hole on the withdrawal resistance of 6-penny nails from the side grain of clear SP stud sections. Each point is an average of 60 observations.

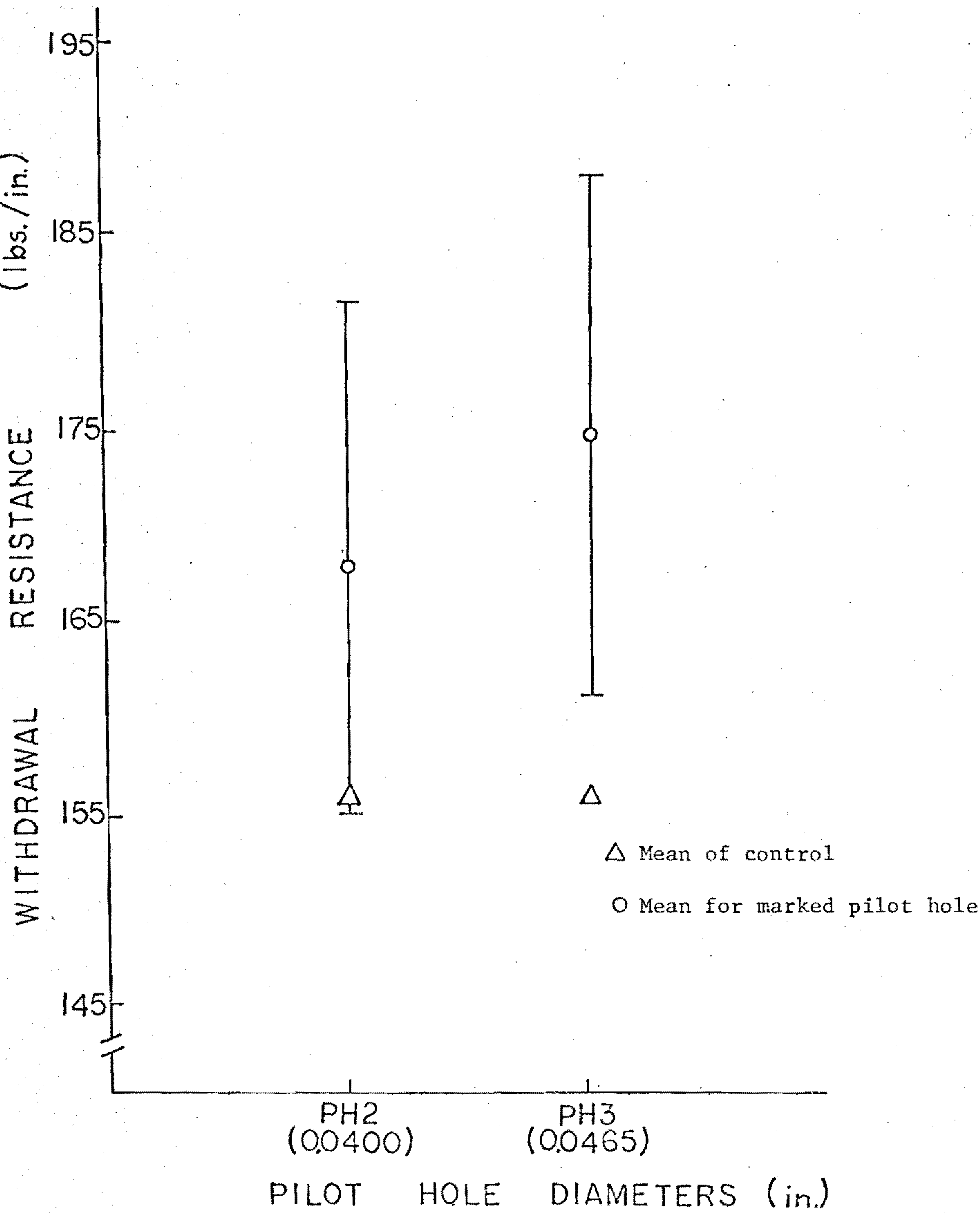


Figure 5.9: Tukey pairwise confidence intervals for the effect of pilot hole diameter on the withdrawal resistance of 6-penny nails from the side grain of clear DF stud sections. Intervals are formed by adding the mean pilot hole withdrawal resistance to the Tukey pairwise confidence intervals found in Table B-2.

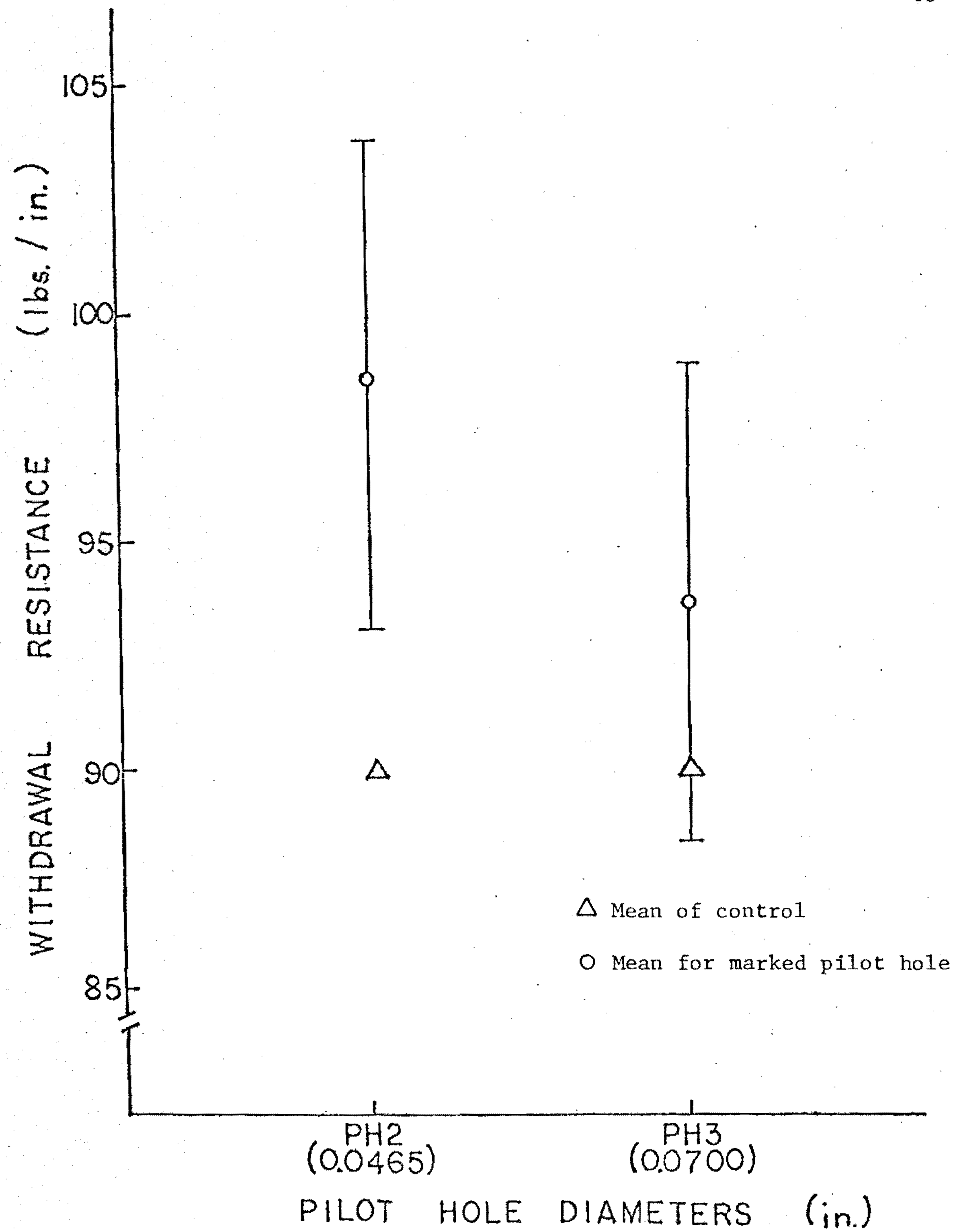


Figure 5.10: Tukey pairwise confidence intervals for the effect of pilot hole diameter on the withdrawal resistance of 6-penny nails from the side grain of clear ES stud sections. Intervals are formed by adding the mean pilot hole withdrawal resistance to the Tukey pairwise confidence intervals found in Table B-2.

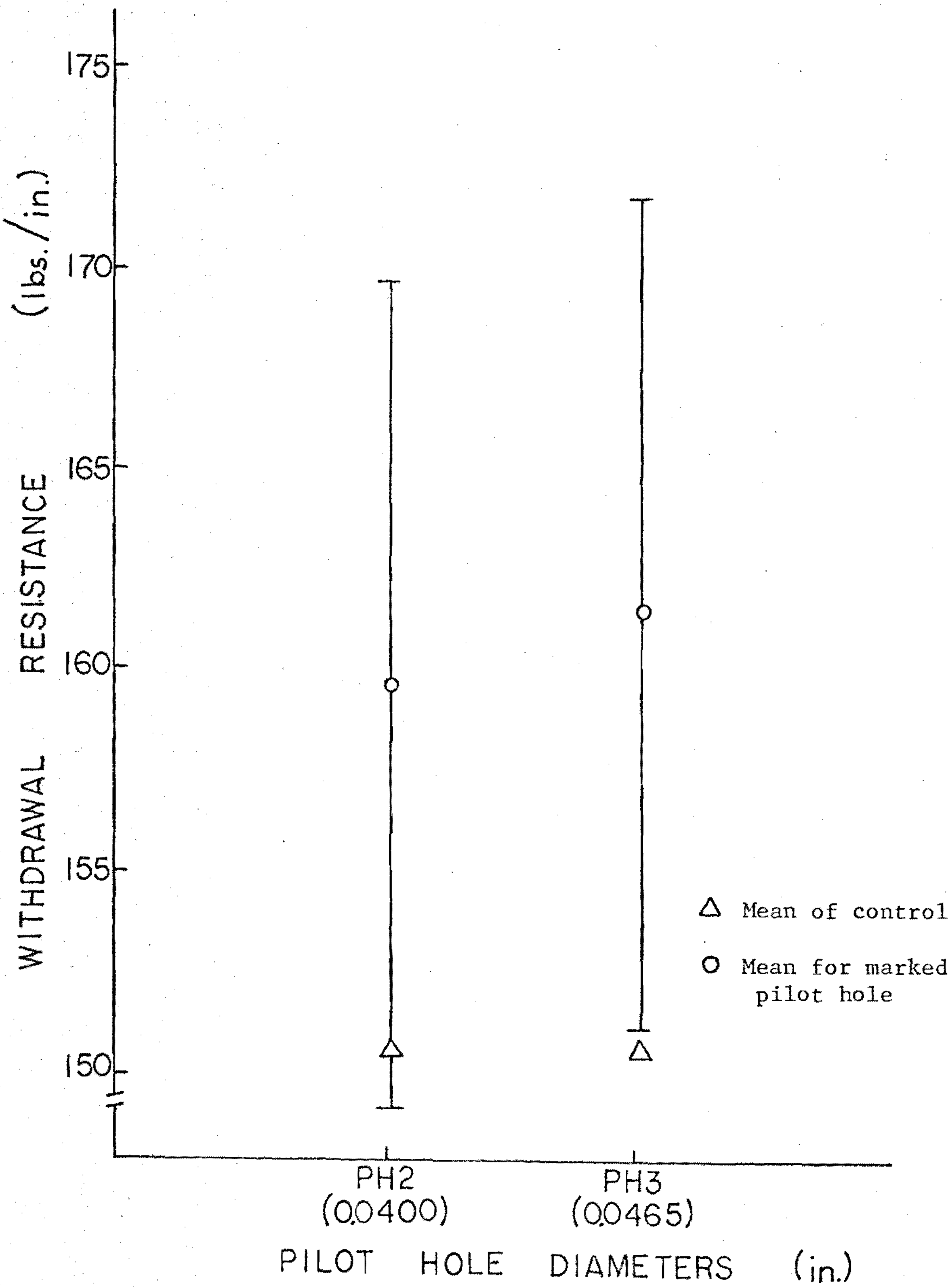


Figure 5.11: Tukey pairwise confidence intervals for the effect of pilot hole diameter on the withdrawal resistance of 6-penny nails from the side grain of clear SP stud sections. Intervals are formed by adding the mean pilot hole withdrawal resistance to the Tukey pairwise confidence intervals found in Table B-2.

The pairwise comparisons indicate that for DF there was no significant difference in WR between the control, no hole (PH1) and PH2 (0.0400 inch diameter). For ES there was no significant difference between PH1 and PH3 (0.0700 inch diameter) and for SP there was no significant difference between PH1 and PH2 (0.0400 inch diameter).

The final test conducted was to determine if nailing in either the wide or narrow face (factor B main effects) had an effect on WR. The test was made using an F-statistic (15) which compared the variability of the WR among the faces (MSB) to the variability due to error (MSE) (15). This test indicated whether WR was independent of face, and/or the angle between the axis of the nail and the growth ring. The face differences were found to be significant at the five percent level for all species tested (Table B-4, Appendix B).

This test appears to contradict the earlier paired t-test made for the same hypothesis (Table B-3). One explanation for this contradiction is that the F-test was based on a larger sample size, 90 pairs as opposed to the t-statistic which was based on 30 pairs. The F-test contained the information of combinations involving all three PH's while only the control (PH1) was used in the paired t-test. Therefore, the F-test was a more powerful test. Also, larger experimental error may have been present when all PH's were considered. The control nails are driven into solid wood and, therefore, a possible experimental deviation introduced by pushing nails into predrilled pilot holes did not exist for the controls. The drill bits used for pre-drilling the smallest two PH's were delicate and deflected away from their straight line paths when they came in contact with the more dense summerwood. The nail was much stiffer than the drill bits and was, therefore, more likely to pierce the denser summerwood without deflecting. Naturally, WR was larger when the nail was bent in the wood than when it was straight. The larger WR due to pre-drilled PH's may therefore have influenced the results enough to cause a detection of face differences with the F-test.

Table B-6 (Appendix B) lists 95 and 99 percent paired t-test confidence intervals for the difference in treatment means (wide and narrow face controls) (12) for all three species. These tables show that the mean WR for the narrow face of the DF specimens exceeds the mean value for the wide face by 1.4 pounds per inch at the least or 26.7 pounds per inch at the most with 95 percent confidence. For a family confidence coefficient of 99 percent, the mean WR for the narrow face is less than the mean value for the wide face by as much as 2.5 pounds per inch or more than the mean value by as much as 30.6 pounds per inch. Inspection of the confidence intervals for the ES and SP species show similar results. These results further indicate that WR may be independent of the angle the axis of the nail makes with the growth rings, or if a dependence is present it is a weak one.

There is also a practical consideration which works against including into the prediction equations the angle between the axis of the nail and the growth ring. Lumber used on the job site is made up of a mixture of many growth-ring angles and it would be impractical and expensive to sort the lumber according to growth-ring angles.

5.2.2 Coefficient of Static Friction

To determine if all the friction coefficients came from the same population a paired t-test (12) (taskfile "D" in Appendix A) was performed on 14 pairs of randomly selected nail sites from the wide face of DF specimens (Appendix C). The identical test was performed on 14 randomly selected pairs of nail sites from the narrow face. Table B-7 (Appendix B) summarizes the results.

The results in Table B-7 indicate with 95 percent confidence that the friction coefficient values are statistically equal on the wide face. The same is true for the friction coefficients on the narrow face.

One friction coefficient value was then chosen at random from each of the 14 pairs of wide face values and one from each of the 14 pairs of narrow face values. The narrow and wide face values were then paired together and compared by a t-test. The results presented in Table B-7 indicate that the friction coefficient values are independent of face. It was therefore concluded that only one static friction test need be run for each specimen.

5.2.3. Correction of Foundation Modulus for Grain Angle

Since the value of k_o changes at any angle θ, the cross-section of the nail was subdivided into 32 identical slices (Fig. 5.12) each with arc length D_i. Since the cross-section is symmetrical through wood and nails with respect to two perpendicular axes, the main foundation modulus need only be determined for one quarter of the cross-

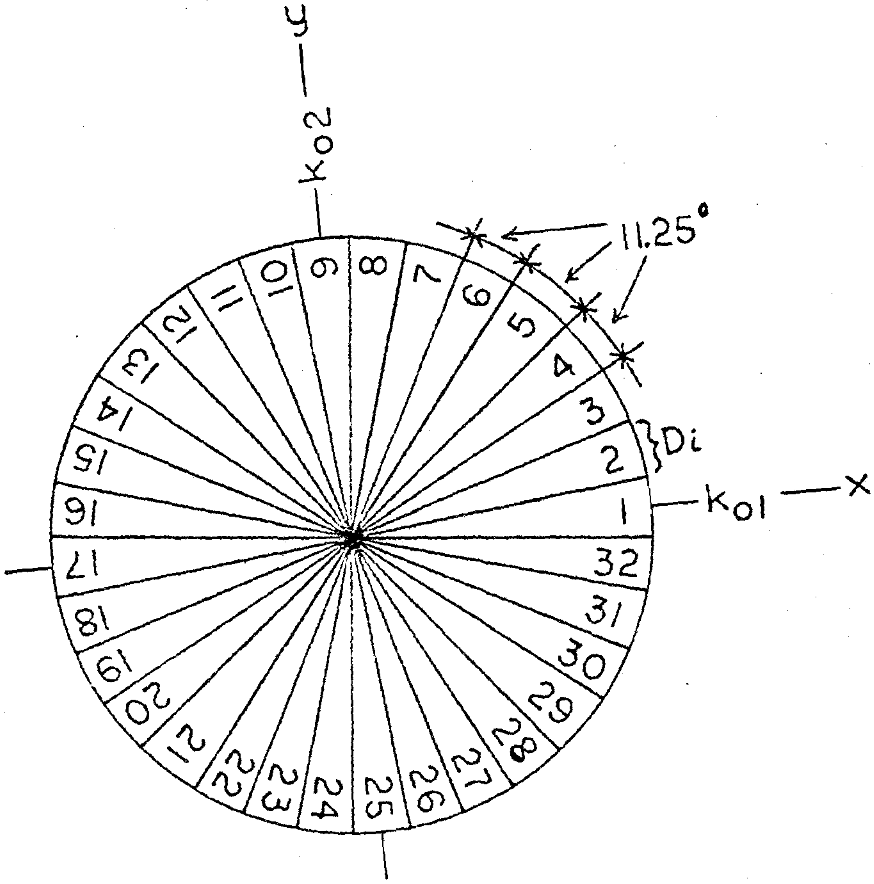


Figure 5.12: Nail cross-section subdivided into 32 slices. Each slice has equal arc length D_i.

section or the seven full slices (slices 2 through 8) and the two half slices (slices 1 and 9) cut at the angles presented in Figure 5.12.

