AN ABSTRACT OF THE THESIS OF

Richard C. Toupin for the degree of Master of Forestry in Forest Engineering presented on April 25, 1985.

Title: Load-Deformation Characteristics of Multiple Stump Anchor Systems.

Abstract approved: Marvin R. Pyles

Dr. Marvin R. Pyles

This paper documents the development of a model which determines multiple stump anchor system displacement as a response to skyline load for four anchor rigging configurations: 1. Series multiple, 2. Tieback, 3. Elevated tieback, and 4. Equalizer block. It also documents the field testing of four two stump anchors rigged in the four rigging configurations. A comparison of the model and field results is presented, as well as a discussion of load transfer from the skyline to the second stump.

Diagrams are presented which illustrate the model load-deformation curves for a variety of stump sizes and pretensions between the two stumps prior to skyline loading. Also presented on these diagrams are the loads at which system failure occurs.

Load-deformation curves for all four rigging configurations are similar when the two stumps are the same strength. When one stump is weaker than the other, the equalizer block system load-deformation curve is different from the curves for the other three systems, and the system fails at a lower total load.

Four sets of two stumps were field tested in the four rigging configurations. Within a load range common to all rigging configurations, the load-deformation curves for the four rigging configurations were similar.

Load-deformation curves for the model and field test data were compared. Curves were most similar for the series multiple and high pretension tieback configurations.

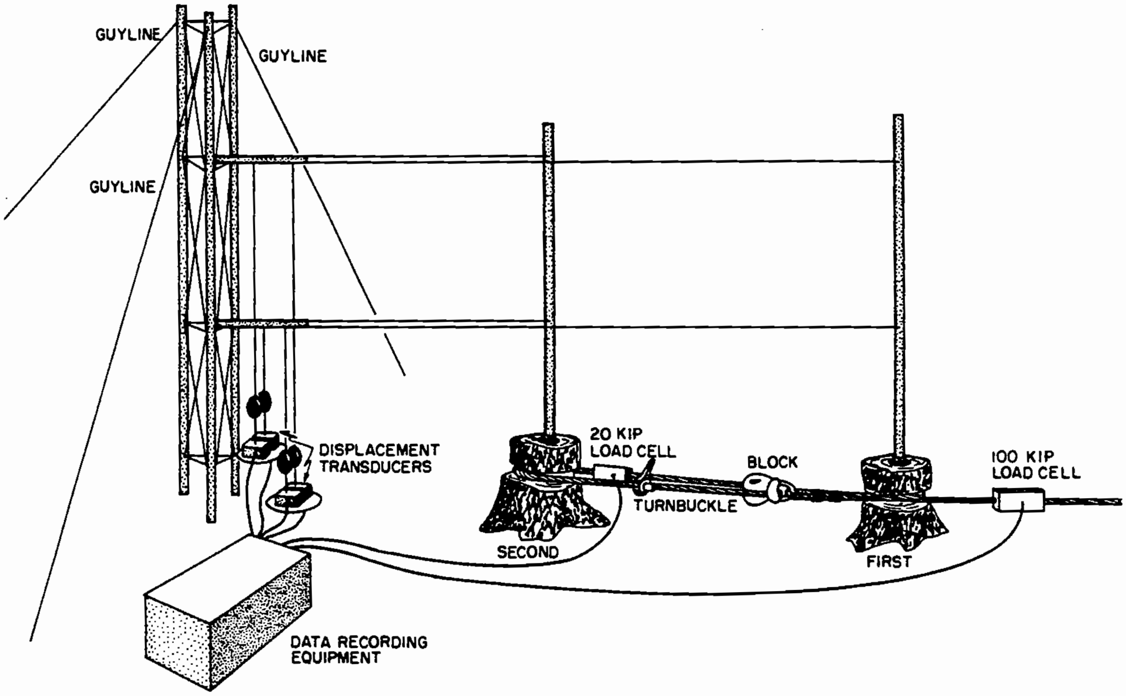
Since the load-deformation characteristics for the series multiple and the two tieback systems are similar, the preferable system is the one that is easiest to rig. The series multiple system requires less hardware to rig because the skyline is used as the link between the two stumps, rather than a twister. Consequently, the series multiple system appears to be the preferred system.

The equalizer block system appears to be the least preferred system because it is likely to fail at a lower system load than the other systems.

The results presented are of limited scope. The field data was collected during August 1984 when soil moisture conditions were relatively dry, and the model computations are restricted because the linkage between the stumps was assumed to be rigid.

It is recognized that the capacity of a stump to resist applied loads might be influenced by varying soil moisture contents, particularly at a saturated level. However, the tests documented in this report were conducted when soil moisture was at a low level. The resulting load-deformation curves can be expected to change in magnitude as soil moisture content varies.

The model load-deformation curves were developed with the assumption that the linkage between the two stumps was rigid. The linkage is not rigid in a real anchor system. The positions of the system load-deformation curves may change if the linkage length is affected by line stretch, line travel, or wood crushing. The ranking of the four systems from preferred to least preferred could change if these three factors were included in the multiple stump model.


GUYLINE
GUYLINE
GUYLINE
DISPLACEMENT TRANSDUCERS
20 KIP LOAD CELL
BLOCK
100 KIP LOAD CELL
TURNBUCKLE
SECOND
FIRST
DATA RECORDING EQUIPMENT

LOAD-DEFORMATION CHARACTERISTICS OF MULTIPLE STUMP ANCHOR SYSTEMS

by

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I. INTRODUCTION

Stumps are the most common anchors used with cable logging systems. For stumps to provide anchorage with the same degree of safety as other components of a cable logging system they must have an ultimate pull-out resistance well above any load that will be applied by the cable system. Stumps capable of providing sufficient pull-out resistance when used individually may not always be available, particularly when the anchors need to be located in second growth stands. Two alternatives to the use of individual stumps are artificial anchors and multiple stump anchors. Artificial anchors can be equipment such as tractors, or structures such as deadmen anchors. Multiple stump anchors consist of two or more stumps rigged together to hold the applied load. To select between artificial anchors and multiple stump anchors, it is necessary to know the cost and physical capabilities of each. This paper documents an investigation of the physical capabilities of multiple stump anchor systems.

A. Study Objectives

The focus of this paper is on two stump multiple stump anchor systems even though more than two stumps can be used. The reason for this was to gain an understanding of the two stump system behavior before attempting an analysis of a system with more than two stumps.

Soil moisture content is likely to influence the behavior of the multiple stump anchor systems. However since the goal was to develop an understanding of anchor system behavior before trying to explain all the factors which might influence system behavior, it was decided not to conduct field measurements at more than one soil moisture content.

There were two objectives for this study; first to describe the load transfer from the skyline to each of the stumps in the multiple stump system; and second to develop a model which would predict anchor system displacement as a response to applied load for multiple stump anchor systems.

B. Description of Four Multiple Stump Anchor Systems

There are several ways to rig two stumps together as a multiple stump anchor. Four possible methods are presented in this paper.

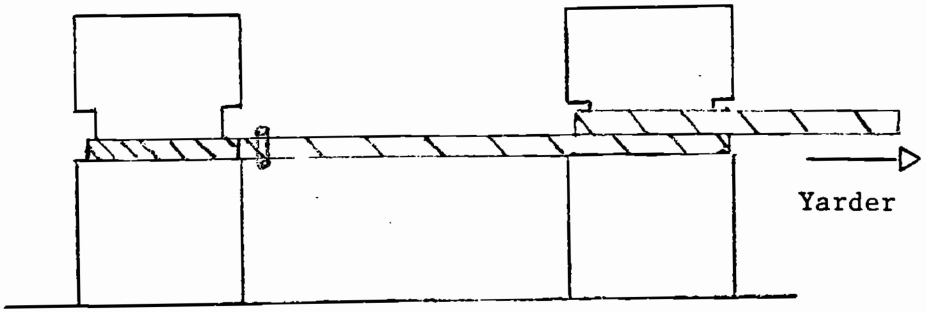
1. Series Multiple Anchor

A typical series multiple anchor system is rigged using the skyline with a spliced eye in the end, and a shackle. The skyline is wrapped around the first stump in a notch, passed to the second stump, and then wrapped around the second stump in a notch. The end of the skyline is tied off on itself with a shackle. Of the four configurations analyzed, the series multiple configuration requires the least amount of hardware to rig. Consequently, it may be the fastest one to set up. The system is illustrated in Figure 1.

2. Tieback Anchor

A typical tieback anchor system is rigged using the skyline with a spliced eye and shackle, and a tieback line. The skyline is wrapped around the first stump in a notch and secured to itself with a shackle. Haywire is usually used for the tieback line. Haywire is normally wrapped around the two stumps several times to link them together. The haywire is then tensioned with a twister. A twister consists of a large stick placed between the haywire wraps which is twisted so that the haywire is tensioned. This configuration is more involved to rig than the series multiple system because it requires the separate twister lines between the two stumps. In this study, two lines tensioned with a turnbuckle were used as the tieback line between the stumps because the turnbuckle allowed more control of the tensioning than was possible with a twister. Figure 2 illustrates this configuration. For clarity in the figure, the multiple haywire wraps around the two stumps are shown as single lines.

SIDE VIEW



TOP VIEW

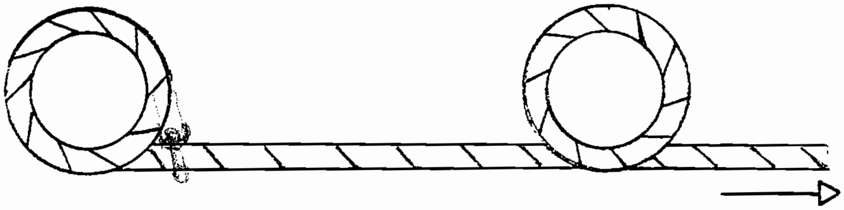
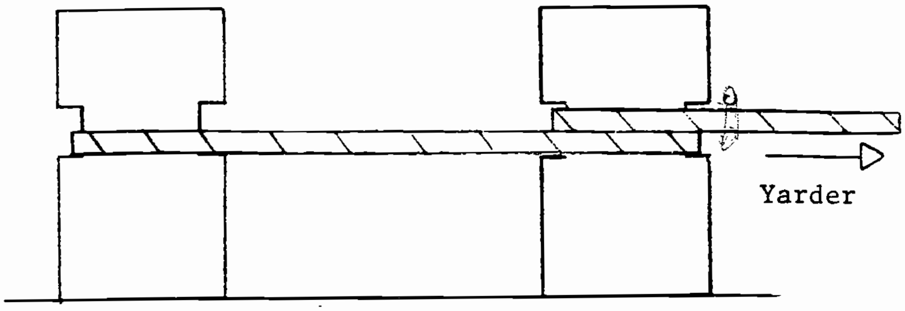


Figure 1

Side and top view of the series multiple rigging configuration without the test equipment.