The values of k_{o1} and k_{o2} are experimentally determined as described in Chapter 4.3.3 and then adjusted according to equation 3.17 by the Fortran IV program "FM" (Appendix A). The values for all nail sites on the wide and narrow faces of all specimens are presented in Appendix C. These values are then read into the Fortran IV program "WK" (Appendix A) which evaluates the total normal force on the nail according to equation 3.11.

5.2.4. Regression

The Fortran IV program "WK" (Appendix A) calculates values of W, WR, and WK by the various prediction models presented in this thesis. These values are found in Table B-8 (Appendix B). In order to determine how well the predicition models developed in this thesis predicted values of W, WR and WK, comparisons were made between the actual experimental results of W, WR and WK and the values obtained using the prediction models. These comparisons were made using simple linear regression (taskfile "E" in Appendix A) (13, 15), the straight-line probabilistic model being:

$$y = \beta_o + \beta_1 X + \varepsilon \qquad (5.1)$$

where

y = dependent variable;

X = independent variable;

ε = random error component;

β_o = y - intercept of regression line; and

β_1 = slope of regression line

Here the experimental result is the dependent variable and the predicted result the independent variable. Regression equations between experimental and predicted values of W, WR and WK are given in Table B-9 (Appendix B) along with their coefficients of determination (R^2). R^2 is a measure of the independent variables' ability in reducing the variation of the dependent variable (15). Therefore, the greater the value of R^2, the greater is the relationship between the dependent and independent variables.

R^2 values listed in Table B-9 show that the experimental results of W, WR and WK correlated well with the results obtained from the prediction models developed in this thesis. Therefore, the models adequately predict values of W, WR and WK for nails withdrawn from the side grain of DF, ES and SP boards.

5.2.5. Comparisons Between Prediction Models and Emperical Formulas

Values of W and WR as predicted by the emperical formulas 2.2 (PMAX) and 2.1 (PALL) respectively are found in Table B-8. To determine how well these emperical formulas predicted values of W and WR, comparisons were made between the actual experimental values of W and WR and the values obtained from these two formulas. Comparisons were made by the same method used in Chapter 5.2.4. Regression equations between experimental and predicted values of W and WR along with their R^2 values are given in Table B-10 (Appendix B).

To determine whether the prediction models developed in this thesis or the widely used emperical formulas are a better predictor for W and WR for nails withdrawn from the side grain of DF, ES and SP boards, a comparison of the R^2 values need only be made. For all species tested, the correlation between the prediction model for W (equation 3.12) and experimental results (R^2 values in Table B-9) are higher than the correlation between the emperical formula for W (equation 2.2) and the experimental results (R^2 values in Table B-10). Therefore, the prediction model given by equation 3.12 is a better predictor of W. Also, for all species tested, the correlation between the prediction model for WR (equation 3.13) and experimental results (R^2 values in Table B-9) are higher than the correlation between the emperical formula for WR (equation 2.1) and the experimental results (R^2 values in Table B-10). Therefore, the prediction model given by equation 3.13 is a better predictor of WR.

The poor correlations between experimental results and the values arrived at by the traditional emperical formulas for W and WR (equations 2.2 and 2.1 respectively) are really not indicative of their predictive powers. A partial explanation for their apparent inferiority to the prediction equations developed in this thesis are that they have constants based on the mean results of many tests. If the average μ_s, y, k_{o1} and k_{o2} are determined over hundreds of replications for any given species and used in conjunction with the models presented in this thesis, it is expected that the correlations will not be as favorable. However, it is felt that the theoretical models presented in this thesis are better predictors for W, WR, and WK since they are based on the actual mechanisms involved and not just the material properties (SG, nail diameter and length) as is the case with the emperical formulas.

VI. Conclusions and Recommendations

This study supports the following conclusions:

1. The amount of collapsed wood fibers due to a nail penetrating the side grain of clearwood can be approximated by comparing the withdrawal resistance of nails driven into predrilled pilot holes against nails driven into solid wood. These collapsed wood fibers serve primarily as a packing around the nail and have little or no effect on nail withdrawal stiffness;
2. The amount of wood fiber that is elastically and plastically compressed by the nail can be approximated by the difference between the volume of the nail (volume of the nail shank imbedded into the wood excluding the point) and the volume of collapsed wood fibers. The volume of collapsed fibers is equal to the volume of the pilot hole (depth of hole equal to the nail penetration depth excluding the point) described in conclusion 1;
3. The average static coefficient of friction between common bright nails and the distorted wood surface due to nail penetration is independent of grain angle;
4. Withdrawal stiffness of common bright nails from the side grain of wood is independent of grain angle;
5. The foundation modulus greatly affects the pressure exerted by the wood medium to the nail;
6. The following prediction models developed in this thesis predict values of withdrawal load, withdrawal resistance and withdrawal

stiffness which compare closely to experimental values as shown by the high correlations between predicted and experimental results:

$$W = \mu_s L y \sum_{i=1}^{32} D_i k_{oi} \qquad (3.12)$$

$$WR = \mu_s y \sum_{i=1}^{32} D_i k_{oi} \qquad (3.13)$$

$$WK = \frac{\mu_s L y}{WD} \sum_{i=1}^{32} D_i k_{oi} \qquad (3.14)$$

7. The prediction models developed in this thesis predict values of withdrawal load and withdrawal resistance more closely than the accepted emperical formulas for Douglas-fir, Engelman-spruce and southern-yellow pine.

The following are recommendations of this study:

1. The developed prediction models for the withdrawal of nails from the side grain of wood may be used for the structural design of nailed wood systems;
2. The amount of collapsed and elastically and plastically compressed wood fibers should be determined over a larger sample size for the most common nail diameters and wood species used for nailed wood systems;
3. The coefficient of static friction between wood and nail should be tested over larger sample sizes to determine mean values for the commercially important structural species;

4. The foundation modulus for the end and radial grains should be determined for the commercially important structural species; and
5. Further studies should be conducted on the application of the developed prediction procedure for other commercially important stud species, composite boards and nail types.

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APPENDIX A

Fortran IV Program "WR"

```
      PROGRAM WR (TAPE1,TAPE2,OUTPUT)
  100 FORMAT (I2,I4,I3,F6.2,6X,F6.1)
  110 FORMAT (I2,I4,I3,F6.2,F8.2)
  200 DO 400 I=1,30
      READ (1,100) ISP,IREP,IPH,PD,WL
      PD=PD/2.54-.1
      WDR=WL/PD
      WRITE (2,110) ISP,IREP,IPH,PD,WDR
  400 CONTINUE
      END FILE2
      STOP
      END
```

Task File "A"

```
VAR,10
LOG,JA
TTYON
FORMAT,(2X,F4.0,F3.0,6X,F8.2)
READ,JONDFWW,1-3
NAME,1,REP,2,PH,3,WR
NAMELIST,1-3
N,1-3
ANOVA,PH,REP
DESIGN,REP,PH
AVTABLE,WR
F,1,3
F,2,3
INTERMEANS,PH
END
EXIT
```

Task File "B"

```
VAR,6
LOG,JA
TTYON
FORMAT,(15X,F8.2)
READ,JONDFCW,1
READ,JONDFCN,2
READ,JONESCW,3
READ,JONESCN,4
READ,JONSPCW,5
READ,JONSPCN,6
TTWODEP,1,2$C
TTWODEP,3,4$C
TTWODEP,5,6$C
MEAN,1-6
STDEV,1-6
EXIT
```

Task File "C"

```
VAR,10
LOG,JA
TTYON
FORMAT,(F2.0,F4.0,F3.0,6X,F8.2)
READ,JONSP,1-4
NAME,1,FACE,2,REP,3,PH,4,WR
NAMELIST,1-4
N,1-4
ANOVA,FACE,PH,REP
DESIGN,REP,FACE,PH,FACE*PH
AVTABLE,WR
F,1,5
F,2,5
F,3,5
F,4,5
INTERMEANS,FACE,PH,FACE*PH
END
EXIT
```

Task File "D"

```
VAR,10
LOG,JA
TTYON
FORMAT,(F4.2,F6.2)
READ,JONFCWF,1,2
READ,JONFCNF,3,4
READ,JONFCWN,5,6
TTWODEP,1,2$C
TTWODEP,3,4$C
TTWODEP,5,6$C
MEAN,1-6
STDEV,1-6
EXIT
```

Fortran IV Program "FM"

```
      PROGRAM FM (TAPE1,TAPE2,TAPE3,OUTPUT)
  100 FORMAT (I2,I3,F6.1,F6.4,F6.1,F6.4,F6.1,F6.4,F6.1,F6.4)
  105 FORMAT (5X,8F6.3)
  110 FORMAT (I2,I3,4F12.4)
  115 FORMAT (*              WIDE FACE                 NARROW FACE*)
  120 FORMAT (*SP RP     KOE         KORT         KOE         KORT*)
  130 FORMAT (*        (PSI/IN)    (PSI/IN)    (PSI/IN)    (PSI/IN)*/)
      PRINT (3,115)
      PRINT (3,120)
      PRINT (3,130)
C
C     THIS PROGRAM READS FROM 1=FMD AND 2=FMMD AND WRITES ON 3=TAPE3.
C     THE MAIN PURPOSE OF THIS PROGRAM IS TO CALCULATE THE
C     FOUNDATION MODULUS FOR BOTH END AND RADIAL-TANGENTIAL MIX GRAINS ON THE
C     WIDE AND NARROW FACES OF EACH SPECIMEN ACCORDING TO THE FOLLOWING FORMULA:
C
C            KO = PL(LN(2B+A)-LN(A))/2YWBX
C
C            BX = (B-A)/2      IF   (2L+A) .LE. B
C
C            BX = L            IF   (2L+A) .GT. B
C
C            BX = STRAIN LENGTH (INCHES)
C
C     INPUT VARIABLES ARE:
C
C            SP - SPECIES
C            RP - REPITITIONS
C             P - LOAD (LBS)
C             Y - DEFORMATION DUE TO P (INCHES)
C             B - SPECIMEN LENGTH PERPENDICULAR TO LOADING (INCHES)
C             L - SPECIMEN LENGTH PARALLEL TO LOADING (INCHES)
C
C     OUTPUT VARIABLES ARE:
C
C            SP - SPECIES
C            RP - REPITITIONS
C           KOE - FOUNDATION MODULUS FOR THE END GRAIN
C                 (LBS/IN PER INCH OF DEFLECTION)
C          KORT - FOUNDATION MODULUS FOR THE MIXED RADIAL-TANGENTIAL GRAIN
C                 (LBS/IN PER INCH OF DEFLECTION)
C
  200 DO 400 I=1,30
      READ (1,100) ISP,IRP,EPW,EYW,RTPW,RTYW,EPN,EYN,RTPN,RTYN
      READ (2,105) BEW,XLEW,BRTW,XLRTW,BEN,XLEN,BRTN,XLRTN
```

Fortran IV Program "FM" continued

```
      C=2.54
C
C             W - BEARING LENGTH = 1.320 INCHES
C             A - BEARING WIDTH = 0.182 INCHES
C
      W=1.320
      A=0.182
      X1=EYW/C
      X2=RTYW/C
      X3=EYN/C
      X4=RTYN/C
      IF ((2.*XLEW+A) .LE. BEW) BX1=(BEW-A)/2.
      IF ((2.*XLEW+A) .GT. BEW) BX1=XLEW
      IF ((2.*XLRTW+A) .LE. BRTW) BX2=(BRTW-A)/2.
      IF ((2.*XLRTW+A) .GT. BRTW) BX2=XLRTW
      IF ((2.*XLEN+A) .LE. BEN) BX3=(BEN-A)/2.
      IF ((2.*XLEN+A) .GT. BEN) BX3=XLEN
      IF ((2.*XLRTN+A) .LE. BRTN) BX4=(BRTN-A)/2.
      IF ((2.*XLRTN+A) .GT. BRTN) BX4=XLRTN
      XKOEW=(EPW*XLEW)*(ALOG(2.*BX1+A)-ALOG(A))/(2.*X1*W*BX1)
      XKORTW=(RTPW*XLRTW)*(ALOG(2.*BX2+A)-ALOG(A))/(2.*X2*W*BX2)
      XKOEN=(EPN*XLEN)*(ALOG(2.*BX3+A)-ALOG(A))/(2.*X3*W*BX3)
      XKORTN=(RTPN*XLRTN)*(ALOG(2.*BX4+A)-ALOG(A))/(2.*X4*W*BX4)
      WRITE (3,110) ISP,IRP,XKOEW,XKORTW,XKOEN,XKORTN
  400 CONTINUE
      END FILE 3
      STOP
      END
```

Fortran IV Program "WK"

```
      PROGRAM WK ( TAPE1,TAPE2,TAPE3,TAPE4,OUTPUT )
  100 FORMAT (I2,I4,3X,F6.2,6X,F6.1,F6.4,F4.2,2F6.2,3F7.4,I3)
  110 FORMAT (9X,F6.2,12X,F6.4)
  120 FORMAT (5X,2F12.4)
  130 FORMAT (I2,I4,F7.1,F8.2,F9.2,F7.1,F8.2,F9.2,
     1F6.1,F5.2,F7.1,F8.2,I4)
C
C          PROGRAM WK READS FROM TAPE1=CONTROL NAIL SITE DATA, TAPE2=STATISTICALLY
C     DETERMINED NAIL SITE DATA, TAPE3=FOUNDATION MODULUS DATA, AND WRITES ON
C     TAPE4.
C
C     INPUT VARIABLES ARE:
C
C          ISP - SPECIES (1=DOUGLAS-FIR, 2=ENGELMANN-SPRUCE,AND 3=SOUTHERN PINE)
C         IREP - REPITITION
C          PDC - PENETRATION DEPTH OF CONTROL NAIL (CM)
C          PDT - PENETRATION DEPTH OF TEST NAIL (CM)
C          WLC - WITHDRAWAL LOAD OF CONTROL NAIL (LBS)
C          WCC - WITHDRAWAL CREEP OF CONTROL NAIL (CM)
C          WCT - WITHDRAWAL CREEP OF TEST NAIL (CM)
C          SFC - STATIC FRICTION COEFFICIENT
C           GW - GREEN WEIGHT (G)
C         XODW - OVEN-DRY WEIGHT (G)
C           XL - SPECIMEN LENGTH (IN)
C            W - SPECIMEN WIDTH (IN)
C            D - SPECIMEN DEPTH (IN)
C         IAGL - ANGLE MEASURED BETWEEN THE AXIS OF THE NAIL AND GROWTH RING (DEGREES)
C         XKOE - FOUNDATION MODULUS DETERMINED FOR THE END GRAIN
C                (LBS/IN PER INCH OF DEFLECTION)
C        XKORT - FOUNDATION MODULUS DETERMINED FOR THE MIX RADIAL-TANGENTIAL GRAIN
C                (LBS/IN PER INCH OF DEFLECTION)
C
```

Fortran IV Program "WK" continued

```
C     OUTPUT VARIABLES ARE:
C
C          ISP - SPECIES
C         IREP - REPITITION
C          WLC - WITHDRAWAL LOAD OF CONTROL NAIL (LBS)
C          WRC - WITHDRAWAL RESISTANCE OF CONTROL NAIL (LBS/IN)
C          WKC - WITHDRAWAL STIFFNESS OF CONTROL NAIL (PSI)
C          WLP - PREDICTED WITHDRAWAL LOAD (LBS)
C          WRP - PREDICTED WITHDRAWAL RESISTANCE (LBS/IN)
C          WKP - PREDICTED WITHDRAWAL STIFFNESS (PSI)
C          XMC - MOISTURE CONTENT (%)
C           SG - SPECIFIC GRAVITY BASED ON OVEN-DRY WEIGHT AND VOLUME AT TEST MC
C         PMAX - AVERAGE MAXIMUM WITHDRAWAL LOAD (LBS)
C         PALL - ALLOWABLE PMAX PER INCH OF NAIL PENETRATION*5 (LBS/IN)
C         IAGL
C
C          THE NAIL CROSS-SECTION IS SUBDIVIDED INTO 32 EQUAL SLICES WITH ARC
C     LENGTH DI (IN). SINCE A CIRCLE HAS 4-FOLD SYMMETRY, THE MEAN FOUNDATION
C     MODULUS IS DETERMINED FOR THE 7 FULL SLICES (XK2 TO XK8) AND 2 HALF
C     SLICES (XK1 & XK9) BY EQUATION 3.   IN THE TEXT. THE 32 SLICES ARE
C     THEN MADE UP OF 4*(THE 7 FULL SLICES) + 8*(THE 2 HALF SLICES).THE
C     1/4 CIRCLE IS SUBDIVIDED BY THE FOLLOWING ANGLES: 0, 11.25, 22.5, 33.75,
C     45, 56.25, 67.5, 78.75, AND 90 (ALL IN DEGREES). NOTE THAT SINE 11.25
C      = COSINE 78.75, AND COSINE 11.25 = SINE 78.75, ECT.
C
      CO=3.1416/180.
      F1=CO*11.25
      F2=CO*22.5
      F3=CO*33.75
      C1=COS(F1)**4
      C2=SIN(F1)**4
      C3=SIN(F1)**2*COS(F1)**2
      C4=COS(F2)**4
```