SIDE VIEW



TOP VIEW

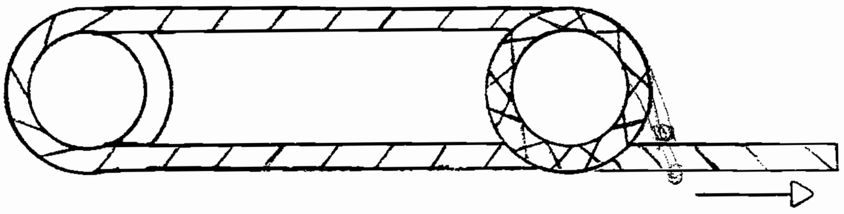


Figure 2

Side and top view of the tieback rigging configuration without the test equipment.

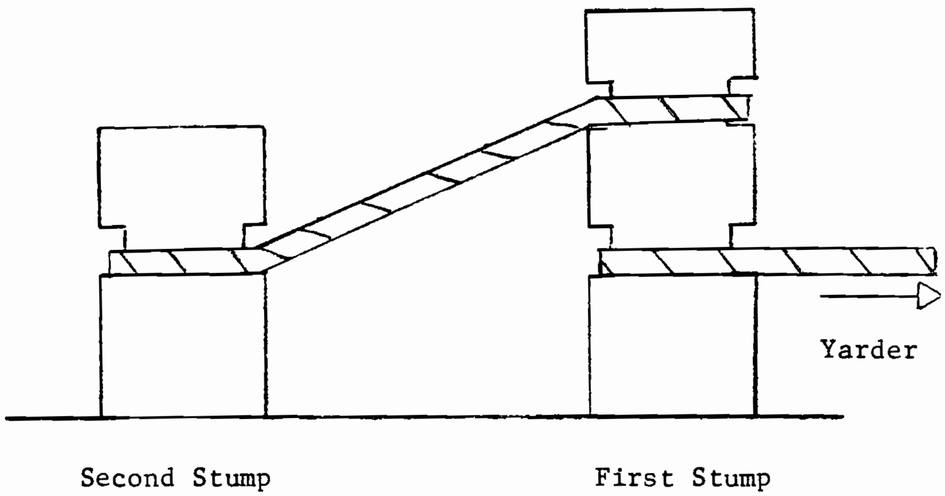
3. Elevated Tieback Anchor

The elevated tieback anchor system illustrated in Figure 3, is a variation of the tieback configuration. The only difference is the point of attachment of the tieback line on the first stump. It is fastened to the first stump higher than where the skyline is attached. This configuration was considered because of the possibility that its use might increase the portion of total system load being resisted by the second stump over that of the regular tieback configuration.

4. Equalizer Block Anchor

The equalizer block anchor system consists of an equalizer line that is passed through a block and tied off on either side of it to a stump. The skyline is attached to the block. The two stumps may be in line with the skyline, or there may be an angle between them. If the two stumps, equalizer block, and skyline are not in line, then the load applied to each stump will be larger than if they were in line. Figure 4, from Studier and Binkley (1974) in Cable Logging Systems, illustrates the impact of varying angles between the two stumps. In the figure, if angle B equals zero then the load applied to each stump is one half the skyline load. When angle B equals 60 degrees, the tension in the equalizer line, which is the load on each stump, equals the tension in the skyline. An equalizer block

SIDE VIEW



TOP VIEW

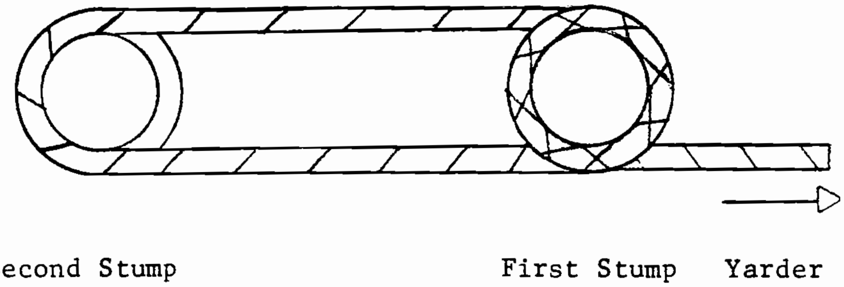


Figure 3

Side and top view of the elevated tieback rigging configuration without the test equipment.

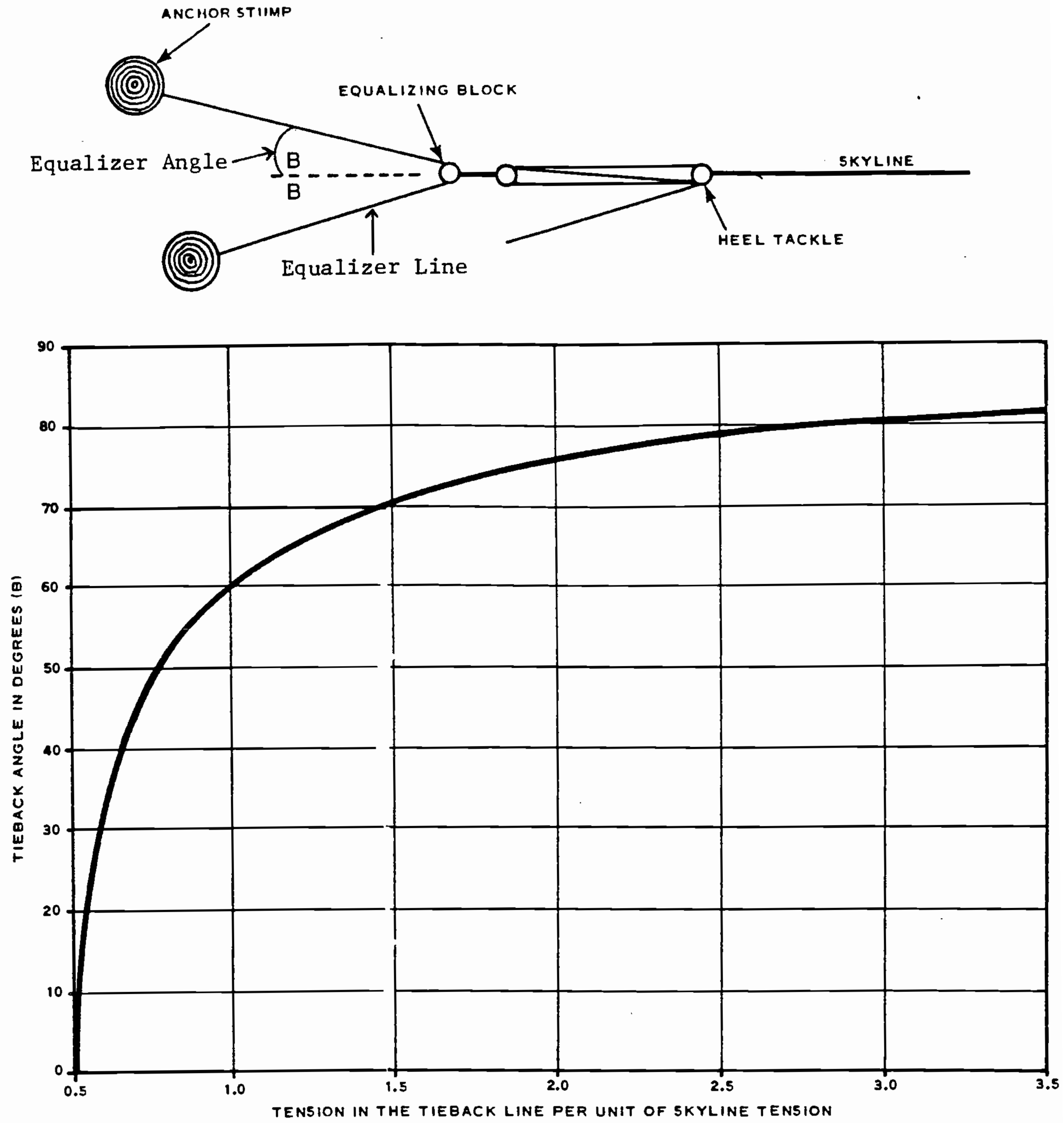


Figure 4

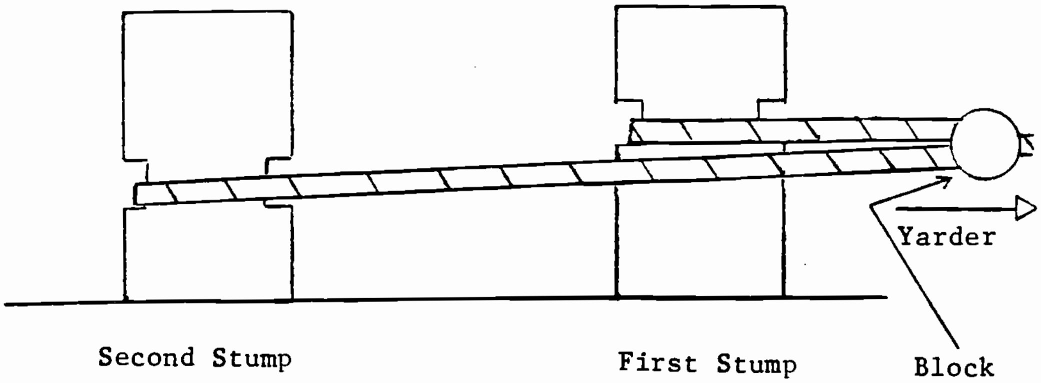
Equalizer line load vs. equalizer line angle B.

Skyline load equals equalizer line load which is the load on each stump when angle B equals 60 degrees. (After Studier and Binkley, 1974) configuration is illustrated in Figure 5. In this study, the stumps, block and skyline were all in line, even though for clarity the figure shows the stumps separated.

C. Study Procedure

The study consisted of two major stages. The first stage was to develop a multiple stump model capable of modeling system load-deformation behavior, the second was to collect data on field tests of the four rigging configurations. Data was collected and analyzed both to determine how load was distributed in each of the rigging configurations, and to evaluate whether or not the model predictions were similar to what might be expected in a real situation.

SIDE VIEW



TOP VIEW

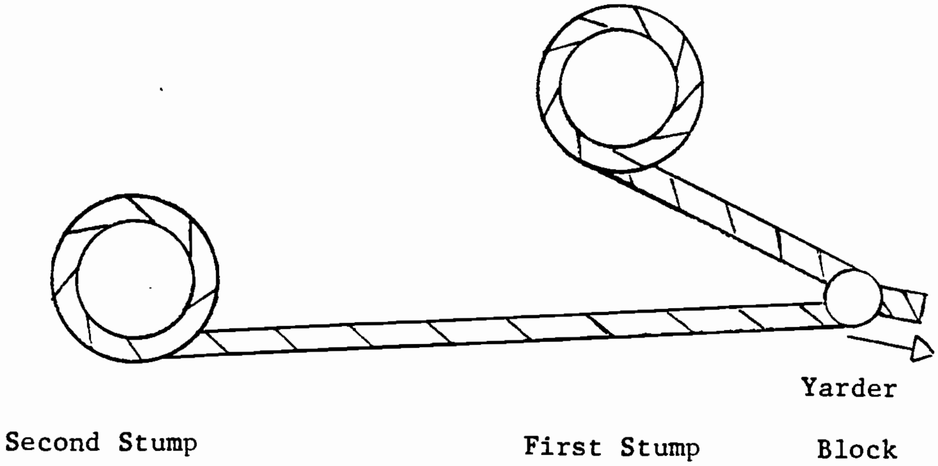


Figure 5

Side and top view of the equalizer block rigging configuration without the test equipment. During the tests, the two stumps and the block were in line.

II. PRESENT KNOWLEDGE ON STUMP LOAD-DEFORMATION BEHAVIOR

The bulk of the information about stumps documented in the published literature deals with the character of stumps and their root systems from the biological or silvicultural perspective. A significant amount of this published work focuses on root system distribution. It is reasonable to expect that information on root system distribution for a stump would be valuable in an attempt to evaluate the capacity of that stump as an anchor. This may well be the case, but it does not increase the ability to assess the anchor capacity of stumps used in cable logging systems. Practical assessment of stump anchor capacity must be based on above ground measurements of the tree because it is difficult to know the actual distribution and strength of roots. Local information about soil type and profile are only partially useful for the prediction of stump anchor capacity because soil characteristics are not easily related to stump strength. Published information on stump anchor capacity and behavior, and particularly information relating capacity and behavior to above ground measurements is limited to a few items. Four sources are presented in this paper.

In a discussion of Pestal's work, in the Symposium on forest operations in mountainous regions (1973), there is an equation for determining the resisting capacity of an anchor tree.

$$S_{max} = D^2/3 \qquad (1)$$

The term anchor tree is used rather than stump. S_{max} is defined as the maximum possible tension in the skyline in metric tons when fastened without torsion at ground level. D is the diameter of the tree in decimeters at a height of 1.3 meters above the ground. The significance of exceeding S_{max} is not clear from the presentation of Pestal's work. It is not clear whether or not S_{max} is an ultimate capacity or a safe working load. There is no indication of which tree species the equation was developed to represent, although it was stated that the resistance of anchor trees is variable and depends on tree species, ground conditions, and slope.

Studier and Binkley (1974) in Cable Logging Systems, present a discussion which states that the stump anchor holding power varies approximately with the square of the stump diameter. To use this relationship to evaluate stump strength, it is necessary to know the ultimate strength of at least one stump. Ultimate stump strength from the perspective of the person using the stump as an anchor can be defined as the maximum load the stump can resist before its displacement is considered unacceptable by the user. Other stump strengths are related to the known stump strength by the square of their diameters. Studier and Binkley also present a discussion of series multiple and tieback anchor systems. They state that one third of the skyline tension is passed to the second stump in a series multiple anchor system. In the discussion of tieback systems, the analysis is limited to a force balance on the first stump with the assumption that one half of the horizontal component of skyline load is passed to the second stump.

Kimbell conducted research on multiple stump anchors with a series multiple rigging configuration (1981). In each of her anchor sets, the incoming line was wrapped 360 degrees around the notched first stump, then wrapped in a notch around the second stump and tied off on itself. Kimbell concluded from measurements that the ratio of incoming line tension to outgoing line tension on the front stump was approximately 9 to 1; but did vary from about 1.6 to 1 to about 12 to 1 when a regression equation was used in which stump diameter, coefficient of static friction, and incoming load were varied. Kimbell attempted to vary the coefficient of static friction by changing cable diameters.

Stoupa conducted research on single stump anchor systems (1984). Her objectives were to develop a set of empirical equations that could be used to predict response and load carrying capabilities of single stump anchors. Stoupa's equations are regression equations developed from her field data. Stoupa's field procedure included measuring movement of the test stumps in response to measured applied loads. The movement observed was predominantly rotational, but empirical equations were developed for both rotation and translational displacements. The translational displacement equations relate applied load to horizontal movement at a height of one foot above the ground surface. This height was selected as an approximation of a commonly used rigging height on stumps.

Before Stoupa's model can be used to relate stump displacement to applied load, it is necessary to determine two parameters; ultimate load, and normal load, Ax. After these two values are determined, loads are calculated for varying displacements. Stoupa also presented an equation for the depth below the stump to its point of rotation.

Stoupa used the following equation to predict the ultimate load a stump anchor could withstand.

$$\text{Ultimate Load} = 260.19\ (\text{stump diameter})^{1.99} \qquad (2)$$

Diameter is expressed in inches and ultimate load in pounds. In Stoupa's work, ultimate load coincided with the breaking of most small roots and some large roots on the opposite side of the stump from the direction of pull. In addition, the stump rootball was becoming defined when the stump reached its ultimate load.

Stoupa presents an equation which relates the load that causes one inch of displacement at one foot above the ground surface to stump diameter.

$$Ax = 150.91\ (\text{Stump Diameter})^{2.05} \qquad (3)$$

Ax is the normal load expressed in pounds and stump diameter is expressed in inches. Stoupa decided to use one inch of displacement after developing several load deformation curves relating horizontal stump movement to load. She observed that the transition zone between the straight line and curved portions of the load-deformation curves varied from 0.75 to 1.5 inches with an average of about 1 inch.

In order to relate applied load L in pounds, and displacement X in inches, at one foot above the ground, Stoupa presents the following equation.

$$L = 0.99\ Ax\ (X)^{0.49} \qquad (4)$$

When load is applied to a stump parallel to the ground surface, the stump displaces by rotating about a point some distance below the ground surface. Stoupa developed an equation to describe this depth below the ground surface in which depth and stump diameter are expressed in inches.

$$\text{Depth} = 2.19\ (\text{stump diameter})^{1.28} \qquad (5)$$

Stoupa's model can be used to construct load-deformation curves for single stumps. A load-deformation curve is a way of relating applied loads on the stump to its displacement.

III. MULTIPLE STUMP MODEL

The practical result of a multiple stump model is a prediction of a safe working load for the anchor system. Criteria for determining this safe working load are not currently available, and their development was beyond the scope of this project. These criteria should be based on the load-deformation behavior of the multiple stump anchor system. To facilitate the development of these criteria, the final result for the multiple stump model presented here consists of a set of empirical equations that can be used to predict multiple stump anchor system load-deformation behavior.

Behavior of the individual stumps in a multiple stump system is a function of the linkage between them. The linkage is the means for applying load, and through the linkage stiffness and response to load, it also controls displacement of the individual stumps. The total load resisted by the system is the sum of the load on each stump. Since individual stump loads are related and together form the system load, and displacements also are related, it is possible to combine two single stump models to form a multiple stump model.

The nature of the linkage between the two stumps determines how the single stump models are combined. The linkage in the series multiple and the two tieback systems is represented by a single rigid line in the model, even though in reality there may be more than one line for the two tieback systems. The linkage between the two stumps for the equalizer block system is a rigid line attached to one stump which then passes through an equalizer block and is attached to the next stump.

For the series multiple and tieback configurations, the first stump displacement at the rigging height is the same as the second stump displacement since the link between the stumps is assumed to be rigid. For the elevated tieback configuration, the first stump displacement at the skyline rigging height is less than the second stump displacement. The skyline is attached to the first stump lower than the point of linkage attachment. The linkage is still assumed to be rigid, so the displacement of the linkage attachment point on the first stump is approximately equal to the second stump displacement at the linkage attachment point (Figure 6). The displacements are not exactly equal because the linkage is no longer horizontal as it is in the regular tieback system, but is now inclined at a small angle.

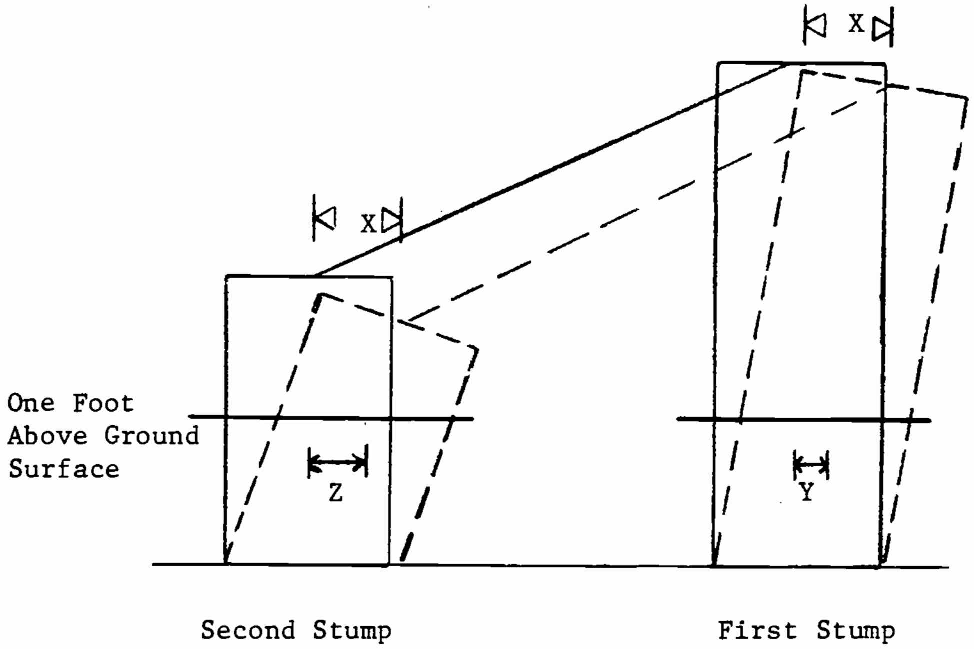


Figure 6

Schematic illustration of the difference between displacement at one foot height for the first and second stumps with the elevated tieback configuration.