Fortran IV Program "WK" continued

```
      C5=SIN(F2)**4
      C6=SIN(F2)**2*COS(F2)**2
      C7=COS(F3)**4
      C8=SIN(F3)**4
      C9=SIN(F3)**2*COS(F3)**2
      C10=COS(CO*45.)**4
C
C              Y - DEFLECTION (IN)
C             DI - THE ARC LENGHT OF 1/32 OF A CIRCLE WITH RADIUS .113 IN (IN)
C
      XND=.113
      XNR=XND/2.
      DI=(3.1416*XND)/32.
  200 DO 400 I=1,30
      READ (1,100) ISP,IREP,PDC,WLC,WCC,SFC,GW,XODW,
     1XL,W,DE,IAGL
      READ (2,110) PDT,WCT
      READ (3,120) XKOE,XKORT
      IF ((ISP .EQ. 1) .OR. (ISP .EQ. 3)) PH=.0400
      IF (ISP .EQ. 2) PH=.0700
      Y=XNR-PH/2.
      PDC=PDC/2.54-.1
      WCC=WCC/2.54
      WRC=WLC/PDC
      WKC=WLC*PDC/WCC
C
C              G - MODULUS OF RIGIDITY (PSI)
C              V - POISSON'S RATIO
C
      IF ((ISP .EQ. 1) .OR. (ISP .EQ. 3)) G=.071*XKOE
      IF (ISP .EQ. 2) G=.063*XKOE
      IF ((ISP .EQ. 1) .OR. (ISP .EQ. 3)) V=.371
      IF (ISP .EQ. 2) V=.420
```

Fortran IV Program "WK" continued

```
      XK1=XKOE
      XK9=XKORT
      A=XKOE*XKORT*G
      B=XKORT*G
      C=XKOE*G
      D=XKOE*XKORT
      E=2.*V*B
      XK2=A/(C1*B+C2*C+C3*D-C3*E)
      XK3=A/(C4*B+C5*C+C6*D-C6*E)
      XK4=A/(C7*B+C8*C+C9*D-C9*E)
      XK5=A/(C10*B+C10*C+C10*D-C10*E)
      XK6=A/(C8*B+C7*C+C9*D-C9*E)
      XK7=A/(C5*B+C4*C+C6*D-C6*E)
      XK8=A/(C2*B+C1*C+C3*D-C3*E)
C
C           XN - THE TOTAL NORMAL FORCE ON THE NAIL (LBS)
C
      XN=PDC*Y*DI*2.*(XK1+XK9+2.*XK2+2.*XK3+2.*XK4
     1+2.*XK5+2.*XK6+2.*XK7+2.*XK8)
      WLP=XN*SFC
      WRP=WLP/PDC
      PDT=PDT/2.54-.1
      WCT=WCT/2.54
      WKP=WLP*PDT/WCT
      XMC=((GW-XODW)/XODW)*100.
      C11=2.54**3
      VO=XL*W*DE*C11
      SG=XODW/VO
C
C         XL12 - SPECIMEN LENGTH CORRECTED TO 12% MC (IN)
C          W12 - SPECIMEN WIDTH CORRECTED TO 12% MC (IN)
C          D12 - SPECIMEN DEPTH CORRECTED TO 12% MC (IN)
C          V12 - SPECIMEN VOLUME AT 12% MC (CUBIC CENTIMETERS)
```

Fortran IV Program "WK" continued

```
C        SG12 - SPECIFIC GRAVITY BASED ON OVEN-DRY WEIGHT AND VOLUME
C               AT 12% MC
C        XLOD - SPECIMEN LENGTH CORRECTED TO 0% MC (IN)
C         WOD - SPECIMEN WIDTH CORRECTED TO 0% MC (IN)
C         DOD - SPECIMEN DEPTH CORRECTED TO 0% MC (IN)
C         VOD - SPECIMEN VOLUME AT 0% MC (CUBIC CENTIMETERS)
C        SGOD - SPECIFIC GRAVITY BASED ON OVEN-DRY WEIGHT AND VOLUME
C
      C12=.002
      C13=.098
      C14=.046
      C15=XMC-12.
      C16=XMC
      C17=XMC-30.
      C18=5./2.
      XL12=XL-(C12*C15)/(30.+C12*C17)
      W12=W-(C13*C15)/(30.+C13*C17)
      D12=DE-(C14*C15)/(30.+C14*C17)
      V12=XL12*W12*D12*C11
      SG12=XODW/V12
      PMAX=7850.*SG12**C18*XND*PDC
      XLOD=XL-(C12*C16)/(30.+C12*C17)
      WOD=W-(C13*C16)/(30.+C13*C17)
      DOD=DE-(C14*C16)/(30.+C14*C17)
      VOD=XLOD*WOD*DOD*C11
      SGOD=XODW/VOD
      PALL=1380.*SGOD**C18*XND*5.
      WRITE (4,130) ISP,IREP,WLC,WRC,WKC,WLP,WRP,WKP,
     1XMC,SG,PMAX,PALL,IAGL
  400 CONTINUE
      END FILE4
      STOP
      END
```

Task File "E"

```
VAR,20
LOG,JA
TTYON
FORMAT,(6X,F7.1,F8.2,F9.2,F7.1,F8.2,F9.2,F6.1,F5.2,F7.1,F8.2,F4.0)
READ,JONDFR,1-11
NAME,1,WLC,2,WRC,3,WKC,4,WLP,5,WRP,6,WKP,7,MC,8,SG,9,PMAX,10.PALL.11,AGL
NAMELIST,1-11
N,1-11
MEAN,1-11
SCATTER,4,1
REGRESS,1,4
ADD,4$F
AVTABLE
RCOEFSE$T
RESIDUAL,12
SCATTER,4,12
END
SCATTER,5,2
REGRESS,2,5
ADD,5$F
AVTABLE
RCOEFSE$T
RESIDUAL,13
SCATTER,5,13
END
SCATTER,6,3
REGRESS,3,6
ADD,6$F
AVTABLE
RCOEFSE$T
RESIDUAL,14
SCATTER,6,14
END
SCATTER,9,1
REGRESS,1,9
ADD,9$F
AVTABLE
RCOEFSE$T
RESIDUAL,15
SCATTER,9,15
END
SCATTER,10,2
REGRESS,2,10
ADD,10$F
AVTABLE
RCOEFSE$T
RESIDUAL,16
SCATTER,10,16
END
EXIT
```

APPENDIX B

Table B-1: Analysis of Variance Table for WR of Nails Pulled from the Wide Faces of DF Blocks.

Source of Variation	df	MS	F-ratio
Blocks	29	3153.68	5.972 **
PH	3	4080.88	7.728 **
Error	87	528.06	
Total	119		

** Significant at the 5% level.

Table B-2: Tukey Pairwise Confidence Intervals for the Comparison of the WR of the Control (PH1) Against All Other Treatment Means (PH2, PH3, PH4) of Nails Pulled from the Wide Faces of DF Blocks Using a 90 Percent Family Confidence Coefficient.

Basic Results for Computing Intervals

j	PH	n_j	$\overline{X}_j$
1	0.0000	30	164.86
2	0.0400	30	174.69
3	0.0465	30	179.81
4	0.0700	30	192.87

MSE = 528.06

Formula For Computing Intervals

$$D - Ts(D) \leq \mu_j - \mu_j' \leq D + Ts(D)$$

$$q(.90;\ 4,116) = 3.28$$

$$T = 1/\sqrt{2}\ q\ (1-\alpha;\ r,\ n_T-r)$$

$$D = \overline{X}_j - \overline{X}_j'$$

$$s(D) = \left(\frac{2MSE}{n}\right)^{1/2} = 5.93$$

$$Ts(D) = 13.77$$

Confidence Intervals

$$-3.94 \leq \mu_2 - \mu_1 \leq 23.60$$

$$1.18 \leq \mu_3 - \mu_1 \leq 28.72$$

$$14.24 \leq \mu_4 - \mu_1 \leq 41.78$$

Table B-3: Paired T-Test Results (Two Tailed Test) on the WR for Nails Without the PH (PH1) Pulled from the Wide and Narrow Faces of DF Blocks.

Null Hypothesis : Mean of Difference = 0

Alternate Hypothesis : Mean of Difference ≠ 0

FACE	SPECIES	$\overline{X}$	S	n_D	$\overline{X}_D$	S_D	T-VALUE
Wide	DF	164.86	32.37	30	18.15	7.06	2.57 **
Narrow	DF	146.71	25.01				
Wide	ES	91.49	16.83	30	3.93	3.55	1.11 **
Narrow	ES	87.55	15.61				
Wide	SP	150.87	37.76	30	1.78	4.51	0.26 *
Narrow	SP	149.69	36.07				

DF

95% CONFIDENCE INTERVAL (3.711 to 32.587)

99% CONFIDENCE INTERVAL (-1.310 to 37.608)

ES

95% CONFIDENCE INTERVAL (-3.318 to 11.181)

99% CONFIDENCE INTERVAL (-5.840 to 13.702)

SP

95% CONFIDENCE INTERVAL (-8.048 to 10.398)

99% CONFIDENCE INTERVAL (-11.255 to 13.606)

* Non-significant at the 1% level.
** Non-significant at the 5% level.

Table B-4: Analysis of Variance Tables for WR of Nails Pulled from the Wide and Narrow Faces of DF, ES and SP Blocks.

DF

Source of Variation	df	MS	F
Blocks	29	3052.33	4.914 **
PH	2	5407.94	8.706 **
Face	1	8871.31	14.281 **
Face * PH	2	216.14	0.348
Error	145	621.19	
Total	179		

ES

Source of Variation	df	MS	F
Blocks	29	801.31	5.146 **
PH	2	1161.03	7.457 **
Face	1	1031.24	6.623 **
Face * PH	2	9.67	0.062
Error	145	155.70	
Total	179		

Table B-4 Continued

		SP	
Source of Variation	df	MS	F
Blocks	29	7131.10	8.698 **
PH	2	2184.96	2.665 *
Face	1	9863.76	12.031 **
Face * PH	2	2468.54	3.011 *
Error	145	819.88	
Total	179		

* Significant at the 10% level.
** Significant at the 5% level.

Table B-5: Tukey Pairwise Confidence Intervals for the Comparison of the WR of the Control (PH1) Against All Other Treatment Means (PH2, PH3) of Nails Pulled from the Wide and Narrow Faces of DF, ES and SP Blocks.

Basic Results for Computing Intervals

DF

j	PH	n_j	$\overline{X}_j$
1	0.0000	60	155.79
2	0.0400	60	168.04
3	0.0465	60	174.48

MSE = 621.19

ES

j	PH	n_j	$\overline{X}_j$
1	0.0000	60	89.52
2	0.0465	60	98.31
3	0.0700	60	93.52

MSE = 155.70

SP

j	PH	n_j	$\overline{X}_j$
1	0.0000	60	150.23
2	0.0400	60	158.47
3	0.0465	60	162.05

MSE = 819.88

Table B-5 Continued

DF

$q(.99;\ 3,\ 177) \cong 4.20$

$T = 1/\sqrt{2}\ q\ (1-\alpha;\ r,\ n_T - r) = 2.97$

$s(D) = (\frac{2MSE}{n})^{1/2} = 4.55$

$Ts(D) = 13.51$

Confidence Intervals

$-1.26 \leq \mu_2 - \mu_1 \leq 25.76$

$5.18 \leq \mu_3 - \mu_1 \leq 32.20$

ES

$q(.95;\ 3,\ 177) \cong 3.36$

$T = 1/\sqrt{2}\ q\ (1-\alpha;\ r,\ n_T - r) = 2.38$

$s(D) = (\frac{2MSE}{n})^{1/2} = 2.28$

$Ts(D) = 5.41$

Confidence Intervals

$3.37 \leq \mu_2 - \mu_1 \leq 14.20$

$-1.41 \leq \mu_3 - \mu_1 \leq 9.41$

SP

$q(.90;\ 3,\ 177) \cong 2.93$

$T = 1/\sqrt{2}\ q\ (1-\alpha;\ r,\ n_T - r) = 2.072$

$s(D) = (\frac{2MSE}{n})^{1/2} = 5.228$

$Ts(D) = 10.831$

Confidence Intervals

$-2.64 \leq \mu_2 - \mu_1 \leq 19.03$

$0.94 \leq \mu_3 - \mu_1 \leq 22.60$

Table B-6: Confidence Intervals for the Difference in Mean WR Between the Wide and Narrow Faces of DF, ES and SP Blocks

Basic Results for Computing Intervals

Species	Face	$\overline{X}$	*b	MSE = S^2_D	S_D
DF	Wide	173.12	30	621.19	24.92
DF	Narrow	159.08			
ES	Wide	96.18	30	155.70	12.48
ES	Narrow	91.39			
SP	Wide	164.34	30	819.88	28.63
SP	Narrow	149.53			

Formula for Computing Intervals

$$\overline{X}_i - \overline{X}_j \pm t_{\alpha/2,\ n-k-b+1}\ S(2/b)^{1/2}$$

$$t_{.05/2,\ 90-3-30+1} = 1.960$$

$$t_{.01/2,\ 90-3-30+1} = 2.576$$

Confidence Intervals

DF

95% CONFIDENCE INTERVAL: $1.427 \leq \mu_W - \mu_N \leq 26.653$

99% CONFIDENCE INTERVAL: $-2.537 \leq \mu_W - \mu_N \leq 30.617$

ES

95% CONFIDENCE INTERVAL: $-1.528 \leq \mu_W - \mu_N \leq 11.102$

99% CONFIDENCE INTERVAL: $-3.512 \leq \mu_W - \mu_N \leq 13.068$

SP

95% CONFIDENCE INTERVAL: $0.314 \leq \mu_W - \mu_N \leq 29.296$

99% CONFIDENCE INTERVAL: $-4.240 \leq \mu_W - \mu_N \leq 33.850$

Table B-7: Paired T-Test Results (Two-Tailed Test) on the Coefficient of Static Friction of Nails Pulled from Wide and Narrow Face Half-holes of DF Blocks.

Null Hypothesis : Mean of Difference = 0

Alternate Hypothesis : Mean of Difference ≠ 0

Face	$\overline{X}$	S	n_D	$\overline{X}_D$	S_D	T-VALUE
Wide	.380	.047	14	-.009	.012	-.785 **
Wide	.389	.025				
Narrow	.389	.032	14	.012	.013	.968 **
Narrow	.376	.035				
Wide	.391	.037	14	-.001	.010	-.145 **
Narrow	.392	.029				

95% Confidence Intervals

Wide Face	(-.349 to .163)
Narrow Face	(-.150 to .392)
Wide and Narrow Faces	(-.228 to .199)

** Non-significant at the 5% level.

Table B-8: Experimental and Predicted Values of W, WR and WK

KEY TO OUTPUT FROM PROGRAM WK

```
  SP  - SPECIES ( 1=DOUGLAS-FIR, 2=ENGELMANN-SPRUCE, 3=SOUTHERN PINE )
 REP  - REPITITIONS
 WLC  - WITHDRAWAL LOAD OF THE CONTROL NAIL (LBS)
 WRC  - WITHDRAWAL RESISTANCE OF THE CONTROL NAIL (LBS/IN)
 WKC  - WITHDRAWAL STIFFNESS OF THE CONTROL NAIL (LBS-IN/IN)
 WLP  - PREDICTED WITHDRAWAL LOAD (LBS)
 WRP  - PREDICTED WITHDRAWAL RESISTANCE (LBS/IN)
 WKP  - PREDICTED WITHDRAWAL STIFFNESS (LBS-IN/IN)
  MC  - MOISTURE CONTENT (%)
  SG  - SPECIFIC GRAVITY BASED ON OVEN-DRY WEIGHT AND VOLUME AT TEST MC
PMAX  - AVERAGE MAXIMUM WITHDRAWAL LOAD (LBS)
PALL  - ALLOWABLE PMAX PER INCH OF NAIL PENETRATION MULTIPLIED BY 5 (LBS/IN)
 AGL  - THE ANGLE MEASURED BETWEEN THE AXIS OF THE NAIL AND GROWTH RING (DEGREES)
```