X is the displacement of the linkage attachment point on each stump.

Y is the displacement of the first stump.

Z is the displacement of the second stump.

Calculation of elevated tieback displacement is illustrated in Figure 7. As shown in Figure 7, all displacements are related by similar triangles. To determine Y, it is first necessary to find the depth of the point about which the stump rotates when load is applied (equation 5).

System displacement for all multiple stump anchor configurations is skyline displacement. This provides for a common basis for comparison of the four configurations. For the series multiple, tieback, and elevated tieback configurations, the skyline displacement is equal to first stump displacement. Displacement of the equalizer block system is the displacement of the block which is the average of the two individual stump displacements.

System load is the sum of the load on each stump for all rigging configurations.

Stoupa's single stump model is used to calculate load-deformation curves for each stump. This is done by calculating the loads for increasing displacements for the series multiple, tieback and elevated tieback configurations, and by calculating displacements for increasing loads for the equalizer block system. The load-deformation curves for the individual stumps are added together to form a load-deformation curve for the two stump system. In Stoupa's model all displacements occur at one foot above the ground level. Since the multiple stump model is based on

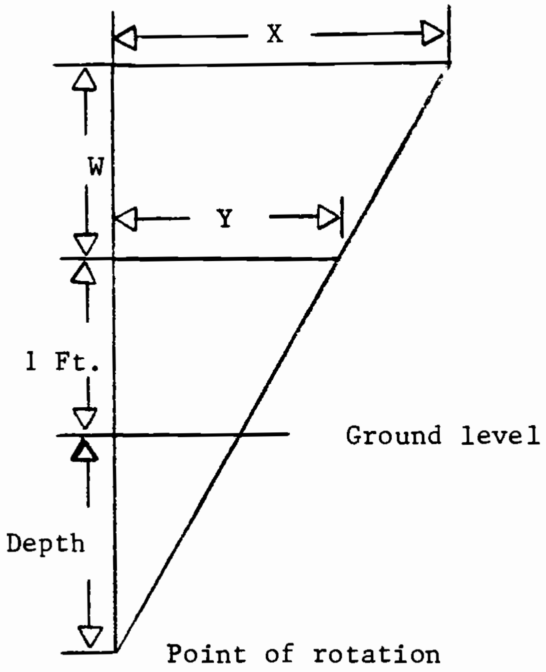


Figure 7

Illustration of the solution procedure for the determination of first stump displacement at one foot height given displacement of the linkage attachment point for the elevated tieback configuration.

X = Displacement of the first stump at the point of linkage line attachment.

W = Height in inches above one foot above ground level.

Depth = Distance below the ground level to the stump point of rotation.

$Y = (X(\text{Depth} + 12)) / (\text{Depth} + 12 + W)$

Stoupa's model, all displacements included in load-deformation curves in this paper occur at one foot above the ground level.

There are a number of approaches that can be used to calculate the load-deformation curve for multiple stump systems within the constraints presented above. The following discussion explains the approach used in this study to develop individual load-deformation curves, and add them together to form a system load-deformation curve. The model uses a slightly different combination approach for each configuration.

A. Series Multiple

1. The ultimate load for both the first and second stump is determined with equation 2.

$$\text{Ultimate Load}_1 = 260.19(\text{stump diameter}_1)^{1.99} \qquad (6)$$

$$\text{Ultimate Load}_2 = 260.19(\text{stump diameter}_2)^{1.99}$$

The subscripts 1 and 2 indicate stump 1 and stump 2. Ultimate loads are expressed in pounds and stump diameters in inches. Within the model the ultimate load is used to determine the endpoint of the load-deformation curve.

2. The normal load (Ax) for each stump is determined with equation 3.

$$Ax_1 = 150.91\ (\text{stump diameter}_1)^{2.05} \qquad (7)$$

$$Ax_2 = 150.91\ (\text{stump diameter}_2)^{2.05}$$

Ax is expressed in pounds and stump diameter in inches.

3. The load corresponding to a given displacement can be determined with equation 4.

$$L_1 = 0.99\ Ax_1\ (X)^{0.49} \qquad (8)$$

$$L_2 = 0.99\ Ax_2\ (X)^{0.49}$$

X is displacement in inches of each stump and L is the load at each displacement in pounds.

Figure 8 illustrates typical individual stump and system load-deformation curves.

B. Tieback and Elevated Tieback

System load-deformation curves are calculated differently for the two tieback configurations than for the series multiple or the equalizer block systems. With the tieback configurations, it is possible to begin with a pretension in the line between the stumps before the yarder applies a load to the system.

If a stump has an initial load on it from a pretension, then it has displaced away from its unloaded position. Prior to loading the stump through increases in skyline tension, its beginning load-deformation characteristics are represented by a point other than zero on the load-

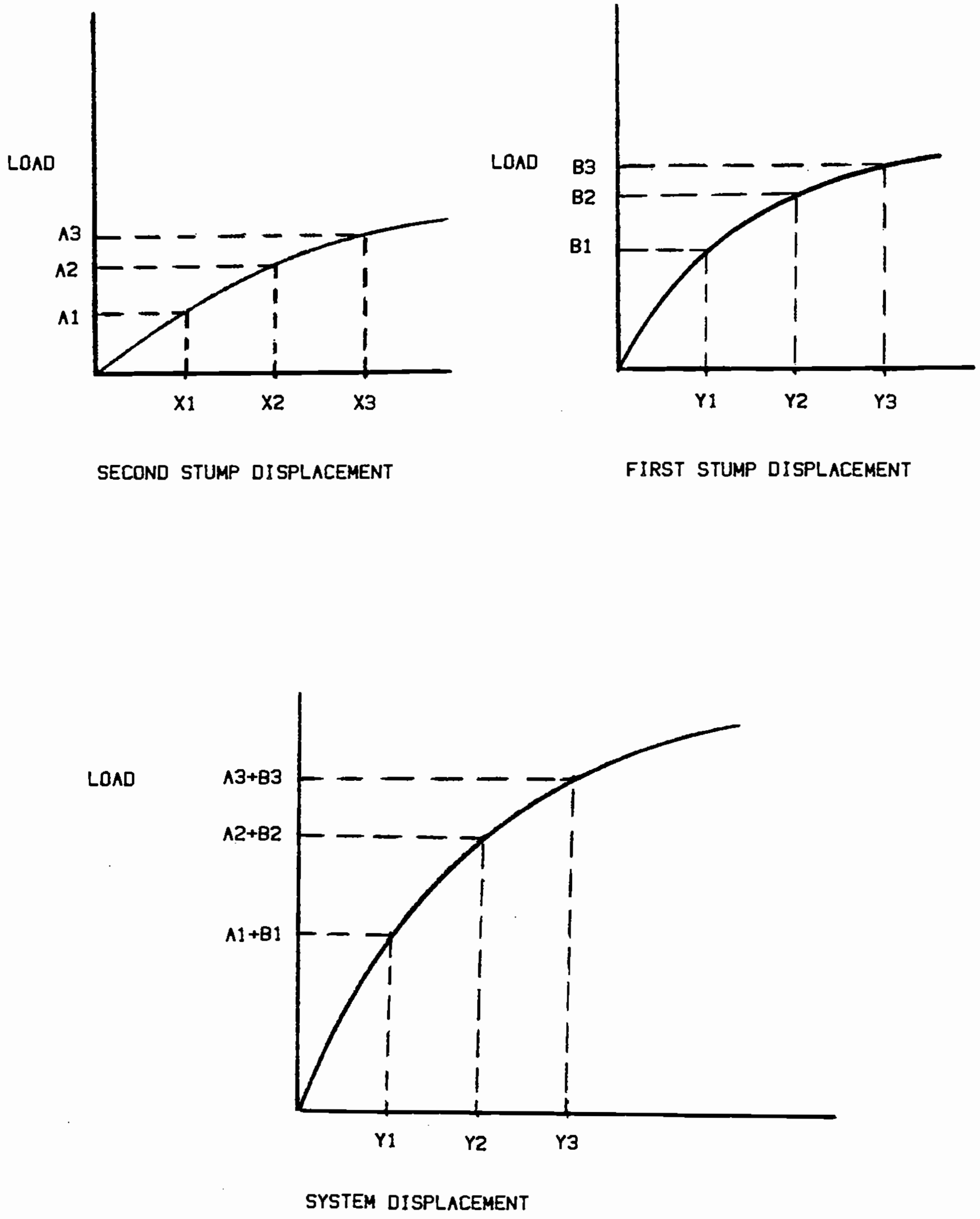


Figure 8

Series multiple individual stump and system load deformation curves. The system load deformation curve is the sum of the individual stump load deformation curves.

deformation curve. If a pretension exists, the initial load and displacement of the first stump is negative--negative only because the load is in a direction opposite to the direction of yarder applied load. The second stump has an initial positive load and displacement on its load-deformation curve because it also has an initial pretension. When the first stump has negative displacement, it has moved toward the second stump. It is assumed that the load-deformation curve for negative loading has the same shape as one for positive loading. If stump resistance to displacement were to vary with direction of pull, possibly due to varying root structure around the stump, the assumption about equal but opposite sign load-deformation curves for loads applied in opposite directions would not be true. Investigation of the influence of rooting structure on stump load-deformation characteristics was beyond the scope of this study. Figure 9 illustrates the shape of equal positive and negative load-deformation curves.

To construct the system load-deformation curve, the following procedure was followed.

1. The first and second stump ultimate loads are determined with equation 2.

   $\text{Ultimate Load}_1 = 260.19\ (\text{stump diameter}_1)^{1.99}$

   $\text{Ultimate Load}_2 = 260.19\ (\text{stump diameter}_2)^{1.99}$

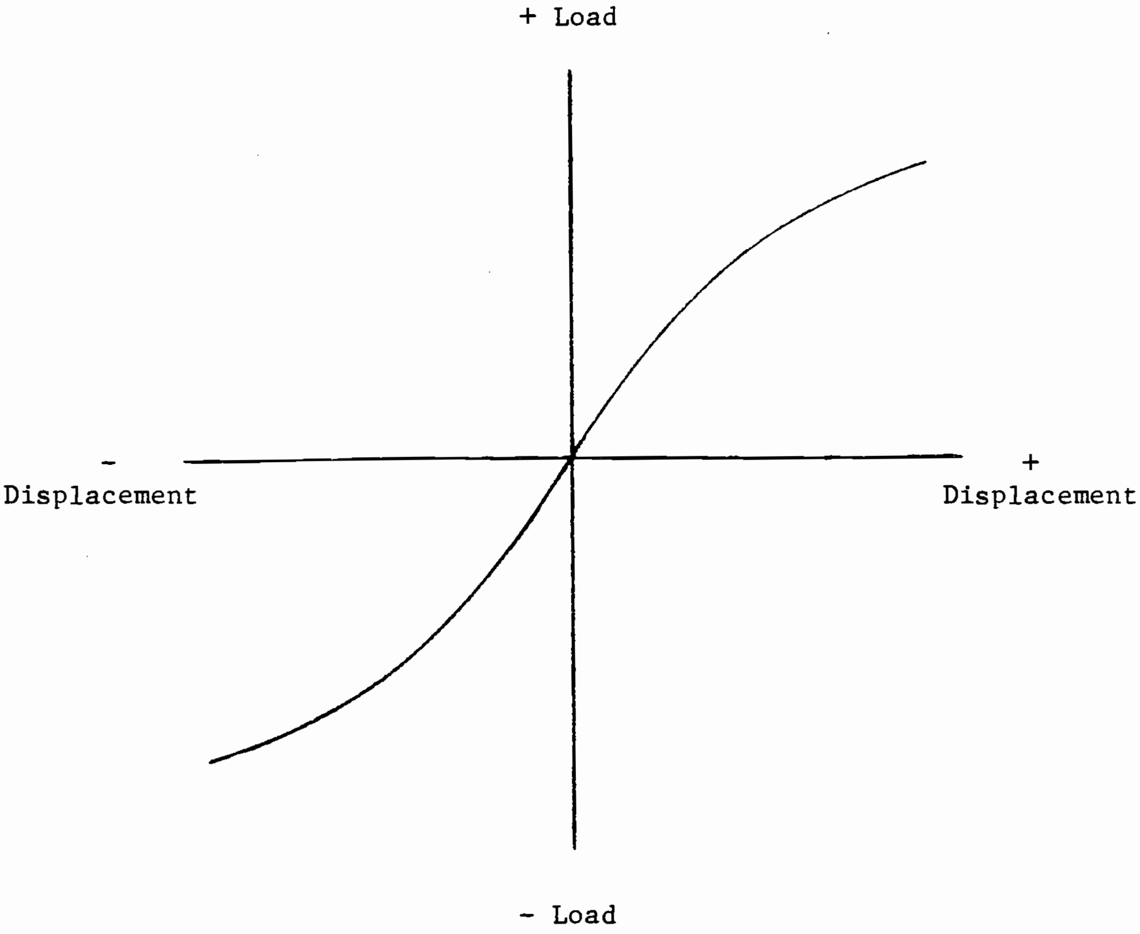


Figure 9

First stump positive and negative load deformation curves.

2. The normal load (Ax) for each stump is determined with equation 3.

   $Ax_1 = 150.91\ (\text{stump diameter}_1)^{2.05}$

   $Ax_2 = 150.19\ (\text{stump diameter}_2)^{2.05}$

3. The initial displacement for both stumps is determined with equation 9 for the first stump and 10 for the second stump. Pretension is expressed in pounds and is initially negative for the first stump and positive for the second stump. X_1 is first stump displacement, X_2 is second stump displacement, both in inches.

   $$X_{1\ \text{initial}} = -((\text{ABS}(\text{pretension})/Ax_1/.99)^{2.041}) \quad (9)$$

   $$X_{2\ \text{initial}} = (\text{pretension}/Ax_2/.99)^{2.041} \quad (10)$$

   ABS refers to the absolute value of pretension. $X_{1\ \text{initial}}$ and $X_{2\ \text{initial}}$ along with the positive and negative pretension form the beginning points on the individual stump load-deformation curves. The first point on the system load-deformation curve is zero displacement and load. Load is zero because it is the sum of the pretension on both stumps. Displacement is zero because at this stage the skyline has not yet caused the system to displace through load application. Once load is applied, the system load increases from zero, and system displacement, which is displacement of the first stump, increases from zero.

4. The load corresponding to a range of displacements can be determined using variations of equation 4. Selection of the form of equation 4 to use is dependent upon whether or not $X_1 > 0$, $X_1 < 0$, and $X_2 > 0$. The difference between the forms of equation 4 are the displacements X_1 and X_2. One form determines negative load for negative displacement X_1, another form determines positive load for positive displacement X_1. Positive load for positive displacement X_2 is determined with the final form of equation 4.

$$L_1 = -(.99\ Ax_1\ (ABS\ (X_1))^{0.49}\ ),\ X1<0$$
$$L_2 = .99\ Ax_2\ (X2)^{0.49},\ X2>0$$
$$L1 = .99\ Ax_1\ (X_1)^{0.49},\ X1>0$$

System load is the sum of the first and second stump loads. System displacement is first stump displacement.

Figure 10 illustrates typical individual stump and system load-deformation curves for the tieback and elevated tieback systems. Note that the addition of the first and second stump curves produces an "S" shaped system curve. This curve shape illustrates the varying stiffness, or resistance to displacement of the tieback systems over a range of displacements. The curve begins with a shallow slope near the origin of the axes which becomes steeper then shallow again, as the curve moves away from the origin. The

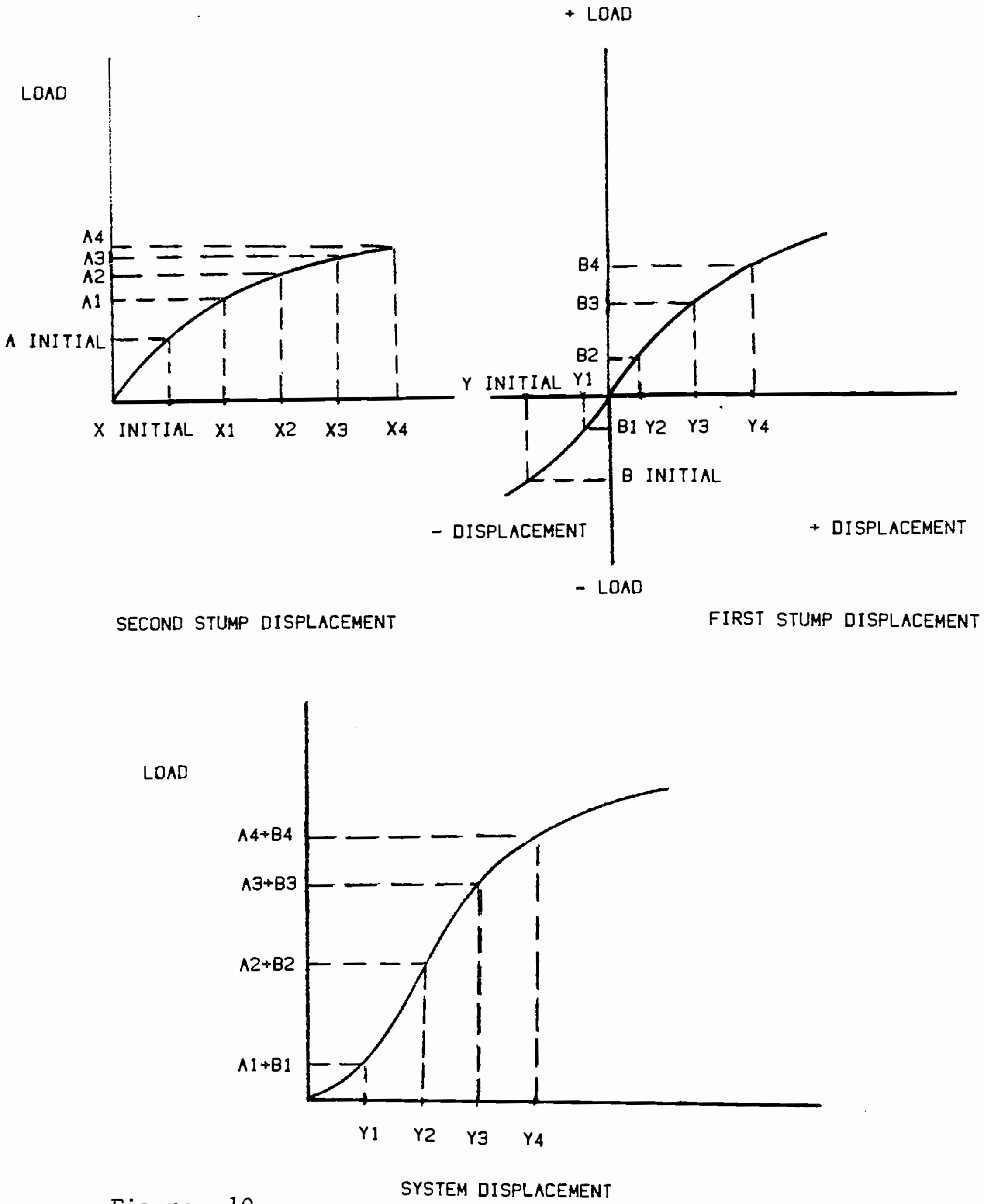


Figure 10

Tieback and elevated tieback individual stump and system load deformation curves. The system load deformation curve is the sum of the individual stump load deformation curves.

other rigging configurations start at the origin with a steep slope which becomes less steep as the curves move away from the origin. This means that the tieback systems are easier to displace when load is initially applied to them than the other systems, but after some initial displacement, their stiffness increases and it becomes more difficult to displace them. Since the first stump is starting with an initial negative load, it does not require any system load to displace back to its zero displacement position. The second stump is starting from a location other than zero on its load-deformation curve, consequently, decreasing increments of load are required to cause the same displacement. The system load required to cause the first increments of system displacement are small. As the first stump moves from negative to positive displacement, the system load required for an increment of displacement becomes larger.

C. Equalizer Block

The model procedures for this configuration are different than those for the other configurations. With this system, stump load is incremented rather than displacement. This approach was used because the load on each stump is the same due to the use of the equalizer block and is one half the skyline load since in the model the stumps and skyline were assumed to be in line. If there were an angle between the stumps from the block, then the load on each stump would be more than half the skyline load as shown in Figure 4. System displacement is the average of both stump displacements.