Table B-8: Experimental and Predicted Values of W, WR and WK continued

SP	REP	WLC	WRC	WKC	WLP	WRP	WKP	MC	SG	PMAX	PALL	AGL
1	1	116.0	205.18	4870.64	108.3	191.56	5179.30	9.1	.45	65.2	118.68	35
1	2	89.5	164.02	4771.04	86.2	158.03	4597.19	9.1	.49	78.3	149.67	37
1	3	111.5	167.98	6266.30	113.9	171.58	6237.14	9.6	.42	65.5	101.60	57
1	4	78.5	127.32	5100.87	81.0	131.41	4929.77	9.5	.37	44.2	73.65	82
1	5	95.5	155.89	5364.55	95.4	155.71	5133.69	9.7	.42	61.7	103.76	59
1	6	87.0	125.84	6418.99	73.3	106.06	6120.59	9.6	.39	57.5	85.66	78
1	7	80.0	129.76	5617.94	74.1	120.18	5568.21	9.7	.42	61.1	101.82	22
1	8	89.5	128.00	5577.26	84.6	120.95	5625.29	9.7	.47	92.1	137.00	18
1	9	92.0	153.13	5801.32	83.7	139.26	5518.52	9.3	.47	79.4	135.91	67
1	10	108.0	170.81	5980.97	100.2	158.55	5781.45	9.3	.47	80.7	130.86	59
1	11	134.0	215.96	5631.57	125.1	201.55	5638.26	9.2	.48	83.1	137.45	28
1	12	116.5	180.87	6148.19	99.4	154.40	5910.28	9.9	.45	73.5	117.20	44
1	13	88.5	174.80	4215.22	75.2	148.50	3952.66	8.9	.43	52.4	106.37	26
1	14	104.5	154.68	5692.76	97.5	144.36	5307.11	9.5	.52	111.7	171.76	3
1	15	104.0	177.77	4697.39	92.2	157.59	4227.24	9.6	.47	76.6	134.34	16
1	16	78.0	152.87	4745.92	71.3	139.66	4609.32	8.5	.47	65.5	131.94	43
1	17	82.0	153.60	4447.68	72.9	136.56	4273.05	8.5	.52	85.9	167.41	35
1	18	73.5	132.78	4512.71	69.5	125.64	4304.85	9.4	.52	92.0	172.87	90
1	19	114.5	183.37	6197.85	102.5	164.09	5822.76	9.4	.48	84.2	139.98	47
1	20	101.0	177.41	5197.37	97.9	172.03	5015.87	9.0	.46	67.9	122.45	22
1	21	95.0	171.62	5683.83	89.9	162.45	6017.54	8.2	.42	54.1	100.23	45
1	22	70.0	111.40	5449.76	75.7	120.55	5274.86	8.1	.45	72.0	117.60	30
1	23	133.5	199.94	5352.62	133.2	199.51	5369.43	9.2	.48	93.4	143.13	65
1	24	100.5	181.56	4180.56	99.4	179.52	4179.21	9.7	.41	52.4	97.02	24
1	25	120.0	188.61	6255.48	115.2	181.00	6407.82	9.0	.51	99.6	162.01	58
1	26	68.0	108.22	5682.09	70.6	112.40	5434.77	9.2	.49	88.9	146.56	50
1	27	86.0	131.91	5216.70	87.9	134.84	5146.49	9.0	.39	53.7	84.30	54
1	28	146.5	203.78	6011.44	151.2	210.38	6336.02	9.0	.64	200.0	288.75	65
1	29	169.5	249.44	5874.64	151.3	222.71	6266.57	8.8	.55	132.6	199.97	55
1	30	104.5	167.36	5487.98	109.4	175.25	5690.19	9.4	.41	56.9	93.25	2

Table B-8: Experimental and Predicted Values of W, WR and WK continued

SP	REP	WLC	WRC	WKC	WLP	WRP	WKP	MC	SG	PMAX	PALL	AGL
1	1	115.7	151.02	6992.30	110.2	143.82	6795.50	9.1	.45	88.4	118.68	64
1	2	119.4	177.77	7488.84	114.1	169.86	7278.72	9.1	.49	96.3	149.67	41
1	3	127.4	187.48	5817.26	128.8	189.59	5921.21	9.6	.42	67.1	101.60	41
1	4	100.4	150.36	5582.90	94.4	141.43	5282.58	9.5	.37	47.8	73.65	0
1	5	126.0	167.91	6173.68	126.8	168.98	6093.09	9.7	.42	75.6	103.76	26
1	6	77.3	114.42	5481.27	67.0	99.18	5174.52	9.6	.39	56.2	85.66	9
1	7	84.0	116.85	6338.18	93.0	129.33	6208.10	9.7	.42	71.2	101.82	58
1	8	83.7	122.46	5675.91	75.5	110.50	5337.09	9.7	.47	90.0	137.00	71
1	9	105.1	142.30	5476.88	103.2	139.75	5404.48	9.3	.47	97.7	135.91	18
1	10	94.0	140.78	6326.35	85.6	128.22	6160.17	9.3	.47	85.2	130.86	25
1	11	107.7	146.60	6379.94	104.6	142.33	6293.73	9.2	.48	98.4	137.45	65
1	12	132.0	183.61	6479.35	121.9	169.58	5960.15	9.9	.45	82.1	117.20	55
1	13	123.7	179.95	5982.83	118.2	171.99	5685.22	8.9	.43	71.2	106.37	48
1	14	127.7	187.92	4919.87	117.4	172.80	4507.08	9.5	.52	112.4	171.76	79
1	15	114.4	172.35	4026.69	117.1	176.46	4383.15	9.6	.47	87.0	134.34	80
1	16	103.1	154.41	5464.30	103.8	155.45	5302.21	8.5	.47	85.7	131.94	46
1	17	95.4	142.04	5812.59	91.9	136.85	5643.53	8.5	.52	108.1	167.41	51
1	18	110.4	167.31	5573.20	104.1	157.70	5175.40	9.4	.52	109.7	172.87	17
1	19	111.1	149.63	6330.35	109.5	147.43	6330.51	9.4	.44	81.4	112.77	32
1	20	101.8	134.25	5683.10	98.0	129.18	5664.69	9.0	.46	90.5	122.45	65
1	21	91.7	126.17	5642.61	99.4	136.74	5360.34	8.2	.42	71.0	100.23	49
1	22	88.4	130.09	5528.20	81.9	120.58	5302.02	8.1	.45	77.9	117.60	63
1	23	108.4	163.31	4650.44	104.3	157.20	4528.69	9.2	.48	92.8	143.13	33
1	24	100.4	138.15	5148.29	104.7	144.07	5012.53	9.7	.41	68.8	97.02	56
1	25	92.7	124.19	3254.80	96.8	129.69	3276.20	9.0	.51	116.8	162.01	36
1	26	86.0	116.44	7014.61	86.4	117.04	6879.61	9.2	.49	104.5	146.56	3
1	27	88.0	111.43	7916.05	87.9	111.36	7944.29	9.0	.39	65.1	84.30	44
1	28	119.0	160.27	5754.72	127.3	171.44	6097.38	9.0	.64	206.6	288.75	37
1	29	66.5	91.50	3675.42	73.7	101.46	3847.79	8.8	.55	141.8	199.97	9
1	30	120.0	150.44	8104.00	115.1	144.36	7806.22	9.4	.41	72.6	93.25	87

Table B-8: Experimental and Predicted Values of W, WR and WK continued

SP	REP	WLC	WRC	WKC	WLP	WRP	WKP	MC	SG	PMAX	PALL	AGL
2	1	29.0	45.58	2677.94	31.2	49.08	2572.74	10.2	.30	27.8	44.86	86
2	2	75.5	111.75	4011.08	73.6	109.01	4166.80	10.3	.39	55.7	85.48	87
2	3	56.5	89.92	4420.29	51.3	81.62	4067.05	10.6	.43	66.3	109.41	90
2	4	80.0	123.45	4207.03	70.1	108.20	4082.17	10.3	.41	60.3	96.61	88
2	5	55.5	83.12	4706.40	52.2	78.14	4585.94	10.0	.38	52.6	80.59	89
2	6	67.0	94.76	5231.83	59.2	83.76	5077.49	9.9	.28	25.1	36.28	90
2	7	55.5	84.11	4947.77	64.4	97.64	5298.75	10.0	.46	80.3	126.21	89
2	8	62.5	91.98	4649.78	59.4	87.44	4635.05	10.1	.36	44.3	66.66	85
2	9	63.5	98.59	4617.16	60.0	93.14	4274.91	10.3	.40	57.4	92.48	90
2	10	68.5	102.59	5751.29	62.2	93.16	5954.59	10.4	.46	85.4	132.55	89
2	11	69.5	100.53	5676.37	66.1	95.58	5493.71	10.2	.40	60.1	90.00	85
2	12	61.0	94.13	5516.81	59.9	92.43	5477.01	10.6	.43	67.5	107.90	89
2	13	65.0	88.95	4904.07	56.3	77.08	4729.89	10.3	.33	38.7	53.83	88
2	14	64.0	96.99	4206.43	55.3	83.76	3985.02	10.3	.40	57.2	89.94	85
2	15	60.5	92.80	5357.65	58.0	89.04	5345.55	10.5	.43	67.2	105.91	89
2	16	71.0	106.33	4596.03	69.6	104.27	4453.54	10.1	.35	42.3	64.79	85
2	17	55.0	87.53	4571.88	42.4	67.45	4307.14	10.2	.33	34.6	57.12	85
2	18	51.0	78.70	4349.53	49.0	75.61	4350.67	10.1	.36	44.6	70.42	82
2	19	31.5	44.55	4714.50	30.1	42.61	4572.22	10.1	.30	30.6	44.19	85
2	20	72.0	114.59	5472.00	59.8	95.22	5226.28	9.8	.35	38.5	62.22	78
2	21	49.5	76.39	4968.11	52.8	81.42	5046.44	9.8	.39	53.7	84.71	84
2	22	66.5	102.62	4998.13	63.1	97.31	4822.76	10.1	.35	42.1	66.52	90
2	23	61.5	93.76	4855.88	60.6	92.32	4992.34	10.5	.43	71.1	112.40	89
2	24	67.0	97.47	4698.07	53.5	77.80	4463.97	10.1	.35	44.0	65.42	88
2	25	64.0	95.29	4747.13	61.6	91.73	5034.49	9.9	.38	52.5	80.01	88
2	26	68.0	106.88	5159.06	56.8	89.30	4836.40	10.4	.38	50.4	80.94	88
2	27	64.0	91.02	4991.44	67.3	95.69	5167.69	9.9	.44	79.0	116.43	89
2	28	63.0	91.65	5263.06	58.1	84.54	4927.89	10.1	.35	42.6	63.37	90
2	29	48.5	70.56	3714.08	43.6	63.46	3576.36	9.5	.44	74.9	112.93	88
2	30	56.0	88.02	5292.16	57.2	89.92	5270.16	9.7	.43	66.2	107.55	83

Table B-8: Experimental and Predicted Values of W, WR and WK continued

SP	REP	WLC	WRC	WKC	WLP	WRP	WKP	MC	SG	PMAX	PALL	AGL
2	1	51.0	78.22	3286.23	46.1	70.70	3682.86	10.2	.30	28.5	44.86	18
2	2	61.0	91.90	4550.71	67.1	101.09	4722.33	4.1	.39	50.3	78.50	11
2	3	69.5	101.69	5027.17	65.0	95.08	4614.75	10.6	.43	72.1	109.41	8
2	4	58.0	85.85	5104.00	69.0	102.16	4892.83	10.3	.41	62.9	96.61	6
2	5	63.0	94.35	5713.80	63.7	95.37	5666.07	10.0	.38	52.6	80.59	12
2	6	63.0	91.13	4478.87	57.5	83.18	4063.80	9.9	.28	24.5	36.28	15
2	7	80.0	117.05	6064.63	76.6	112.11	5683.59	10.0	.46	83.2	126.21	13
2	8	62.5	93.60	5247.52	66.8	100.05	5126.78	10.1	.36	43.5	66.66	5
2	9	66.0	90.81	5720.00	73.2	100.67	5832.48	10.3	.40	64.8	92.48	15
2	10	60.5	90.61	5130.40	63.2	94.72	5047.77	10.4	.46	85.4	132.55	32
2	11	47.5	67.18	4308.59	53.0	75.01	4418.33	10.2	.40	61.4	90.00	17
2	12	72.5	100.85	3351.52	69.6	96.87	3729.90	10.6	.43	74.8	107.90	3
2	13	48.0	67.88	5288.83	52.3	74.00	5189.57	10.3	.33	37.4	53.83	5
2	14	63.5	92.91	4792.87	72.5	106.05	4938.26	10.3	.40	59.3	89.94	14
2	15	67.0	100.34	5463.08	67.0	100.34	5474.66	10.5	.43	68.8	105.91	46
2	16	53.0	75.80	4547.25	65.4	93.50	4602.60	10.1	.35	44.3	64.79	12
2	17	50.5	71.82	4274.55	55.9	79.44	4511.23	10.2	.33	38.7	57.12	20
2	18	47.0	68.77	4827.93	58.2	85.18	4863.61	10.1	.36	47.1	70.42	23
2	19	38.0	54.65	4329.55	44.3	63.78	4170.88	10.1	.30	30.0	44.19	17
2	20	52.5	76.37	5392.06	60.1	87.46	5153.99	9.8	.35	42.1	62.22	23
2	21	70.0	104.83	5139.39	69.9	104.65	5066.76	9.8	.39	55.3	84.71	12
2	22	62.0	96.85	4710.84	63.1	98.61	4723.05	10.1	.35	41.6	66.52	11
2	23	68.0	100.65	4862.00	72.1	106.71	4903.59	10.5	.43	73.3	112.40	14
2	24	64.0	94.18	4700.60	65.5	96.37	4709.76	10.1	.35	43.5	65.42	7
2	25	60.5	88.01	5530.52	69.2	100.65	5238.36	9.9	.38	53.8	80.01	15
2	26	74.5	99.80	5861.08	75.3	100.81	5801.12	10.4	.38	59.1	80.94	10
2	27	73.5	108.16	5285.87	67.9	99.98	5006.75	9.9	.44	76.3	116.43	11
2	28	42.5	60.78	4574.55	52.2	74.63	4642.73	10.1	.35	43.4	63.37	6
2	29	43.0	62.55	4290.17	50.2	72.96	4613.80	9.5	.44	74.9	112.93	14
2	30	68.5	99.08	5543.13	61.1	88.36	5217.54	9.7	.43	72.0	107.55	13

Table B-8: Experimental and Predicted Values of W, WR and WK continued

SP	REP	WLC	WRC	WKC	WLP	WRP	WKP	MC	SG	PMAX	PALL	AGL
3	1	87.0	146.73	5283.15	82.4	138.98	5610.62	9.9	.42	58.9	101.55	55
3	2	97.5	135.62	7296.52	105.6	146.87	6911.46	10.0	.54	135.0	194.71	69
3	3	92.5	156.01	7409.84	97.8	164.90	7361.25	9.9	.58	128.4	224.37	50
3	4	82.0	127.31	5684.41	79.1	122.83	5813.39	9.7	.41	58.1	92.14	90
3	5	118.0	196.41	7089.29	128.8	214.37	6759.55	9.9	.58	132.4	228.47	50
3	6	111.5	168.98	4816.34	107.6	162.99	5035.55	9.8	.63	181.8	285.85	88
3	7	65.5	98.10	5908.94	69.3	103.79	6141.48	9.8	.41	61.5	94.20	2
3	8	163.0	239.87	6102.78	165.3	243.32	6239.97	9.5	.62	178.4	272.07	63
3	9	100.5	156.03	5390.75	98.4	152.82	5267.46	9.7	.56	127.6	202.87	76
3	10	110.0	160.94	4960.00	112.1	163.97	5065.69	9.4	.51	109.4	165.95	90
3	11	112.5	191.01	5685.81	119.6	203.11	5396.74	10.0	.48	80.2	139.10	80
3	12	104.5	147.79	4533.38	102.5	145.03	4619.97	9.9	.57	146.9	212.64	88
3	13	120.0	176.59	5178.00	118.9	174.92	4870.86	9.6	.58	151.5	231.04	69
3	14	84.0	130.42	5305.95	79.5	123.37	5284.89	9.7	.50	96.2	152.56	68
3	15	91.0	144.82	6287.27	88.7	141.21	6250.08	9.8	.52	103.5	170.82	67
3	16	119.0	194.25	5896.94	121.1	197.64	5864.12	9.8	.51	96.7	163.50	33
3	17	80.5	141.40	5061.00	85.6	150.40	5157.90	10.0	.44	61.6	110.47	0
3	18	70.5	119.70	5247.16	73.2	124.29	5295.77	9.2	.54	106.8	185.40	72
3	19	68.0	101.24	4915.59	78.3	116.64	5130.95	8.9	.46	82.3	126.99	82
3	20	71.0	114.43	5738.26	66.9	107.90	5627.82	9.5	.48	85.5	142.75	89
3	21	94.0	145.94	6774.63	88.3	137.14	6587.21	9.7	.57	137.0	217.55	88
3	22	80.0	130.59	4576.47	74.3	121.31	4368.58	9.8	.44	68.3	113.95	54
3	23	90.5	137.15	5617.70	80.4	121.89	5424.09	9.7	.45	79.2	124.28	89
3	24	62.5	91.98	5959.94	74.0	108.87	5669.66	9.7	.52	114.0	170.50	0
3	25	153.5	224.59	5693.93	170.7	249.80	6022.03	9.2	.57	145.9	218.28	60
3	26	82.5	128.09	5191.15	75.6	117.38	4975.47	9.8	.55	123.4	198.42	72
3	27	122.5	194.96	6109.69	122.1	194.26	6125.40	9.6	.57	130.7	212.78	69
3	28	115.0	160.85	6961.33	113.4	158.66	6880.77	9.8	.52	121.1	173.08	55
3	29	124.5	182.16	6020.39	113.7	166.33	6241.62	9.8	.62	180.5	270.59	85
3	30	57.0	81.98	5592.33	51.3	73.78	5421.71	9.6	.39	58.3	85.69	78