The procedure for the equalizer block system is as follows:

1. The ultimate load for each stump is determined with equation 2.

   $\text{Ultimate Load}_1 = 260.19\ (\text{Stump diameter}_1)^{1.99}$ (6)

   $\text{Ultimate Load2} = 260.19\ (\text{Stump diameter}_2)^{1.99}$

2. The normal load (Ax) for each stump is determined with equation 3.

   $Ax_1 = 150.91\ (\text{Stump diameter}_1)^{2.05}$ (7)

   $Ax_2 = 150.91\ (\text{Stump diameter}_2)^{2.05}$

3. Displacement for each stump at each load are calculated with equation 11.

$$\text{Displacement}_{1 \text{ or } 2} = (L_{1 \text{ or } 2} / Ax_{1\text{or}2} / 0.99)^{2.041} \qquad (11)$$

Figure 11 illustrates typical individual stump and system load-deformation curves.

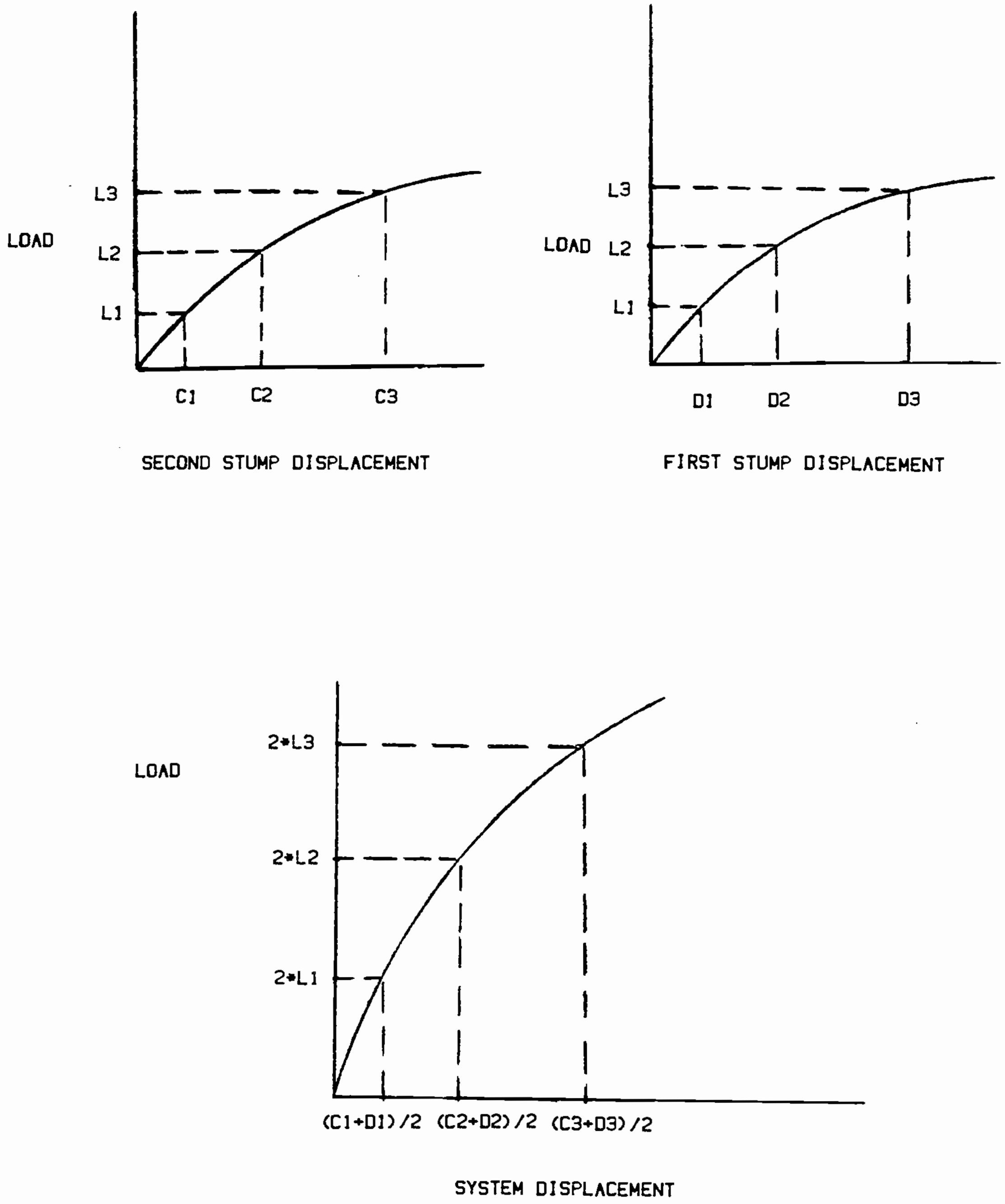


Figure 11

Equalizer block individual stump and system load deformation curves. The system load deformation curve is the sum of the individual stump load deformation curves.

IV. FIELD LOAD TEST PROCEDURE

A. Study Site Description

Trees selected for testing were in a second growth Douglas-fir stand located on the Oregon State University MacDonald Forest northwest of Corvallis, Oregon. A second growth stand with stump diameters less than 20 inches was selected for testing because this is the type of stand where individual stumps may not be capable of providing adequate pull out resistance. Consequently, multiple stump anchor systems are likely to be necessary in this type of stand. The stumps used to test the four rigging configurations ranged in diameter from 10.5 to 18 inches. Average tree height was 90 feet for the eight trees tested.

There were three soil horizons in the test area. The first was an organic layer which was generally less than four inches thick. The second horizon was twenty inches thick and was classified as an MH soil with the Unified Soil Classification System. The third horizon, which lies between 20 and 50 inches in depth was also an MH. The soil is further characterized as being a member of the Price Series which has a basalt parent material from the Siletz River volcanics (Oregon State University 1982-1983).

According to Stoupa, soil water content ranging from 20 to 40 percent in soils classified ML-MH with the Unified Soil Classification System showed little correlation with the maximum load a stump was able to resist. If the range in water content is larger, then soil water content may influence stump capacity.

Because data collection was to be completed during a short period in August 1984, it was decided that the potential range in soil moisture was small. Consequently, the likely influence of soil moisture on the project results was believed to be small. Soil moisture data was not collected.

In order to develop general parameters that describe load-deformation behavior for a range of stump diameters within the study area, each rigging configuration needs to be tested on its own stump set throughout the range of stump diameters. The testing of one configuration per stump set as opposed to all four per set eliminates the influence of one test on another. If the diameter range of interest is 10 to 20 inches which is a common range for second growth Douglas-fir, and if it were desired to measure load-deformation behavior at every two inch diameter class for each of the four rigging configurations, then 24 tests on 24 sets of two stumps would have been required. It took approximately one full day to run all four tests on one stump set, with most of the time being spent rigging the system. Consequently, running one test per stump set is likely to also take almost a full day. Time was not available for this type of testing so the option of nondestructive testing of all four configurations on each stump set was selected. In principle, nondestructive testing can done by limiting loads to the elastic range. Load tests were conducted on four two stump systems.

Stump diameters and positions were as follows:

TABLE 1. Stump diameter and positions

Stump Set	1st Stump Diameter (in)	2nd Stump Diameter (in)
1	12.7	12.2
2	14.3	12.9
3	10.5	10.5
4	14.2	18.0

B. Data Collection Equipment

The load and deformation measurements were made using computer driven electronic equipment. Displacements were measured with four Celesco Pt - 101 variable resistance displacement transducers, which were read to the nearest 1/100 inch. A 100 kip and a 20 kip load cell were used to measure loads applied to the stump anchors. The load cells were accurate to 300 pounds and 30 pounds respectively. A

Hewlett-Packard 3421A Data Acquisition and Control Unit was used to read the two displacement transducers per stump and the two load cells. It was programmed to read the six instruments every 15 seconds. The data was received and stored by a portable computer. A Validyne transducer amplifier was used to:

1. Zero the load cells.
2. Scale the load cell readings and amplify them so that they could be recorded.

The Validyne also provided a power source for the displacement transducers.

A Skagit B20F yarder was used to apply load to the anchor system through a block purchase of either 7:1 or 14:1 depending on the rigging configuration.

The anchor system loading and data collection procedure was as follows. Throughout the data collection, after every change in yarder applied load, five sets of readings were taken. Five sets were measured so that any time dependent displacement or load relaxation could be evaluated. For example, after loading stopped the lines and other rigging hardware could respond to the increased tension by time dependent stretching and creep through the rigging system. Also after a load increase, the stump rootball system may creep as roots break and soil shears at constant load. The five measurements spaced at 15 second intervals, and recorded after every load increase, provided for an assessment of time dependent behavior.

The data acquisition unit made five initial readings of the six instruments spaced at 15 second intervals. This was done to establish an initial zero reading. The process of increasing the load on the system followed by the recording of five sets of measurements to assess creep was repeated until the upper displacement transducer registered 0.25 inches of movement on either of the stumps. In an effort to nondestructively sample the stumps, the upper limit of 0.25 inches on the upper displacement transducer was selected as a means of protecting the stump from permanent displacement. This number was an estimate based on Stoupa's published load-deformation curves for single stumps. It turned out that some permanent displacement did occur even with the use of this upper displacement limit.

Initially, load-deformation curves were plotted for all the data including the five sets of recordings at each load level. Figure 12 illustrates a load-deformation diagram which includes the data from all five sets of measurements at each load level. Note that the shape of the curve would not change much if either the first or fifth set of data for each increment of load would have been used to plot the data. In addition, it is not known which of the first or fifth points gives a more accurate view of the load-

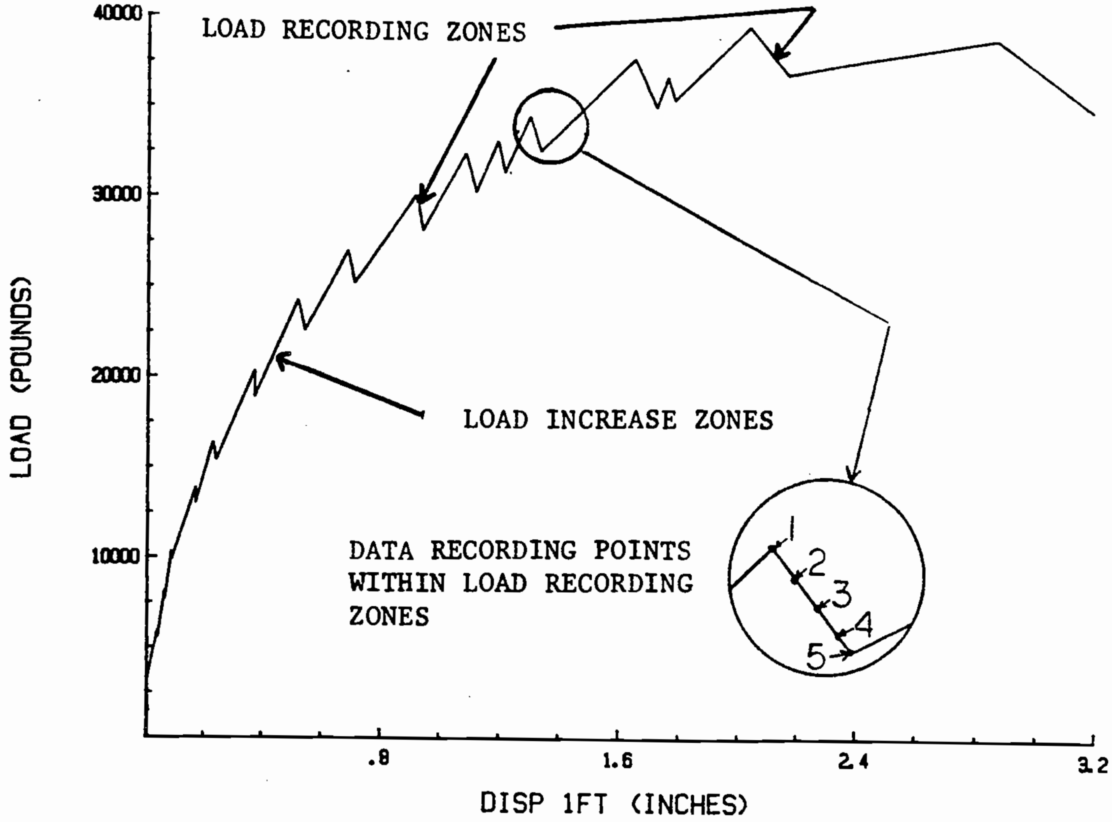


Figure 12

Illustration of the loading and recording sequence for the second stump of set three pull to failure test (stump 7).

deformation characteristics of the anchor system. The influence of rigging hardware stretch may make the use of one or the other of the two points less representative of the actual stump behavior depending on when the stretch occurs after each load increase. The first set was selected for use throughout this analysis. The results of this analysis would not differ much if the fifth set would have been used. The difference between the first and fifth sets typically was less than 10%.

Recording periods are illustrated on Figure 12. For the lower loads, the vertical lines indicate that the displacement was not changing when loading was stopped. Load did decrease during the recording phase however because the rigging lines and hardware were stretching and slack was working out of the system. At this stage, the load on the stumps was small enough so that they did not continue to displace after loading was stopped. At higher loads this vertical line segment developed a negative slope indicating that the stump displaced after loading stopped even as the load decreased slightly. The reason for this is that the stump was subjected to loads high enough to cause the roots to continue to break and the soil to shear even when no further load application occurred.

The preceding paragraphs describe the data collection procedure for the equalizer block configuration. The procedure for the other configurations differ from that of the equalizer block system in one way. More than one cycle of loading was applied to the series multiple and the two tieback configurations. Between each of these cycles the tension in the line between the stumps was changed. For the two tieback configurations, the tension was changed with a turnbuckle in the rigging between the two stumps. For the series multiple system, the tension in the line between the stumps after a cycle was higher than before a cycle because the skyline traveled around the first stump during loading causing an increase in tension between the two stumps. When skyline load was removed, the tension between the stumps did not completely relax because the skyline had crushed into the wood and was not free to move backwards. Testing these three configurations in cycles provided a means for assessing the effect of changing the tension between the stumps.

C. Description of Rigging Used for Data Collection

During data collection, three classes of information were collected for each load point; system load with the 100 kip load cell; load between the two stumps with the 20 kip load cell; and stump displacement. When a stump displaces in response to applied load, it actually rotates about a point below the ground surface (Stoupa 1984). Stump displacement at any height above its point of rotation is then the distance it moves through an arc at that height. Since the amount of displacement is small, it is approximated with line segments. The line segment and the distance to the point of rotation form two legs of a right triangle. If displacement is measured at two heights, then displacement at one foot height can be determined through the solution of the similar triangles. The heights used were typically about three feet and six feet.

The two heights used for displacement measurement were set on a vertical pole mounted on top of each stump. Attached to each of these poles at the measurement heights were two lines which ran horizontally to a reference tower outside of the anchor system. On this tower, each line was attached to a displacement transducer. The four displacement transducers were connected to the Data Acquisition Unit.

To measure loads, the 100 kip load cell was placed in the wire rope line between the 7:1 or 14:1 block purchase and the first stump. The 20 kip load cell was placed in the wire rope line between the two stumps. With the two tieback configurations, there were two lines connected through a block between the two stumps.

The diagram in Figure 13 illustrates a detailed side view of the data collection rigging configuration. Figure 14 illustrates the top and side view of the series multiple configuration, Figure 15 the tieback configuration, Figure 16 the elevated tieback configuration, and Figure 17 the equalizer block configuration.

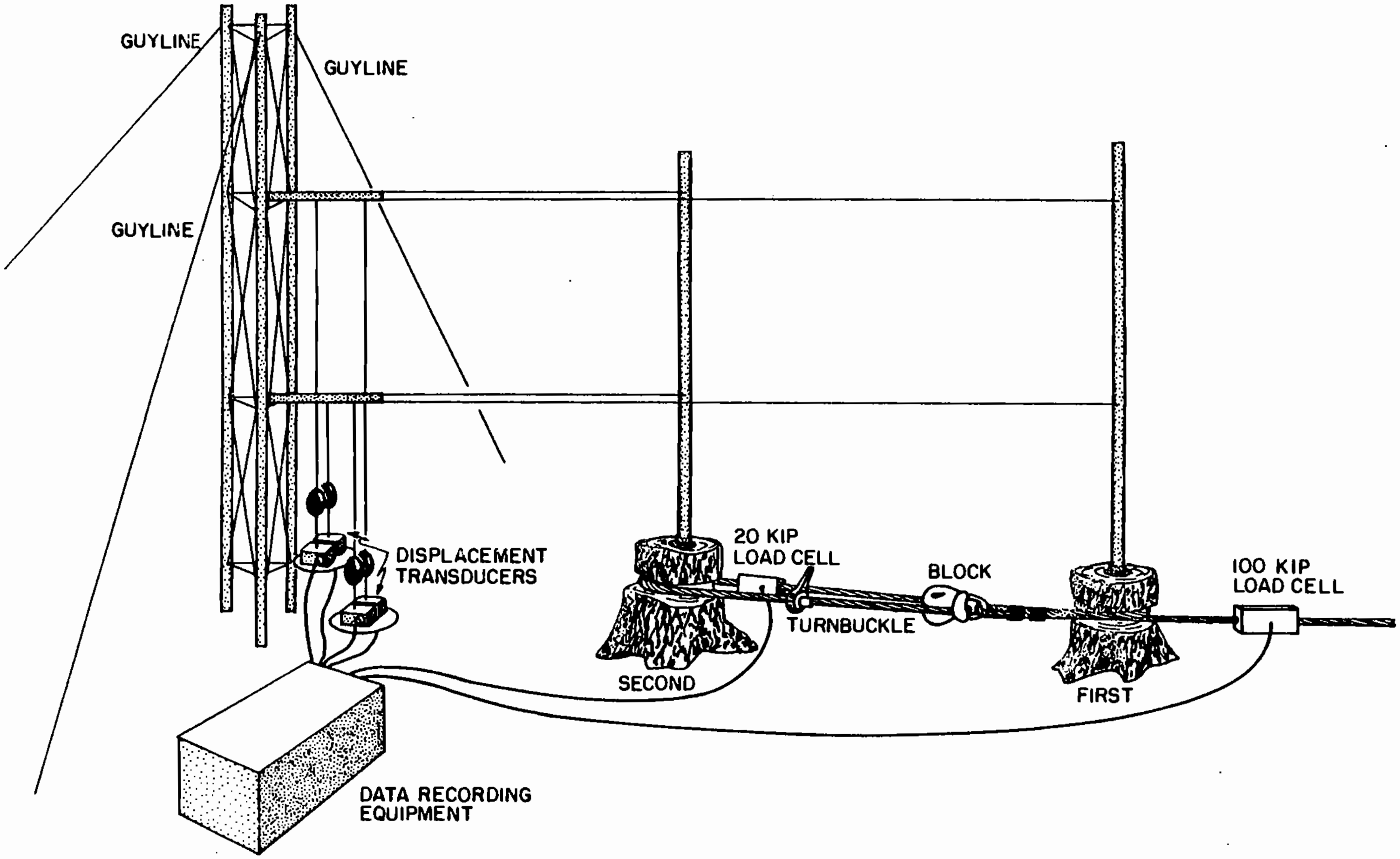
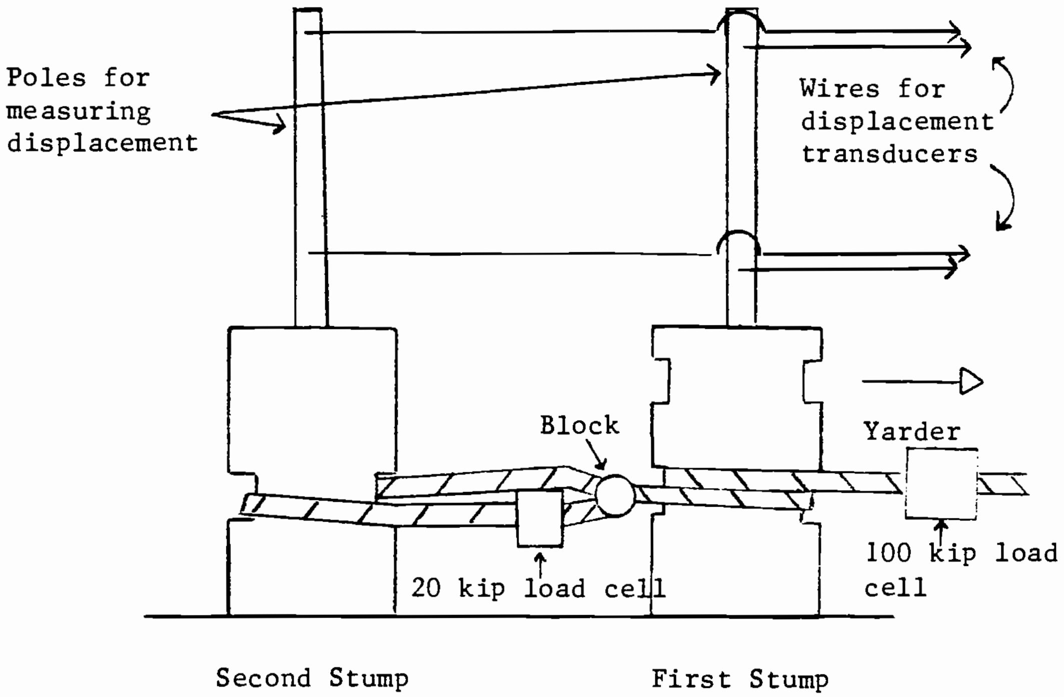


Figure 13

Side view of the data collection rigging configuration for the series multiple system.