Table B-8: Experimental and Predicted Values of W, WR and WK continued

SP	REP	WLC	WRC	WKC	WLP	WRP	WKP	MC	SG	PMAX	PALL	AGL
3	1	91.5	128.69	6143.09	89.9	126.46	6025.83	9.9	.42	70.6	101.55	42
3	2	114.0	158.58	6424.81	112.2	156.12	6474.36	10.0	.54	135.0	194.71	3
3	3	140.5	198.70	6711.12	143.0	202.24	6791.75	9.9	.58	153.2	224.37	28
3	4	89.0	119.23	6367.70	89.5	119.96	6447.43	9.7	.41	67.3	92.14	60
3	5	152.0	214.97	7035.88	157.5	222.69	6871.82	9.9	.58	155.8	228.47	55
3	6	120.0	158.26	7431.51	124.0	163.57	7599.83	9.8	.63	208.9	285.85	23
3	7	80.0	107.74	5825.48	80.2	108.01	6036.28	9.8	.41	68.4	94.20	88
3	8	147.0	196.93	7183.30	137.7	184.48	6870.61	9.5	.62	195.9	272.07	39
3	9	92.5	127.28	6098.39	95.8	131.84	6206.35	9.7	.56	144.0	202.87	0
3	10	109.5	146.69	7414.71	110.7	148.33	7313.41	9.4	.51	119.5	165.95	63
3	11	146.0	196.63	7096.80	146.7	197.59	7019.59	10.0	.48	101.0	139.10	52
3	12	103.0	137.99	5935.81	101.4	135.81	5881.73	9.9	.57	155.1	212.64	35
3	13	147.0	200.10	7927.80	146.8	199.85	7885.12	9.6	.58	163.8	231.04	0
3	14	90.0	119.94	6237.82	81.6	108.74	5805.23	9.7	.50	112.1	152.56	1
3	15	108.5	150.93	6693.28	111.3	154.84	6819.50	9.8	.52	118.5	170.82	43
3	16	96.5	129.28	6930.45	100.3	134.42	6769.27	9.8	.51	117.8	163.50	74
3	17	129.5	166.46	7801.59	120.6	155.00	7540.60	10.0	.44	84.1	110.47	87
3	18	84.0	121.50	7564.31	88.1	127.44	7415.63	9.2	.54	125.3	185.40	4
3	19	96.0	128.61	7913.74	91.1	122.01	7820.07	8.9	.46	91.5	126.99	15
3	20	82.0	112.22	6087.68	88.8	121.51	6184.95	9.5	.48	100.7	142.75	69
3	21	116.0	162.25	5137.95	118.6	165.87	5305.14	9.7	.57	152.1	217.55	0
3	22	107.0	149.66	7772.48	106.5	148.93	7718.60	9.8	.44	79.7	113.95	12
3	23	80.0	110.68	3855.12	85.0	117.64	3933.27	9.7	.45	86.7	124.28	28
3	24	80.0	113.14	6621.20	85.5	120.96	6625.80	9.7	.52	118.6	170.50	87
3	25	160.0	231.44	8565.85	164.5	238.01	8691.85	9.2	.57	147.6	218.28	0
3	26	90.0	123.84	6341.22	81.1	111.65	6542.14	9.8	.55	139.2	198.42	5
3	27	116.5	152.85	8026.48	100.3	131.61	7751.91	9.6	.57	158.5	212.78	73
3	28	136.0	187.13	5422.38	142.4	196.00	5684.85	9.8	.52	123.1	173.08	42
3	29	105.0	153.63	7563.49	110.9	162.24	7757.32	9.8	.62	180.5	270.59	17
3	30	60.0	85.33	3456.77	57.2	81.40	3298.21	9.6	.39	58.9	85.69	27

Table B-8 Continued

SP	Statistic[a]	WLC	WRC	WKC	WLP	WRP	WKP	MC	SG	PMAX	PALL	AGL
1	$\bar{X}$	102.7	155.8	5619	99.2	150.2	5508	9.2	.46	85.0	132.0	43
1	S	20.2	30.1	907	19.6	27.5	902	0.5	.55	29.9	41.6	22
2	$\bar{X}$	60.4	89.5	4845	60.0	88.8	4785	10.0	.38	54.6	83.5	50
2	S	10.7	16.2	642	9.8	14.1	610	0.8	.48	16.2	25.3	37
3	$\bar{X}$	103.3	150.3	6198	103.6	150.7	6175	9.7	.52	117.9	176.1	50
3	S	26.1	36.6	1080	27.3	39.0	1054	0.3	.67	38.4	55.3	31

[a]Based on 60 observations.

Table B-9: Regression Equations Relating Experimental Values of W, WR and WK to the Values Obtained Using the Prediction Models.

Species	Y = a + bX	R^2
DF	W[a] = 5.743 + 0.977X[b]	0.90
ES	W = 6.980 + 0.890X	0.66
SP	W = 6.845 + 0.932X	0.95
DF	WR[c] = 0.148 + 1.036X[d]	0.90
ES	WR = 6.718 + 0.932X	0.66
SP	WR = 12.503 + 0.914X	0.95
DF	WK[e] = 234.264 + 0.977X[f]	0.94
ES	WK = 80.512 + 0.996X	0.90
SP	WK = -27.363 + 1.008X	0.97

[a]W = Experimental Withdrawal Load (lbs)
[b]X = Predicted Withdrawal Load (lbs)
[c]WR = Experimental Withdrawal Resistance (lbs/in)
[d]X = Predicted Withdrawal Resistance (lbs/in)
[e]WK = Experimental Withdrawal Stiffness (lbs/cu. in.)
[f]X = Predicted Withdrawal Stiffness (lbs/cu. in.)

Table B-10: Regression Equations Relating Experimental Values of W and WR to the Values Obtained Using the Empirical Formulas.

Species	Y = a + bX	R^2
DF	W[a] = 82.145 + 0.241X[b]	0.13
ES	W = 46.974 + 0.245X	0.14
SP	W = 52.804 + 0.428X	0.40
DF	WL[c] = 132.67 + 0.175X[d]	0.06
ES	WL = 69.301 + 0.242X	0.14
SP	WL = 80.538 + 0.396X	0.36

[a]W = Experimental Withdrawal Load (lbs)
[b]X = Predicted Withdrawal Load (PMAX) (lbs)
[c]WL = Experimental Withdrawal Resistance (lbs/in)
[d]X = Predicted Withdrawal Resistance (PALL) (lbs/in)

APPENDIX C

RAW DATA FILE CONTAINING THE FOLLOWING INFORMATION (WIDE FACE OF SPECIMEN):

SP - SPECIES (1 = DOUGLAS-FIR, 2 = ENGELMAN SPRUCE, 3 = SOUTHERN PINE)
REP - REPITITION
PH - PILOT HOLE (INCH DIAMETERS)
FOR DF: 1=0.0000, 2=0.0465, 3=0.0400, 4=0.0700
FOR ES: 1=0.0000, 2=0.0700, 3=0.0465
FOR SP: 1=0.0000, 2=0.0465, 3=0.0400
PD - PENETRATION DEPTH OF THE NAIL SHANK (CM)
PL - MAXIMUM PENETRATION LOAD (LBS)
WL - MAXIMUM WITHDRAWAL LOAD (LBS)
WC - WITHDRAWAL CREEP (CM)
SFC - STATIC FRICTION COEFFICIENT
GW - GREEN WEIGHT OF MC SAMPLE (GRAM)
ODW - OVEN-DRY WEIGHT OF MC SAMPLE (GRAM)
L - GREEN LENGTH OF MC SAMPLE (INCH)
W - GREEN WIDTH OF MC SAMPLE (INCH)
D - GREEN DEPTH OF MC SAMPLE (INCH)
ANGL - ANGLE BETWEEN THE AXIS OF THE NAIL AND THE GROWTH RING (DEGREES)

										GREEN DIMENSIONS			
SP	REP	PH	PD (CM)	PL (LBS)	WL (LBS)	WC (CM)	SFC	GW (G)	ODW (G)	L (IN)	W (IN)	D (IN)	ANGL (DG)
1	1	1	1.69	229.0	116.0	.0342	.45	15.65	14.35	2.0091	.9880	.9825	35
1	1	2	1.62	192.0	110.0	.0294							
1	1	3	1.66	172.0	94.0	.0294							
1	1	4	1.70	171.5	107.0	.0297							
1	2	1	1.64	191.5	89.5	.0260	.37	14.65	13.43	2.0061	.8915	.9343	37
1	2	2	1.85	220.5	140.0	.0388							
1	2	3	1.80	191.0	108.0	.0290							
1	2	4	1.76	203.0	132.5	.0310							
1	3	1	1.94	208.0	111.5	.0300	.44	14.51	13.24	2.0022	.9896	.9692	57
1	3	2	1.77	198.5	107.5	.0327							
1	3	3	1.76	185.5	97.0	.0275							
1	3	4	1.68	191.0	126.0	.0339							
1	4	1	1.82	160.0	78.5	.0241	.37	12.96	11.84	2.0097	.9966	.9742	82
1	4	2	1.90	135.5	89.5	.0280							
1	4	3	1.83	160.0	91.0	.0259							
1	4	4	1.78	143.0	98.0	.0268							
1	5	1	1.81	195.0	95.5	.0277	.40	14.61	13.32	2.0088	.9796	.9743	59
1	5	2	1.80	183.5	107.5	.0320							
1	5	3	2.03	216.0	144.0	.0330							
1	5	4	1.75	185.0	110.0	.0313							
1	6	1	2.01	160.0	87.0	.0238	.30	13.52	12.34	2.0097	.9901	.9630	78
1	6	2	2.01	139.5	82.0	.0284							
1	6	3	1.84	147.0	77.5	.0190							
1	6	4	2.01	145.0	101.5	.0310							
1	7	1	1.82	163.0	80.0	.0223	.34	14.88	13.56	2.0137	.9968	.9793	22
1	7	2	1.97	213.0	119.0	.0325							
1	7	3	2.02	172.5	84.5	.0235							

1	7	4	1.75	188.0	109.5	.0277							
1	8	1	2.03	185.5	89.5	.0285	.30	14.79	13.48	2.0128	.9036	.9579	18
1	8	2	1.90	194.0	102.5	.0270							
1	8	3	2.05	173.5	85.0	.0270							
1	8	4	1.88	178.0	104.5	.0290							
1	9	1	1.78	160.0	92.0	.0242	.38	16.80	15.37	2.0118	.9917	.9927	67
1	9	2	1.83	176.0	102.0	.0295							
1	9	3	1.87	169.0	99.0	.0245							
1	9	4	1.78	177.5	134.0	.0327							
1	10	1	1.86	146.0	108.0	.0290	.37	16.90	15.46	2.0133	1.0058	.9983	59
1	10	2	2.09	154.5	143.5	.0380							
1	10	3	1.84	153.0	120.0	.0275							
1	10	4	1.80	145.5	125.0	.0308							
1	11	1	1.83	246.0	134.0	.0375	.45	17.19	15.74	2.0106	1.0090	.9942	28
1	11	2	1.71	200.5	110.5	.0295							
1	11	3	1.85	232.0	124.0	.0354							
1	11	4	1.71	182.5	120.0	.0284							
1	12	1	1.89	224.5	116.5	.0310	.38	16.03	14.58	2.0180	1.0064	.9844	44
1	12	2	1.75	213.5	128.5	.0379							
1	12	3	1.93	252.0	169.0	.0282							
1	12	4	1.89	210.5	148.0	.0335							
1	13	1	1.54	191.5	88.5	.0270	.40	15.36	14.11	2.0185	1.0014	.9896	26
1	13	2	1.84	181.0	100.0	.0280							
1	13	3	1.50	182.0	88.5	.0237							
1	13	4	1.58	146.0	81.5	.0213							
1	14	1	1.97	207.5	104.5	.0315	.37	16.54	15.11	2.0144	.9168	.9640	3
1	14	2	1.91	211.0	156.5	.0450							
1	14	3	1.56	196.0	117.0	.0240							
1	14	4	1.91	218.0	146.0	.0440							
1	15	1	1.74	222.0	104.0	.0329	.47	17.16	15.66	2.0131	1.0109	.9969	16
1	15	2	1.77	208.0	137.5	.0376							
1	15	3	1.79	254.5	150.0	.0335							
1	15	4	1.60	186.0	135.0	.0377							
1	16	1	1.55	164.5	78.0	.0213	.41	16.37	15.09	2.0206	.9973	.9724	43
1	16	2	1.77	170.5	92.5	.0284							
1	16	3	1.58	187.5	92.0	.0205							
1	16	4	1.76	162.5	100.0	.0276							
1	17	1	1.61	200.0	82.0	.0250	.37	16.12	14.86	2.0185	.9052	.9633	35
1	17	2	1.73	202.5	119.0	.0300							
1	17	3	1.86	208.0	111.5	.0274							
1	17	4	1.76	177.5	114.0	.0292							
1	18	1	1.66	161.0	73.5	.0229	.33	16.43	15.02	2.0118	.8999	.9751	90
1	18	2	1.66	177.5	107.5	.0289							
1	18	3	1.82	190.0	121.0	.0253							
1	18	4	1.55	135.0	84.5	.0248							
1	19	1	1.84	208.0	114.5	.0293	.39	15.41	14.09	2.0170	.9186	.9717	47
1	19	2	1.68	176.0	95.0	.0275							
1	19	3	1.76	179.0	89.5	.0265							
1	19	4	1.66	173.5	107.0	.0293							
1	20	1	1.70	203.0	101.0	.0281	.38	16.36	15.01	2.0124	1.0065	.9935	22
1	20	2	1.68	176.0	96.5	.0320							
1	20	3	1.56	168.5	75.0	.0255							
1	20	4	1.83	173.5	113.0	.0311							

1	21	1	1.66	181.5	95.0	.0235	.46	15.10	13.95	2.0039	1.0124	.9947	45
1	21	2	1.74	144.0	72.5	.0190							
1	21	3	1.84	167.0	93.0	.0237							
1	21	4	1.80	163.5	103.0	.0259							
1	22	1	1.85	169.5	70.0	.0205	.30	16.12	14.91	2.0027	1.0051	1.0046	30
1	22	2	1.70	166.0	89.0	.0255							
1	22	3	1.80	176.0	95.0	.0222							
1	22	4	1.67	166.5	97.5	.0238							
1	23	1	1.95	248.5	133.5	.0423	.43	18.01	16.50	2.0079	1.0197	1.0151	65
1	23	2	1.89	212.0	94.5	.0282							
1	23	3	2.10	255.5	143.0	.0458							
1	23	4	1.99	208.0	136.0	.0375							
1	24	1	1.66	182.5	100.5	.0338	.46	15.26	13.91	2.0070	1.0177	1.0052	24
1	24	2	1.71	183.0	109.0	.0295							
1	24	3	1.89	185.5	112.5	.0389							
1	24	4	1.63	165.5	110.5	.0345							
1	25	1	1.87	258.0	120.0	.0310	.44	16.63	15.25	2.0147	.9415	.9665	58
1	25	2	2.03	264.0	160.5	.0380							
1	25	3	1.94	255.5	122.0	.0303							
1	25	4	2.00	243.5	169.5	.0416							
1	26	1	1.85	124.5	68.0	.0191	.38	15.99	14.64	2.0139	.9235	.9863	50
1	26	2	1.87	129.5	78.5	.0187							
1	26	3	1.87	161.5	85.5	.0210							
1	26	4	1.79	119.0	95.5	.0277							
1	27	1	1.91	138.0	86.0	.0273	.41	14.68	13.47	2.0141	1.0230	1.0167	54
1	27	2	1.92	212.0	122.0	.0294							
1	27	3	1.94	178.5	104.5	.0288							
1	27	4	1.93	129.0	92.0	.0210							
1	28	1	2.08	216.0	146.5	.0445	.48	20.42	18.74	2.0129	.9215	.9642	65
1	28	2	2.04	248.0	188.0	.0440							
1	28	3	1.98	223.5	150.0	.0412							
1	28	4	1.96	186.5	181.5	.0507							
1	29	1	1.98	261.5	169.5	.0498	.39	20.23	18.59	2.0137	1.0143	1.0016	55
1	29	2	1.94	214.0	86.5	.0260							
1	29	3	1.96	251.5	133.0	.0412							
1	29	4	1.90	193.5	117.5	.0305							
1	30	1	1.84	166.5	104.5	.0302	.45	15.16	13.86	2.0097	1.0171	1.0150	2
1	30	2	1.80	140.0	101.0	.0278							
1	30	3	1.84	149.0	86.0	.0305							
1	30	4	1.80	138.0	96.0	.0237							
2	1	1	1.87	75.5	29.0	.0175	.40	11.06	10.04	2.0096	1.0223	.9845	86
2	1	2	1.91	85.5	57.5	.0201							
2	1	3	1.88	83.0	46.5	.0194							
2	2	1	1.97	105.0	75.5	.0323	.51	12.80	11.60	2.0121	.9233	.9768	87
2	2	2	1.94	98.0	57.5	.0298							
2	2	3	1.93	117.5	69.5	.0221							
2	3	1	1.85	101.0	56.5	.0204	.46	14.12	12.77	2.0034	.9211	.9820	90
2	3	2	1.84	104.0	61.5	.0200							
2	3	3	1.88	110.0	61.0	.0185							
2	4	1	1.90	119.0	80.0	.0313	.56	13.30	12.06	2.0001	.9146	.9820	88
2	4	2	1.89	108.5	76.0	.0281							
2	4	3	1.92	115.5	62.0	.0175							
2	5	1	1.95	87.0	55.5	.0200	.42	14.42	13.11	2.0070	1.0138	1.0256	89

2	5	2	1.88	86.0	63.0	.0185							
2	5	3	1.88	82.5	53.0	.0172							
2	6	1	2.05	99.0	67.0	.0230	.48	10.31	9.38	1.9994	1.0252	1.0019	90
2	6	2	1.90	86.0	51.0	.0192							
2	6	3	1.94	99.0	68.5	.0215							
2	7	1	1.93	87.5	55.5	.0188	.50	14.81	13.46	1.9938	.9171	.9838	89
2	7	2	1.94	86.0	53.5	.0205							
2	7	3	1.95	96.0	60.0	.0207							
2	8	1	1.98	115.5	62.5	.0232	.43	13.29	12.07	2.0135	1.0254	1.0044	85
2	8	2	1.90	97.0	66.0	.0211							
2	8	3	1.94	102.0	63.5	.0182							
2	9	1	1.89	105.0	63.5	.0225	.46	13.21	11.98	2.0140	.9198	.9800	90
2	9	2	1.90	106.0	69.0	.0231							
2	9	3	1.93	115.0	74.5	.0250							
2	10	1	1.95	126.0	68.5	.0202	.44	15.24	13.81	2.0051	.9226	.9799	89
2	10	2	1.91	115.0	70.0	.0173							
2	10	3	1.96	104.0	63.0	.0159							
2	11	1	2.01	108.5	69.5	.0215	.44	13.24	12.01	2.0128	.9251	.9876	85
2	11	2	2.00	115.5	64.0	.0210							
2	11	3	2.03	116.5	70.5	.0237							
2	12	1	1.90	94.0	61.0	.0182	.49	14.17	12.81	2.0144	.9226	.9837	89
2	12	2	1.90	104.0	61.5	.0180							
2	12	3	1.93	108.5	72.0	.0221							
2	13	1	2.11	111.0	65.0	.0246	.44	13.17	11.94	2.0055	1.0774	1.0329	88
2	13	2	1.90	105.5	72.5	.0196							
2	13	3	2.10	114.5	75.5	.0240							
2	14	1	1.93	97.0	64.0	.0255	.53	13.01	11.80	1.9955	.9187	.9862	85
2	14	2	1.97	107.0	78.0	.0238							
2	14	3	1.88	97.5	58.0	.0214							
2	15	1	1.91	99.5	60.5	.0137	.45	15.21	13.77	2.0027	1.0002	.9844	89
2	15	2	1.93	102.5	78.5	.0182							
2	15	3	1.96	117.0	90.5	.0235							
2	16	1	1.95	111.5	71.0	.0262	.47	13.31	12.09	2.0093	1.0200	1.0249	85
2	16	2	1.93	99.5	60.5	.0262							
2	16	3	1.95	129.5	87.0	.0278							
2	17	1	1.85	83.0	55.0	.0192	.42	10.96	9.95	2.0085	.9240	.9843	85
2	17	2	1.88	78.0	49.5	.0160							
2	17	3	1.87	79.5	54.0	.0178							
2	18	1	1.90	88.5	51.0	.0193	.40	13.74	12.48	2.0060	1.0262	1.0187	82
2	18	2	1.95	93.0	62.0	.0191							
2	18	3	1.93	113.5	83.0	.0264							
2	19	1	2.05	65.5	31.5	.0120	.31	11.37	10.33	2.0035	1.0269	1.0164	85
2	19	2	2.06	75.0	39.0	.0119							
2	19	3	1.90	81.0	50.0	.0160							
2	20	1	1.85	102.0	72.0	.0210	.45	14.09	12.83	2.0105	1.0828	1.0370	78
2	20	2	1.87	107.0	64.0	.0185							
2	20	3	1.90	112.0	69.5	.0205							
2	21	1	1.90	89.5	49.5	.0164	.43	14.83	13.51	2.0108	1.0239	1.0225	84
2	21	2	1.88	89.0	64.0	.0170							
2	21	3	2.00	98.0	67.0	.0200							
2	22	1	1.90	97.5	66.5	.0219	.43	13.31	12.09	2.0071	1.0247	1.0107	90
2	22	2	1.86	105.0	70.0	.0210							
2	22	3	1.91	122.5	80.0	.0271							
2	23	1	1.92	97.5	61.5	.0211	.52	14.33	12.97	2.0051	.9270	.9789	89

2	23	2	1.87	102.0	65.0	.0196							
2	23	3	1.91	102.0	64.0	.0218							
2	24	1	2.00	97.5	67.0	.0249	.47	13.35	12.13	2.0071	1.0233	1.0219	88
2	24	2	1.89	99.0	66.0	.0196							
2	24	3	1.92	112.0	78.5	.0258							
2	25	1	1.96	102.5	64.0	.0230	.44	14.51	13.20	2.0104	1.0249	1.0220	88
2	25	2	1.97	111.0	69.0	.0210							
2	25	3	1.94	137.5	87.5	.0260							
2	26	1	1.87	115.0	68.0	.0213	.45	14.65	13.27	2.0074	1.0269	1.0245	88
2	26	2	1.88	102.5	54.5	.0191							
2	26	3	1.90	109.0	57.0	.0182							
2	27	1	2.04	125.0	64.0	.0229	.45	14.44	13.14	2.0062	.9229	.9787	89
2	27	2	1.89	117.5	67.0	.0213							
2	27	3	1.89	120.0	85.5	.0270							
2	28	1	2.00	98.5	63.0	.0209	.36	13.24	12.03	2.0038	1.0341	1.0171	90
2	28	2	1.95	93.5	64.0	.0200							
2	28	3	1.97	92.0	54.0	.0181							
2	29	1	2.00	76.5	48.5	.0228	.43	14.47	13.22	2.0097	.9242	.9910	88
2	29	2	1.91	78.0	47.5	.0202							
2	29	3	1.98	79.5	53.0	.0240							
2	30	1	1.87	79.5	56.0	.0171	.37	14.59	13.30	2.0121	.9497	.9895	83
2	30	2	1.82	84.5	54.0	.0170							
2	30	3	1.94	87.0	48.5	.0146							
3	1	1	1.76	140.5	87.0	.0248	.42	15.93	14.49	2.0115	1.0237	1.0206	55
3	1	2	1.79	131.0	90.5	.0213							
3	1	3	1.82	139.0	97.5	.0230							
3	2	1	2.08	161.0	97.5	.0244	.41	17.68	16.08	2.0036	.9194	.9804	69
3	2	2	2.01	160.0	125.5	.0283							
3	2	3	2.10	169.0	118.0	.0282							
3	3	1	1.76	210.0	92.5	.0188	.46	19.05	17.33	2.0069	.9279	.9870	50
3	3	2	1.76	183.0	111.0	.0300							
3	3	3	1.82	201.5	105.5	.0208							
3	4	1	1.89	124.0	82.0	.0236	.34	15.41	14.05	2.0107	1.0303	1.0211	90
3	4	2	1.89	118.0	80.0	.0245							
3	4	3	1.90	126.0	82.5	.0224							
3	5	1	1.78	227.0	118.0	.0254	.51	18.91	17.21	2.0052	.9263	.9756	50
3	5	2	1.80	177.5	107.0	.0243							
3	5	3	1.86	196.0	136.0	.0306							
3	6	1	1.93	212.0	111.5	.0388	.36	20.68	18.83	2.0100	.9174	.9830	88
3	6	2	2.11	219.5	110.5	.0402							
3	6	3	2.08	231.0	118.5	.0390							
3	7	1	1.95	99.0	65.5	.0188	.30	15.64	14.24	2.0276	1.0285	1.0199	2
3	7	2	1.93	96.5	75.5	.0210							
3	7	3	1.92	90.5	69.0	.0188							
3	8	1	1.98	217.0	163.0	.0461	.50	20.50	18.73	2.0218	.9243	.9818	63
3	8	2	1.96	208.5	195.0	.0492							
3	8	3	1.99	223.0	168.0	.0460							
3	9	1	1.89	208.0	100.5	.0305	.33	20.78	18.94	2.0103	1.0116	1.0234	76
3	9	2	2.01	207.0	141.5	.0324							
3	9	3	2.02	212.5	140.5	.0330							
3	10	1	1.99	312.0	110.0	.0385	.42	16.70	15.26	2.0133	.9208	.9827	90
3	10	2	1.88	240.0	114.0	.0311							
3	10	3	1.94	197.5	122.0	.0373							
3	11	1	1.75	173.0	112.5	.0296	.55	18.20	16.54	2.0101	1.0313	1.0206	80

3	11	2	1.85	163.5	127.0	.0338							
3	11	3	1.86	181.0	143.0	.0356							
3	12	1	2.05	184.0	104.5	.0414	.45	21.27	19.35	2.0055	1.0149	1.0261	88
3	12	2	2.06	181.5	122.0	.0409							
3	12	3	2.02	257.5	126.0	.0392							
3	13	1	1.98	205.0	120.0	.0400	.42	19.07	17.40	2.0121	.9273	.9760	69
3	13	2	1.94	205.5	160.0	.0423							
3	13	3	1.93	210.5	156.5	.0409							
3	14	1	1.89	135.0	84.0	.0259	.35	18.82	17.15	2.0137	1.0514	.9968	68
3	14	2	1.83	132.0	98.0	.0285							
3	14	3	1.91	139.0	94.0	.0249							
3	15	1	1.85	140.0	91.0	.0231	.50	17.00	15.48	2.0110	.9207	.9886	67
3	15	2	1.86	130.0	92.5	.0257							
3	15	3	1.86	134.0	83.0	.0228							
3	16	1	1.81	222.0	119.0	.0314	.45	16.81	15.31	2.0119	.9301	.9841	33
3	16	2	1.83	174.0	97.0	.0259							
3	16	3	1.77	190.5	101.0	.0313							
3	17	1	1.70	144.0	80.5	.0230	.35	16.75	15.23	2.0116	1.0310	1.0296	0
3	17	2	1.75	120.0	80.0	.0212							
3	17	3	1.76	142.5	100.5	.0250							
3	18	1	1.75	97.5	70.5	.0201	.34	20.23	18.53	2.0063	1.0270	1.0212	72
3	18	2	1.78	92.0	68.0	.0190							
3	18	3	1.86	94.0	66.0	.0222							
3	19	1	1.96	140.0	68.0	.0236	.31	15.02	13.79	2.0052	.9271	.9826	82
3	19	2	2.04	131.5	81.5	.0260							
3	19	3	1.97	144.5	82.0	.0262							
3	20	1	1.83	133.5	71.0	.0195	.40	15.84	14.46	2.0044	.9261	.9880	89
3	20	2	1.87	128.0	80.0	.0224							
3	20	3	1.91	131.5	87.0	.0197							
3	21	1	1.89	180.0	94.0	.0227	.46	21.40	19.50	2.0077	1.0311	1.0063	38
3	21	2	1.80	168.0	138.0	.0305							
3	21	3	1.82	215.0	132.0	.0210							
3	22	1	1.81	136.0	80.0	.0272	.35	16.82	15.32	2.0208	1.0228	1.0258	54
3	22	2	1.85	128.0	98.5	.0329							
3	22	3	1.90	157.5	104.0	.0280							
3	23	1	1.93	200.0	90.5	.0270	.34	15.14	13.80	2.0172	.9288	.9882	89
3	23	2	1.89	181.5	109.0	.0328							
3	23	3	1.94	205.0	122.5	.0250							
3	24	1	1.98	114.5	62.5	.0181	.30	20.93	19.08	2.0127	1.0945	1.0176	0
3	24	2	1.92	107.5	80.0	.0235							
3	24	3	1.94	110.0	74.0	.0220							
3	25	1	1.99	224.5	153.5	.0468	.51	21.59	19.77	2.0133	1.0332	1.0111	60
3	25	2	1.95	206.0	169.5	.0434							
3	25	3	2.00	226.0	183.5	.0495							
3	26	1	1.89	131.5	82.5	.0260	.35	18.22	16.60	2.0131	.9277	.9893	72
3	26	2	1.87	128.0	93.0	.0291							
3	26	3	1.84	145.5	103.0	.0241							
3	27	1	1.85	157.0	122.5	.0320	.37	21.20	19.34	2.0075	1.0238	1.0137	69
3	27	2	1.84	140.0	133.5	.0332							
3	27	3	1.91	177.5	136.0	.0330							
3	28	1	2.07	208.0	115.0	.0300	.44	19.80	18.04	2.0053	1.0300	1.0223	55
3	28	2	1.93	208.5	118.5	.0335							
3	28	3	1.91	233.5	143.0	.0273							
3	29	1	1.99	218.0	124.5	.0359	.41	22.81	20.78	2.0086	1.0221	.9916	85

3	29	2	1.94	221.5	140.0	.0345							
3	29	3	2.00	222.0	111.0	.0318							
3	30	1	2.02	111.5	57.0	.0180	.23	14.91	13.61	2.0051	1.0278	1.0230	78
3	30	2	1.92	128.0	71.0	.0198							
3	30	3	1.85	116.0	68.0	.0151							

RAW DATA FILE CONTAINING THE FOLLOWING INFORMATION (NARROW FACE OF SPECIMEN):

SP - SPECIES (1 = DOUGLAS-FIR, 2 = ENGELMAN SPRUCE, 3 = SOUTHERN PINE)
REP - REPITITION
PH - PILOT HOLE (INCH DIAMETERS)
FOR DF: 1=0.0000, 2=0.0465, 3=0.0400
FOR ES: 1=0.0000, 2=0.0700, 3=0.0465
FOR SP: 1=0.0000, 2=0.0465, 3=0.0400
PD - PENETRATION DEPTH OF THE NAIL SHANK (CM)
PL - MAXIMUM PENETRATION LOAD (LBS)
WL - MAXIMUM WITHDRAWAL LOAD (LBS)
WC - WITHDRAWAL CREEP (CM)
SFC - STATIC FRICTION COEFFICIENT
GW - GREEN WEIGHT OF MC SAMPLE (GRAM)
ODW - OVEN-DRY WEIGHT OF MC SAMPLE (GRAM)
L - GREEN LENGTH OF MC SAMPLE (INCH)
W - GREEN WIDTH OF MC SAMPLE (INCH)
D - GREEN DEPTH OF MC SAMPLE (INCH)
ANGL - ANGLE BETWEEN THE AXIS OF THE NAIL AND THE GROWTH RING (DEGREES)

SP	REP	PH	PD (CM)	PL (LBS)	WL (LBS)	WC (CM)	SFC	GW (G)	ODW (G)	GREEN DIMENSIONS L (IN)	W (IN)	D (IN)	ANGL (DG)
1	1	1	2.20	222.0	115.7	.0322	.45	15.65	14.35	2.0091	.9880	.9825	64
1	1	2	1.94	200.0	120.4	.0329							
1	1	3	1.95	191.0	101.3	.0275							
1	2	1	1.96	248.0	119.4	.0272	.37	14.65	13.43	2.0061	.8915	.9343	41
1	2	2	1.97	246.0	129.8	.0363							
1	2	3	1.90	182.0	109.3	.0258							
1	3	1	1.98	227.0	127.4	.0378	.44	14.51	13.24	2.0022	.9896	.9692	41
1	3	2	1.91	220.0	127.4	.0377							
1	3	3	1.95	190.0	105.3	.0369							
1	4	1	1.95	191.0	100.4	.0305	.37	12.96	11.84	2.0097	.9966	.9742	0
1	4	2	1.93	196.0	118.4	.0361							
1	4	3	2.10	167.0	87.4	.0330							
1	5	1	2.16	243.0	126.0	.0389	.40	14.61	13.32	2.0088	.9796	.9743	26
1	5	2	1.95	218.0	114.7	.0329							
1	5	3	2.08	219.0	128.0	.0380							
1	6	1	1.97	158.5	77.3	.0242	.30	13.52	12.34	2.0097	.9901	.9630	9
1	6	2	2.10	151.0	87.4	.0260							
1	6	3	2.20	167.5	91.7	.0252							
1	7	1	2.08	163.0	84.0	.0242	.34	14.88	13.56	2.0137	.9968	.9793	58
1	7	2	2.19	185.5	104.7	.0310							
1	7	3	1.91	198.0	119.4	.0248							
1	8	1	1.99	166.0	83.7	.0256	.30	14.79	13.48	2.0128	.9036	.9579	71
1	8	2	1.98	194.0	110.7	.0311							
1	8	3	1.95	176.0	94.4	.0240							
1	9	1	2.13	163.5	105.1	.0360	.38	16.80	15.37	2.0118	.9917	.9927	18
1	9	2	2.12	180.0	135.1	.0369							
1	9	3	1.94	168.5	106.0	.0322							

1	10	1	1.95	162.5	94.0	.0252	.37	16.90	15.46	2.0133	1.0058	.9983 25
1	10	2	1.96	164.0	116.0	.0319						
1	10	3	2.06	182.0	123.7	.0251						
1	11	1	2.12	215.0	107.7	.0315	.45	17.19	15.74	2.0106	1.0090	.9942 65
1	11	2	2.00	228.0	119.1	.0330						
1	11	3	2.15	228.0	145.3	.0315						
1	12	1	2.08	242.0	132.0	.0372	.38	16.03	14.58	2.0180	1.0064	.9844 55
1	12	2	2.15	230.5	141.3	.0400						
1	12	3	1.97	240.0	141.8	.0351						
1	13	1	2.00	224.0	123.7	.0361	.40	15.36	14.11	2.0185	1.0014	.9896 48
1	13	2	1.96	177.0	102.4	.0288						
1	13	3	1.99	206.0	106.7	.0361						
1	14	1	1.98	223.5	127.7	.0448	.37	16.54	15.11	2.0144	.9168	.9640 79
1	14	2	2.13	207.0	154.7	.0417						
1	14	3	2.20	251.0	181.8	.0507						
1	15	1	1.94	238.5	114.4	.0479	.47	17.16	15.66	2.0131	1.0109	.9969 80
1	15	2	2.15	246.0	127.3	.0533						
1	15	3	2.17	240.0	120.0	.0512						
1	16	1	1.95	161.5	103.1	.0320	.41	16.37	15.09	2.0206	.9973	.9724 46
1	16	2	1.93	144.0	122.7	.0339						
1	16	3	1.95	140.0	97.1	.0332						
1	17	1	1.96	150.0	95.4	.0280	.37	16.12	14.86	2.0185	.9052	.9633 51
1	17	2	2.15	162.0	124.7	.0350						
1	17	3	2.01	150.0	119.1	.0286						
1	18	1	1.93	196.0	110.4	.0332	.33	16.43	15.02	2.0118	.8999	.9751 17
1	18	2	1.94	237.5	142.4	.0392						
1	18	3	1.95	216.0	113.1	.0341						
1	19	1	2.14	232.0	111.1	.0331	.39	15.41	14.09	2.0170	.9986	.9717 32
1	19	2	2.00	190.0	116.0	.0333						
1	19	3	1.96	190.0	100.0	.0295						
1	20	1	2.18	199.0	101.3	.0345	.38	16.36	15.01	2.0124	1.0065	.9935 65
1	20	2	2.10	200.0	120.4	.0340						
1	20	3	1.96	219.0	120.0	.0295						
1	21	1	2.10	207.0	91.7	.0300	.46	15.10	13.95	2.0039	1.0124	.9947 49
1	21	2	1.96	210.0	128.0	.0355						
1	21	3	1.98	197.0	118.0	.0320						
1	22	1	1.98	162.5	88.4	.0276	.30	16.12	14.91	2.0027	1.0051	1.0046 63
1	22	2	2.14	176.0	92.0	.0295						
1	22	3	2.15	203.5	126.7	.0293						
1	23	1	1.94	264.0	108.4	.0393	.43	18.01	16.50	2.0079	1.0197	1.0151 33
1	23	2	2.22	238.0	147.7	.0453						
1	23	3	1.99	218.0	110.7	.0400						
1	24	1	2.10	194.5	100.4	.0360	.46	15.26	13.91	2.0070	1.0177	1.0052 56
1	24	2	1.98	173.0	102.7	.0320						
1	24	3	1.92	178.5	112.0	.0348						
1	25	1	2.15	350.0	92.7	.0540	.44	16.63	15.25	2.0147	.9415	.9665 36
1	25	2	1.93	273.5	162.7	.0443						
1	25	3	1.98	268.0	122.7	.0510						
1	26	1	2.13	178.0	86.0	.0230	.38	15.99	14.64	2.0139	0.9235	0.9863 3
1	26	2	2.16	178.0	120.0	.0307						
1	26	3	2.18	151.5	103.0	.0242						
1	27	1	2.26	165.5	88.0	.0223	.41	14.68	13.47	2.0141	1.0230	1.0167 44
1	27	2	2.13	178.5	104.0	.0317						

1	27	3	2.16	163.0	87.0	.0211							
1	28	1	2.14	213.5	119.0	.0390	.48	20.42	18.74	2.0129	0.9215	0.9642	37
1	28	2	2.15	237.0	120.0	.0438							
1	28	3	2.17	270.5	122.0	.0400							
1	29	1	2.10	240.0	66.5	.0334	.39	20.23	18.59	2.0137	1.0143	1.0016	9
1	29	2	2.12	214.0	57.0	.0369							
1	29	3	2.19	218.0	60.5	.0371							
1	30	1	2.28	194.0	120.0	.0300	.45	15.16	13.86	2.0097	1.0171	1.0150	87
1	30	2	2.14	165.5	102.5	.0268							
1	30	3	2.22	187.0	128.5	.0290							
2	1	1	1.91	105.0	51.0	.0257	.40	11.06	10.04	2.0096	1.0223	.9845	18
2	1	2	1.90	101.5	56.0	.0206							
2	1	3	1.99	89.0	46.0	.0198							
2	2	1	1.94	102.0	61.0	.0226	.51	12.08	11.60	2.0121	.9233	.9768	11
2	2	2	1.95	100.0	61.5	.0241							
2	2	3	1.97	106.0	55.0	.0194							
2	3	1	1.99	112.0	69.5	.0240	.46	14.12	12.77	2.0034	.9211	.9820	8
2	3	2	1.93	111.0	67.0	.0236							
2	3	3	1.92	98.5	68.5	.0240							
2	4	1	1.97	95.0	58.0	.0195	.56	13.30	12.06	2.0001	.9146	.9820	6
2	4	2	1.92	120.0	60.9	.0235							
2	4	3	2.03	106.0	72.0	.0246							
2	5	1	1.95	99.0	63.0	.0187	.42	14.42	13.11	2.0070	1.0138	1.0256	12
2	5	2	1.90	106.5	61.5	.0185							
2	5	3	2.02	101.5	66.0	.0212							
2	6	1	2.01	116.0	63.0	.0247	.48	10.31	9.38	1.9994	1.0252	1.0019	15
2	6	2	1.95	112.0	62.8	.0240							
2	6	3	1.94	113.0	73.0	.0240							
2	7	1	1.99	96.0	80.0	.0229	.50	14.81	13.46	1.9938	.9171	.9838	13
2	7	2	1.96	96.0	82.5	.0230							
2	7	3	2.00	96.5	72.0	.0229							
2	8	1	1.95	97.5	62.5	.0202	.43	13.29	12.07	2.0135	1.0254	1.0044	5
2	8	2	1.95	126.0	66.0	.0221							
2	8	3	2.01	119.0	81.0	.0260							
2	9	1	2.10	121.0	66.0	.0213	.46	13.21	11.98	2.0140	.9198	.9800	15
2	9	2	1.96	115.5	63.0	.0214							
2	9	3	2.02	97.5	50.0	.0200							
2	10	1	1.95	93.5	60.5	.0200	.44	15.24	13.81	2.0051	.9226	.9799	32
2	10	2	1.93	100.0	60.8	.0210							
2	10	3	1.93	102.5	80.5	.0234							
2	11	1	2.05	92.5	47.5	.0198	.44	13.24	12.01	2.0128	.9251	.9876	17
2	11	2	1.97	108.5	49.2	.0206							
2	11	3	2.00	111.5	62.0	.0209							
2	12	1	2.08	107.5	72.5	.0395	.49	14.17	12.81	2.0144	.9226	.9837	3
2	12	2	2.00	120.0	67.3	.0326							
2	12	3	2.01	106.5	62.0	.0316							
2	13	1	2.05	92.5	48.0	.0163	.44	13.17	11.94	2.0055	1.0774	1.0329	5
2	13	2	1.95	103.0	48.6	.0171							
2	13	3	2.00	107.5	66.0	.0219							
2	14	1	1.99	104.5	63.5	.0230	.53	13.01	11.80	1.9955	.9187	.9862	14
2	14	2	1.93	100.0	58.5	.0246							
2	14	3	1.96	97.5	61.5	.0225							
2	15	1	1.95	104.0	67.0	.0208	.45	15.21	13.77	2.0027	1.0002	.9844	46

2	15	2	1.97	106.5	72.5	.0210							
2	15	3	1.95	112.0	59.5	.0190							
2	16	1	2.03	106.5	53.0	.0207	.47	13.31	12.09	2.0093	1.0200	1.0249	12
2	16	2	2.00	116.0	55.3	.0248							
2	16	3	1.96	106.0	65.5	.0236							
2	17	1	2.04	98.0	50.5	.0211	.42	10.96	9.95	2.0085	.9240	.9843	20
2	17	2	1.95	92.0	51.3	.0210							
2	17	3	1.96	92.0	61.0	.0235							
2	18	1	1.99	93.5	47.0	.0169	.40	13.74	12.48	2.0060	1.0262	1.0187	23
2	18	2	2.00	110.0	50.2	.0209							
2	18	3	2.05	104.5	55.5	.0183							
2	19	1	2.02	70.0	38.0	.0155	.31	11.37	10.33	2.0035	1.0269	1.0164	17
2	19	2	1.90	81.5	39.5	.0175							
2	19	3	1.90	83.0	46.0	.0190							
2	20	1	2.00	98.5	52.5	.0170	.45	14.09	12.83	2.0105	1.0828	1.0370	23
2	20	2	1.90	89.5	54.5	.0192							
2	20	3	1.92	101.0	54.5	.0206							
2	21	1	1.95	98.0	70.0	.0231	.43	14.83	13.51	2.0108	1.0238	1.0225	12
2	21	2	1.90	98.5	69.5	.0227							
2	21	3	1.94	100.0	65.5	.0230							
2	22	1	1.88	104.0	62.0	.0214	.43	13.31	12.09	2.0071	1.0247	1.0107	11
2	22	2	1.93	115.5	73.4	.0224							
2	22	3	1.93	107.0	75.0	.0239							
2	23	1	1.97	98.5	68.0	.0240	.52	14.33	12.97	2.0051	.9270	.9789	14
2	23	2	1.90	89.0	61.0	.0242							
2	23	3	1.88	97.0	64.5	.0215							
2	24	1	1.98	117.5	64.0	.0235	.47	13.35	12.13	2.0071	1.0233	1.0219	7
2	24	2	1.98	109.5	63.7	.0240							
2	24	3	1.99	112.0	77.5	.0260							
2	25	1	2.00	107.0	60.5	.0191	.44	14.51	13.20	2.0104	1.0249	1.0220	15
2	25	2	1.95	115.0	60.0	.0224							
2	25	3	1.96	112.0	77.0	.0241							
2	26	1	2.15	105.5	74.5	.0241	.45	14.65	13.27	2.0074	1.0269	1.0245	10
2	26	2	1.95	112.0	68.3	.0220							
2	26	3	1.93	106.5	81.0	.0242							
2	27	1	1.98	120.0	73.5	.0240	.45	14.44	13.14	2.0062	.9229	.9787	11
2	27	2	1.89	119.0	73.0	.0222							
2	27	3	1.99	113.5	71.0	.0243							
2	28	1	2.03	93.5	42.5	.0165	.36	13.24	12.03	2.0038	1.0341	1.0171	6
2	28	2	1.98	106.0	40.9	.0194							
2	28	3	1.93	106.0	60.0	.0215							
2	29	1	2.00	64.5	43.0	.0175	.43	14.47	13.22	2.0097	.9242	.9910	14'
2	29	2	1.91	74.5	46.0	.0180							
2	29	3	1.97	64.5	36.0	.0156							
2	30	1	2.01	100.0	68.5	.0217	.37	14.59	13.30	2.0121	.9497	.9885	13
2	30	2	1.80	97.5	64.0	.0181							
2	30	3	1.98	105.0	68.0	.0223							
3	1	1	2.06	146.0	91.5	.0269	.42	15.93	14.49	2.0115	1.0237	1.0206	42
3	1	2	2.07	132.5	94.5	.0247							
3	1	3	2.05	138.5	93.5	.0268							
3	2	1	2.08	201.5	114.0	.0324	.41	17.68	16.08	2.0036	.9194	.9804	3
3	2	2	2.08	157.5	106.0	.0287							
3	2	3	2.10	143.0	109.5	.0320							
3	3	1	2.05	296.0	140.5	.0376	.46	19.05	17.33	2.0069	.9279	.9870	28

3	3	2	2.08	181.0	116.0	.0270							
3	3	3	2.13	222.0	121.5	.0395							
3	4	1	2.15	182.0	89.0	.0265	.34	15.41	14.05	2.0107	1.0303	1.0211	60
3	4	2	2.14	165.5	97.5	.0320							
3	4	3	2.09	161.5	98.0	.0255							
3	5	1	2.05	232.0	152.0	.0388	.51	18.91	17.21	2.0052	.9263	.9756	55
3	5	2	2.10	191.5	115.0	.0288							
3	5	3	1.86	256.0	161.5	.0368							
3	6	1	2.18	258.5	120.0	.0311	.36	20.68	18.83	2.0100	.9174	.9830	23
3	6	2	2.03	280.5	153.0	.0392							
3	6	3	2.08	210.5	104.5	.0298							
3	7	1	2.14	127.0	80.0	.0259	.30	15.64	14.24	2.0276	1.0285	1.0199	88
3	7	2	1.99	134.5	99.0	.0292							
3	7	3	1.97	126.0	88.5	.0228							
3	8	1	2.15	233.0	147.0	.0388	.50	20.50	18.73	2.0218	.9243	.9818	39
3	8	2	2.13	238.0	181.5	.0361							
3	8	3	2.11	255.0	170.0	.0372							
3	9	1	2.10	104.5	92.5	.0280	.33	20.78	18.94	2.0103	1.0116	1.0234	0
3	9	2	2.05	127.0	60.0	.0250							
3	9	3	2.10	128.0	62.0	.0285							
3	10	1	2.15	146.5	109.5	.0280	.42	16.70	15.26	2.0133	.9208	.9827	63
3	10	2	2.23	198.0	103.5	.0304							
3	10	3	2.11	165.0	101.0	.0281							
3	11	1	2.14	189.0	146.0	.0388	.55	18.20	16.54	2.0101	1.0313	1.0206	52
3	11	2	2.10	176.5	154.0	.0400							
3	11	3	2.12	186.0	146.0	.0390							
3	12	1	2.15	207.0	103.0	.0329	.45	21.27	19.35	2.0055	1.0149	1.0261	35
3	12	2	2.01	210.5	92.5	.0260							
3	12	3	2.07	260.5	129.5	.0313							
3	13	1	2.12	137.5	147.0	.0346	.42	19.07	17.40	2.0121	.9273	.9760	0
3	13	2	2.16	220.0	217.0	.0362							
3	13	3	2.08	161.0	51.0	.0340							
3	14	1	2.16	130.5	90.0	.0275	.35	18.82	17.15	2.0137	1.0514	.9968	1
3	14	2	2.05	117.0	85.5	.0655							
3	14	3	1.99	125.5	90.0	.0244							
3	15	1	2.08	157.0	108.5	.0296	.50	17.00	15.48	2.0110	.9207	.9886	43
3	15	2	2.10	162.5	92.5	.0270							
3	15	3	2.00	135.0	72.0	.0285							
3	16	1	2.15	142.0	96.5	.0264	.45	16.81	15.31	2.0119	.9301	.9841	74
3	16	2	2.10	175.0	117.5	.0351							
3	16	3	2.17	157.5	99.0	.0284							
3	17	1	2.23	208.5	129.5	.0328	.35	16.75	15.23	2.0116	1.0310	1.0296	87
3	17	2	2.13	233.5	156.0	.0310							
3	17	3	2.08	218.5	142.0	.0292							
3	18	1	2.01	85.5	84.0	.0195	.34	20.23	18.53	2.0063	1.0270	1.0212	4
3	18	2	2.02	105.0	73.5	.0218							
3	18	3	2.03	95.0	68.0	.0211							
3	19	1	2.15	160.0	96.0	.0230	.31	15.02	13.79	2.0052	.9271	.9826	15
3	19	2	2.05	122.0	85.5	.0200							
3	19	3	2.10	138.0	57.5	.0215							
3	20	1	2.11	145.5	82.0	.0250	.40	15.84	14.46	2.0044	.9261	.9880	69
3	20	2	2.04	144.5	105.0	.0310							
3	20	3	2.10	155.0	88.0	.0265							

3	21	1	2.07	184.0	116.0	.0410	.46	21.40	19.50	2.0077	1.0311	1.0063	0
3	21	2	2.01	179.0	122.5	.0351							
3	21	3	2.03	155.0	92.5	.0397							
3	22	1	2.07	148.0	107.0	.0250	.35	16.82	15.32	2.0208	1.0228	1.0258	12
3	22	2	2.00	165.0	76.0	.0224							
3	22	3	2.03	152.0	66.0	.0245							
3	23	1	2.09	228.0	80.0	.0381	.34	15.14	13.80	2.0172	.9288	.9882	28
3	23	2	2.02	255.0	97.5	.0340							
3	23	3	1.97	249.0	103.5	.0371							
3	24	1	2.05	123.5	80.0	.0217	.30	20.93	19.08	2.0127	1.0945	1.0176	87
3	24	2	2.08	126.0	91.0	.0240							
3	24	3	2.09	126.5	94.5	.0237							
3	25	1	2.01	197.0	160.0	.0328	.51	21.59	19.77	2.0133	1.0332	1.0111	0
3	25	2	1.96	160.0	50.5	.0261							
3	25	3	2.05	218.0	96.0	.0340							
3	26	1	2.10	132.5	90.0	.0262	.35	18.22	16.60	2.0131	.9277	.9893	5
3	26	2	2.05	132.0	78.0	.0219							
3	26	3	2.06	131.0	80.5	.0224							
3	27	1	2.19	189.5	116.5	.0281	.37	21.20	19.34	2.0075	1.0238	1.0137	73
3	27	2	2.12	188.5	168.0	.0301							
3	27	3	2.07	171.0	146.5	.0235							
3	28	1	2.10	211.0	136.0	.0463	.44	19.80	18.04	2.0053	1.0300	1.0223	42
3	28	2	2.00	210.5	140.0	.0390							
3	28	3	2.01	223.0	155.0	.0440							
3	29	1	1.99	131.0	105.0	.0241	.41	22.81	20.78	2.0086	1.0221	.9916	17
3	29	2	1.99	251.0	97.0	.0410							
3	29	3	2.01	197.0	96.0	.0251							
3	30	1	2.04	110.0	60.0	.0310	.23	14.91	13.61	2.0051	1.0278	1.0230	27
3	30	2	2.00	144.0	74.5	.0311							
3	30	3	2.00	154.0	93.0	.0303							

DF STATIC FRICTION COEFFICIENT RESULTS

WIDE FACE RESULTS

.45	.40
.37	.41
.44	.39
.37	.34
.40	.37
.30	.36
.34	.39
.30	.40
.38	.37
.37	.37
.45	.43
.38	.40
.40	.42
.37	.40

NARROW FACE RESULTS

.40	.42
.36	.41
.43	.39
.33	.36
.39	.35
.38	.40
.42	.39
.40	.37
.35	.40
.36	.30
.41	.41
.44	.32
.37	.38
.40	.37

WIDE AND NARROW FACE RESULTS

.45	.42
.41	.36
.39	.43
.37	.36
.40	.35
.36	.38
.39	.42
.30	.37
.38	.40
.37	.37
.45	.41
.40	.44
.40	.38
.40	.40

FILE FMD IS THE RAW DATA FILE CONTAINING THE FOLLOWING INFORMATION TO DETERMINE THE FOUNDATION MODULUS FOR THE GIVEN SPECIES. THE BEARING LENGTH AND WIDTH OF THE BAR USED WAS 1.320 AND 0.182 INCHES RESPECTIVELY.

SP - SPECIES
RP - REPITITION
EL - END GRAIN LOAD
EY - END GRAIN DEFLECTION
RTL - RADIAL-TANGENTIAL GRAIN LOAD
RTY - RADIAL-TANGENTIAL GRAIN DEFLECTION

		WIDE FACE				NARROW FACE			
SP	RP	EL (LBS)	EY (CM)	RTL (LBS)	RTY (CM)	EL (LBS)	EY (CM)	RTL (LBS)	RTY (CM)
1	1	550.0	.0213	215.0	.0205	650.0	.0230	275.0	.0347
1	2	630.0	.0210	220.0	.0170	660.0	.0155	230.0	.0214
1	3	660.0	.0260	250.0	.0320	680.0	.0184	300.0	.0220
1	4	640.0	.0231	200.0	.0277	640.0	.0211	245.0	.0171
1	5	660.0	.0205	200.0	.0305	710.0	.0200	300.0	.0214
1	6	710.0	.0268	215.0	.0258	610.0	.0203	255.0	.0284
1	7	630.0	.0190	210.0	.0224	620.0	.0190	280.0	.0255
1	8	580.0	.0181	175.0	.0190	620.0	.0195	245.0	.0228
1	9	580.0	.0195	220.0	.0340	560.0	.0160	285.0	.0383
1	10	680.0	.0244	240.0	.0270	610.0	.0188	270.0	.0329
1	11	580.0	.0215	245.0	.0329	600.0	.0213	230.0	.0286
1	12	550.0	.0310	275.0	.0230	700.0	.0200	330.0	.0202
1	13	590.0	.0200	205.0	.0280	690.0	.0190	280.0	.0219
1	14	570.0	.0185	240.0	.0320	720.0	.0186	310.0	.0200
1	15	500.0	.0190	200.0	.0300	650.0	.0187	320.0	.0260
1	16	580.0	.0224	170.0	.0288	620.0	.0210	280.0	.0245
1	17	640.0	.0228	180.0	.0280	650.0	.0219	260.0	.0230
1	18	570.0	.0240	235.0	.0191	690.0	.0200	305.0	.0164
1	19	590.0	.0211	175.0	.0380	650.0	.0214	240.0	.0230
1	20	640.0	.0225	300.0	.0397	710.0	.0225	305.0	.0459
1	21	630.0	.0249	215.0	.0290	620.0	.0240	225.0	.0350
1	22	700.0	.0236	300.0	.0390	700.0	.0218	310.0	.0240
1	23	560.0	.0234	300.0	.0382	610.0	.0204	285.0	.0311
1	24	580.0	.0216	265.0	.0445	660.0	.0249	260.0	.0348
1	25	670.0	.0240	280.0	.0395	620.0	.0242	235.0	.0365
1	26	700.0	.0290	220.0	.0330	700.0	.0245	250.0	.0251
1	27	720.0	.0339	300.0	.0410	710.0	.0248	145.0	.0240
1	28	560.0	.0249	350.0	.0328	750.0	.0210	250.0	.0258
1	29	650.0	.0202	320.0	.0448	660.0	.0239	200.0	.0280
1	30	580.0	.0221	295.0	.0250	720.0	.0223	275.0	.0237
2	1	550.0	.0310	135.0	.0470	650.0	.0271	137.5	.0215
2	2	630.0	.0220	152.5	.0234	620.0	.0260	125.0	.0119
2	3	620.0	.0251	137.5	.0290	610.0	.0217	145.0	.0197
2	4	600.0	.0221	130.0	.0260	600.0	.0253	145.0	.0190
2	5	610.0	.0240	155.0	.0298	670.0	.0245	150.0	.0126
2	6	640.0	.0285	160.5	.0260	630.0	.0260	180.0	.0320

2	7	620.0	.0251	152.5	.0215	610.0	.0225	125.0	.0108
2	8	600.0	.0222	150.0	.0235	630.0	.0210	127.5	.0128
2	9	600.0	.0226	147.5	.0249	660.0	.0269	157.5	.0120
2	10	630.0	.0234	160.0	.0219	670.0	.0243	160.0	.0180
2	11	640.0	.0221	160.0	.0240	600.0	.0269	137.5	.0201
2	12	620.0	.0245	152.5	.0260	630.0	.0246	137.5	.0162
2	13	610.0	.0270	152.5	.0240	600.0	.0265	130.0	.0201
2	14	660.0	.0320	152.5	.0281	630.0	.0259	147.5	.0139
2	15	610.0	.0226	150.0	.0260	610.0	.0210	150.0	.0160
2	16	620.0	.0210	155.0	.0225	600.0	.0228	135.5	.0175
2	17	600.0	.0280	150.0	.0302	620.0	.0249	155.0	.0206
2	18	610.0	.0248	152.5	.0238	600.0	.0235	157.5	.0136
2	19	610.0	.0308	160.0	.0500	640.0	.0265	147.5	.0125
2	20	640.0	.0229	150.0	.0220	600.0	.0245	135.0	.0150
2	21	630.0	.0269	160.0	.0215	600.0	.0200	162.5	.0137
2	22	640.0	.0210	152.5	.0223	630.0	.0225	162.5	.0138
2	23	650.0	.0252	150.0	.0375	610.0	.0220	130.5	.0177
2	24	620.0	.0291	152.5	.0260	630.0	.0246	167.5	.0170
2	25	610.0	.0235	157.5	.0190	660.0	.0229	150.0	.0140
2	26	650.0	.0240	152.5	.0270	650.0	.0235	145.0	.0132
2	27	640.0	.0240	165.0	.0204	630.0	.0219	150.0	.0161
2	28	640.0	.0211	175.0	.0219	600.0	.0240	162.5	.0150
2	29	620.0	.0270	112.5	.0430	620.0	.0300	152.5	.0173
2	30	630.0	.0201	185.0	.0215	610.0	.0205	150.0	.0129
3	1	620.0	.0277	305.0	.0359	580.0	.0260	270.0	.0375
3	2	670.0	.0280	305.0	.0319	670.0	.0230	300.0	.0370
3	3	590.0	.0241	300.0	.0319	660.0	.0212	305.0	.0241
3	4	660.0	.0270	305.0	.0332	630.0	.0230	290.0	.0410
3	5	660.0	.0225	320.0	.0300	630.0	.0213	305.0	.0210
3	6	650.0	.0212	315.0	.0300	650.0	.0210	305.0	.0240
3	7	610.0	.0263	300.0	.0328	610.0	.0240	300.0	.0300
3	8	660.0	.0200	330.0	.0260	640.0	.0245	335.0	.0322
3	9	650.0	.0215	305.0	.0230	600.0	.0203	300.0	.0315
3	10	630.0	.0224	285.0	.0340	590.0	.0231	295.0	.0320
3	11	590.0	.0258	305.0	.0250	610.0	.0270	310.0	.0220
3	12	600.0	.0290	300.0	.0303	600.0	.0290	300.0	.0320
3	13	630.0	.0208	325.0	.0398	620.0	.0190	300.0	.0217
3	14	640.0	.0254	330.0	.0459	600.0	.0260	300.0	.0434
3	15	610.0	.0335	345.0	.0420	610.0	.0285	250.0	.0277
3	16	630.0	.0215	320.0	.0280	600.0	.0290	270.0	.0312
3	17	610.0	.0220	300.0	.0240	650.0	.0210	315.0	.0249
3	18	610.0	.0229	305.0	.0385	610.0	.0194	250.0	.0410
3	19	600.0	.0210	310.0	.0474	630.0	.0207	245.0	.0310
3	20	630.0	.0326	225.0	.0390	600.0	.0250	240.0	.0412
3	21	650.0	.0305	310.0	.0294	590.0	.0185	315.0	.0538
3	22	610.0	.0299	320.0	.0250	640.0	.0202	230.0	.0240
3	23	630.0	.0250	310.0	.0375	590.0	.0250	280.0	.0260
3	24	600.0	.0240	195.0	.0232	630.0	.0203	280.0	.0350
3	25	660.0	.0210	305.0	.0230	630.0	.0178	305.0	.0216
3	26	640.0	.0286	305.0	.0352	600.0	.0260	305.0	.0385
3	27	680.0	.0201	315.0	.0210	650.0	.0260	300.0	.0310
3	28	600.0	.0215	310.0	.0459	650.0	.0185	305.0	.0331
3	29	680.0	.0209	310.0	.0210	630.0	.0223	300.0	.0202
3	30	630.0	.0234	200.0	.0400	610.0	.0220	350.0	.0457

FILE FMMD IS THE RAW DATA FILE CONTAINING THE FOLLOWING INFORMATION:

SP - SPECIES
RP - REPITITIONS
BEW - SPECIMEN LENGTH "B" FOR DETERMINING KOEW
LEW - SPECIMEN LENGTH "L" FOR DETERMINING KOEW
BRTW - SPECIMEN LENGTH "B" FOR DETERMINING KORTW
LRTW - SPECIMEN LENGTH "L" FOR DETERMINING KORTW
BEN - SPECIMEN LENGTH "B" FOR DETERMINING KOEN
LEN - SPECIMEN LENGTH "L" FOR DETERMINING KOEN
BRTN - SPECIMEN LENGTH "B" FOR DETERMINING KORTN
LRTN - SPECIMEN LENGTH "L" FOR DETERMINING KORTN

SP	RP	BEW (IN)	LEW (IN)	BRTW (IN)	LRTW (IN)	BEN (IN)	LEN (IN)	BRTN (IN)	LRTN (IN)
1	1	2.221	1.450	1.450	2.221	.688	1.075	1.075	.688
1	2	1.195	1.462	1.462	1.195	.729	.969	.969	.729
1	3	1.172	1.445	1.445	1.172	.743	.936	.936	.743
1	4	1.318	1.488	1.488	1.318	.730	1.006	1.006	.730
1	5	1.265	1.482	1.482	1.265	.742	.951	.951	.742
1	6	1.309	1.476	1.476	1.309	.767	.898	.898	.767
1	7	1.348	1.525	1.525	1.348	.796	.986	.986	.796
1	8	1.280	1.283	1.283	1.280	.808	.957	.957	.808
1	9	1.325	1.488	1.488	1.325	.774	.991	.991	.774
1	10	1.369	1.457	1.457	1.369	.718	.941	.941	.718
1	11	1.137	1.446	1.446	1.137	.780	.993	.993	.780
1	12	1.294	1.459	1.459	1.294	.830	1.014	1.014	.830
1	13	1.250	1.468	1.468	1.250	.798	1.003	1.003	.798
1	14	1.231	1.453	1.453	1.231	.762	.978	.978	.762
1	15	1.388	1.467	1.467	1.388	1.487	.636	.636	1.487
1	16	3.026	1.480	1.480	3.026	1.426	1.033	1.033	1.426
1	17	3.032	1.470	1.470	3.032	1.437	.939	.939	1.437
1	18	3.031	1.461	1.461	3.031	1.445	1.000	1.000	1.445
1	19	3.036	1.478	1.478	3.036	1.446	1.020	1.020	1.446
1	20	3.039	1.457	1.457	3.039	1.446	.916	.916	1.446
1	21	3.041	1.482	1.482	3.041	1.461	1.007	1.007	1.461
1	22	3.046	1.475	1.475	3.046	1.473	.903	.903	1.473
1	23	3.039	1.450	1.450	3.039	1.522	1.040	1.040	1.522
1	24	3.041	1.483	1.483	3.041	1.471	.997	.997	1.471
1	25	3.036	1.490	1.490	3.036	1.519	.988	.988	1.519
1	26	3.034	1.490	1.490	3.034	1.497	.640	.640	1.497
1	27	3.041	1.500	1.500	3.041	1.498	.634	.634	1.498
1	28	3.037	1.463	1.463	3.037	1.529	.636	.636	1.529
1	29	3.040	1.480	1.480	3.040	1.516	.594	.594	1.516
1	30	3.049	1.515	1.515	3.049	1.478	.564	.564	1.478
2	1	2.955	1.533	1.533	2.955	1.495	1.533	1.533	1.495
2	2	2.959	1.547	1.547	2.959	1.503	1.547	1.547	1.503
2	3	2.937	1.544	1.544	2.937	1.495	1.544	1.544	1.495
2	4	2.958	1.539	1.539	2.958	1.490	1.539	1.539	1.490
2	5	2.945	1.573	1.573	2.945	1.497	1.573	1.573	1.497
2	6	2.950	1.533	1.533	2.950	1.504	1.533	1.533	1.504
2	7	2.937	1.579	1.579	2.937	1.492	1.579	1.579	1.492

2	8	2.958	1.545	1.545	2.958	1.492	1.545	1.545	1.492
2	9	2.950	1.717	1.717	2.950	1.497	1.717	1.717	1.497
2	10	2.930	1.630	1.630	2.930	1.492	1.630	1.630	1.492
2	11	2.953	1.562	1.562	2.953	1.506	1.562	1.562	1.506
2	12	2.950	1.515	1.515	2.950	1.506	1.515	1.515	1.506
2	13	2.953	1.488	1.488	2.953	1.501	1.488	1.488	1.501
2	14	2.934	1.511	1.511	2.934	1.499	1.511	1.511	1.499
2	15	2.957	1.522	1.522	2.957	1.491	1.522	1.522	1.491
2	16	2.955	1.554	1.554	2.955	1.498	1.554	1.554	1.498
2	17	2.957	1.547	1.547	2.957	1.498	1.547	1.547	1.498
2	18	2.958	1.539	1.539	2.958	1.496	1.539	1.539	1.496
2	19	2.946	1.557	1.557	2.946	1.499	1.557	1.557	1.499
2	20	2.934	1.542	1.542	2.934	1.492	1.542	1.542	1.492
2	21	2.938	1.571	1.571	2.938	1.495	1.571	1.571	1.495
2	22	2.925	1.539	1.539	2.925	1.495	1.539	1.539	1.495
2	23	2.924	1.562	1.562	2.924	1.500	1.562	1.562	1.500
2	24	2.956	1.529	1.529	2.956	1.497	1.529	1.529	1.497
2	25	2.937	1.523	1.523	2.937	1.502	1.523	1.523	1.502
2	26	2.946	1.553	1.553	2.946	1.499	1.553	1.553	1.499
2	27	2.937	1.553	1.553	2.937	1.496	1.553	1.553	1.496
2	28	2.943	1.571	1.571	2.943	1.498	1.571	1.571	1.498
2	29	2.937	1.530	1.530	2.937	1.504	1.530	1.530	1.504
2	30	2.940	1.523	1.523	2.940	1.490	1.523	1.523	1.490
3	1	3.006	1.455	1.455	3.006	1.470	1.455	1.455	1.470
3	2	3.007	1.453	1.453	3.007	1.518	1.453	1.453	1.518
3	3	3.011	1.404	1.404	3.011	1.459	1.404	1.404	1.459
3	4	3.001	1.468	1.468	3.001	1.513	1.468	1.468	1.513
3	5	3.014	1.390	1.390	3.014	1.464	1.390	1.390	1.464
3	6	2.999	1.605	1.605	2.999	1.512	1.605	1.605	1.512
3	7	3.010	1.451	1.451	3.010	1.508	1.451	1.451	1.508
3	8	3.011	1.421	1.421	3.011	1.497	1.421	1.421	1.497
3	9	3.010	1.449	1.449	3.010	1.526	1.449	1.449	1.526
3	10	3.010	1.431	1.431	3.010	1.509	1.431	1.431	1.509
3	11	3.008	1.462	1.462	3.008	1.474	1.462	1.462	1.474
3	12	2.988	1.420	1.420	2.988	1.512	1.420	1.420	1.512
3	13	3.010	1.514	1.514	3.010	1.515	1.514	1.514	1.515
3	14	2.993	1.540	1.540	2.993	1.476	1.540	1.540	1.476
3	15	2.994	1.483	1.483	2.994	1.487	1.483	1.483	1.487
3	16	3.016	1.495	1.495	3.016	1.447	1.495	1.495	1.447
3	17	3.010	1.477	1.477	3.010	1.440	1.477	1.477	1.440
3	18	3.012	1.400	1.400	3.012	1.475	1.400	1.400	1.475
3	19	3.004	1.483	1.483	3.004	1.515	1.483	1.483	1.515
3	20	3.013	1.460	1.460	3.013	1.468	1.460	1.460	1.468
3	21	2.996	1.205	1.205	2.996	1.460	1.205	1.205	1.460
3	22	2.986	1.511	1.511	2.986	1.479	1.511	1.511	1.479
3	23	2.996	1.441	1.441	2.996	1.506	1.441	1.441	1.506
3	24	3.012	1.523	1.523	3.012	1.504	1.523	1.523	1.504
3	25	2.991	1.480	1.480	2.991	1.517	1.480	1.480	1.517
3	26	2.997	1.508	1.508	2.997	1.476	1.508	1.508	1.476
3	27	3.011	1.511	1.511	3.011	1.473	1.511	1.511	1.473
3	28	2.971	1.367	1.367	2.971	1.494	1.367	1.367	1.494
3	29	2.969	1.057	1.057	2.969	1.489	1.057	1.057	1.489
3	30	2.990	1.336	1.336	2.990	1.513	1.336	1.336	1.513