SIDE VIEW



TOP VIEW

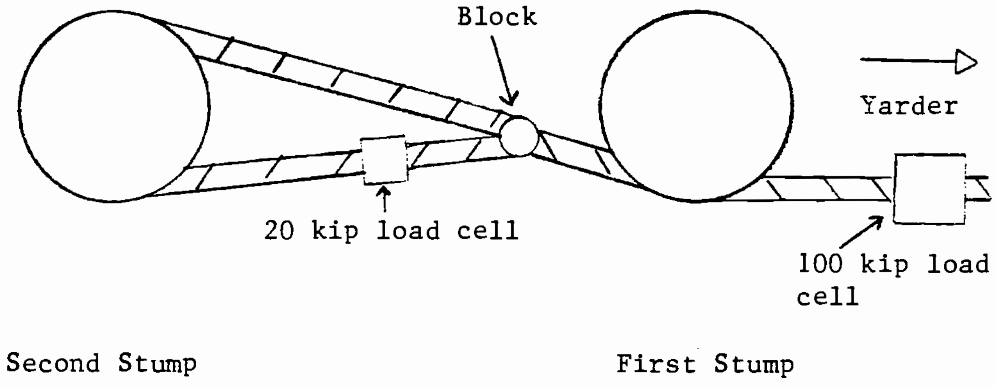


Figure 14

Schematic diagram of the data collection rigging configuration for the series multiple configuration.

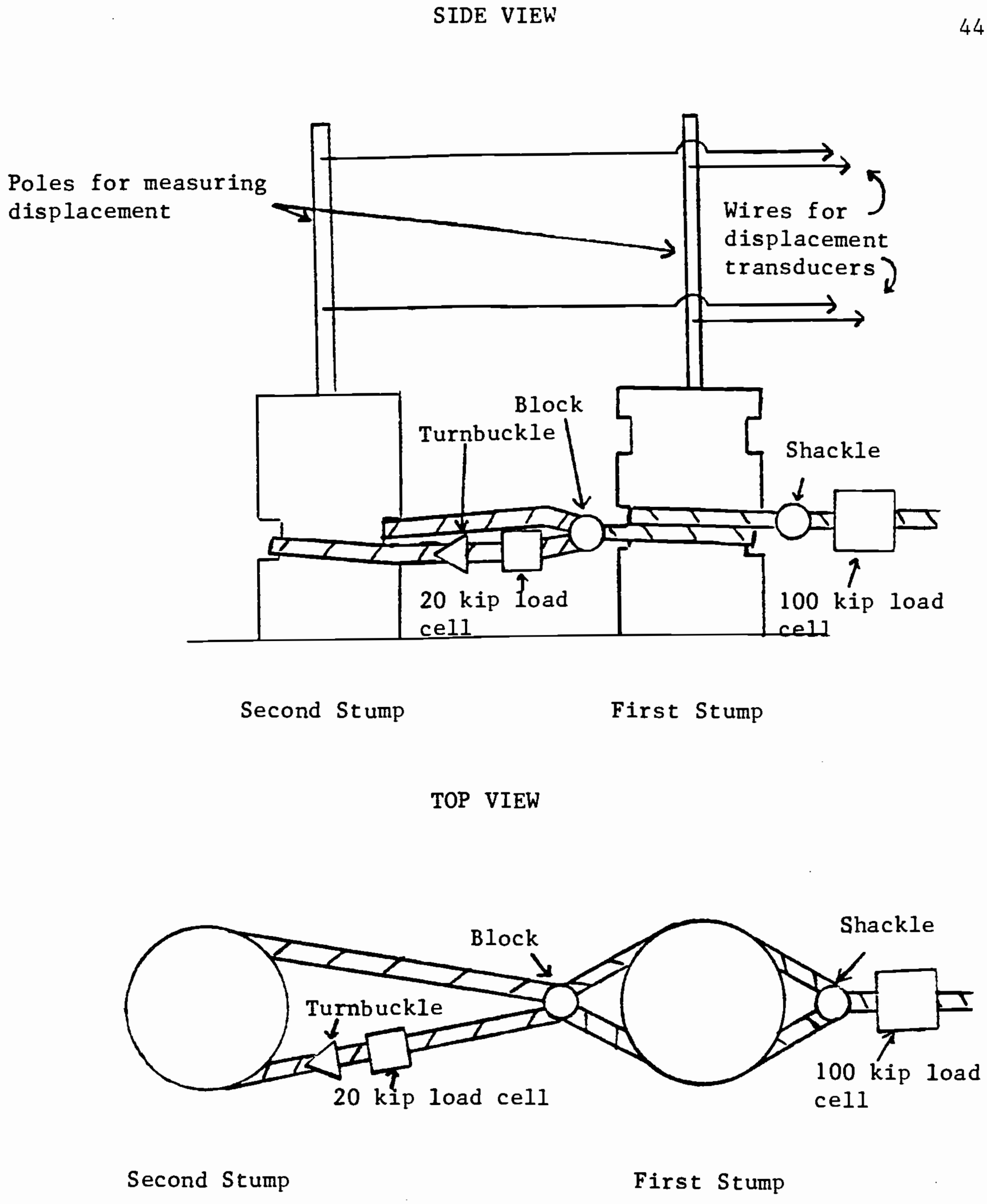
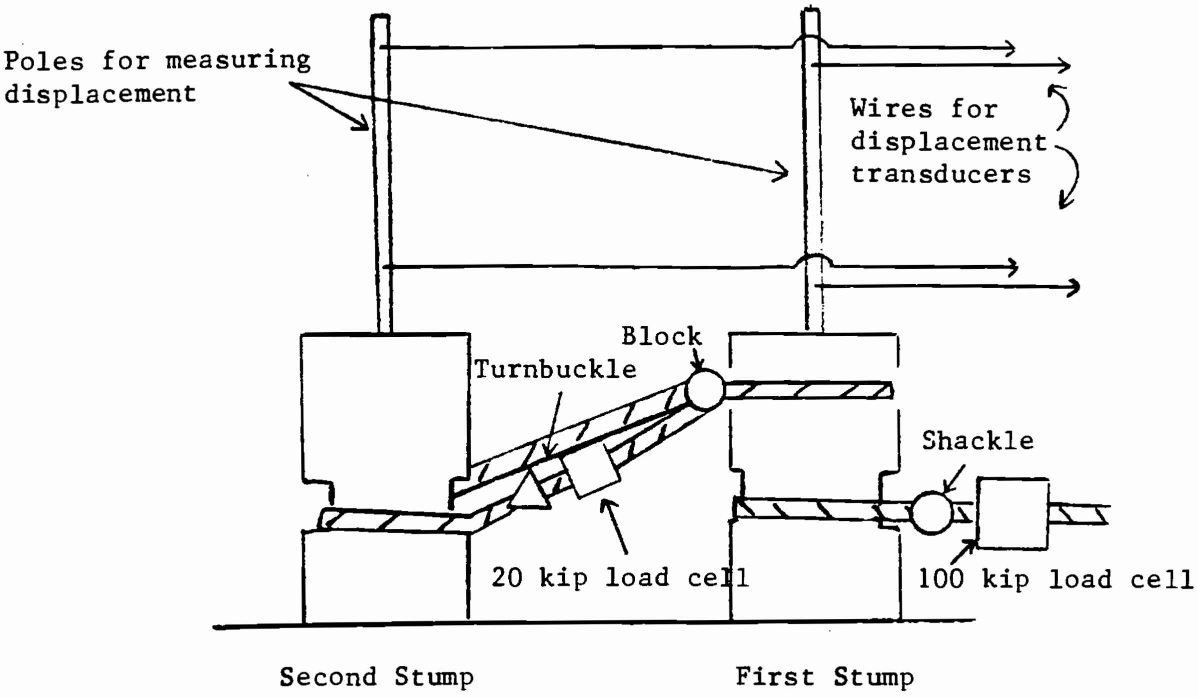


Figure 15

Schematic diagram of the data collection rigging configuration for the tieback configuration.

SIDE VIEW



TOP VIEW

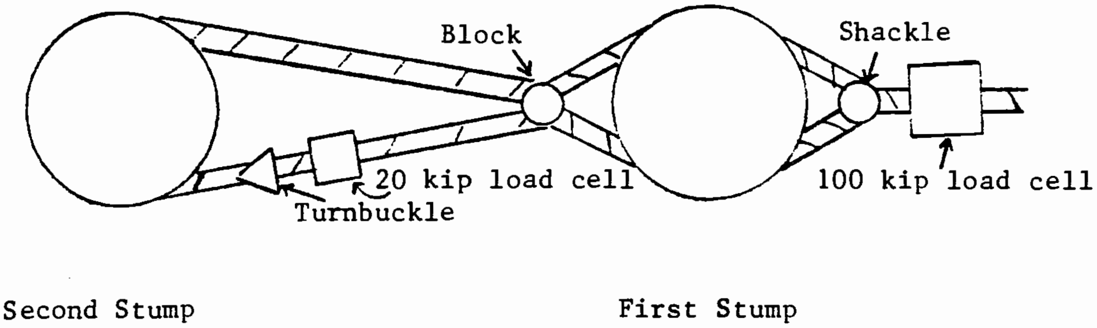
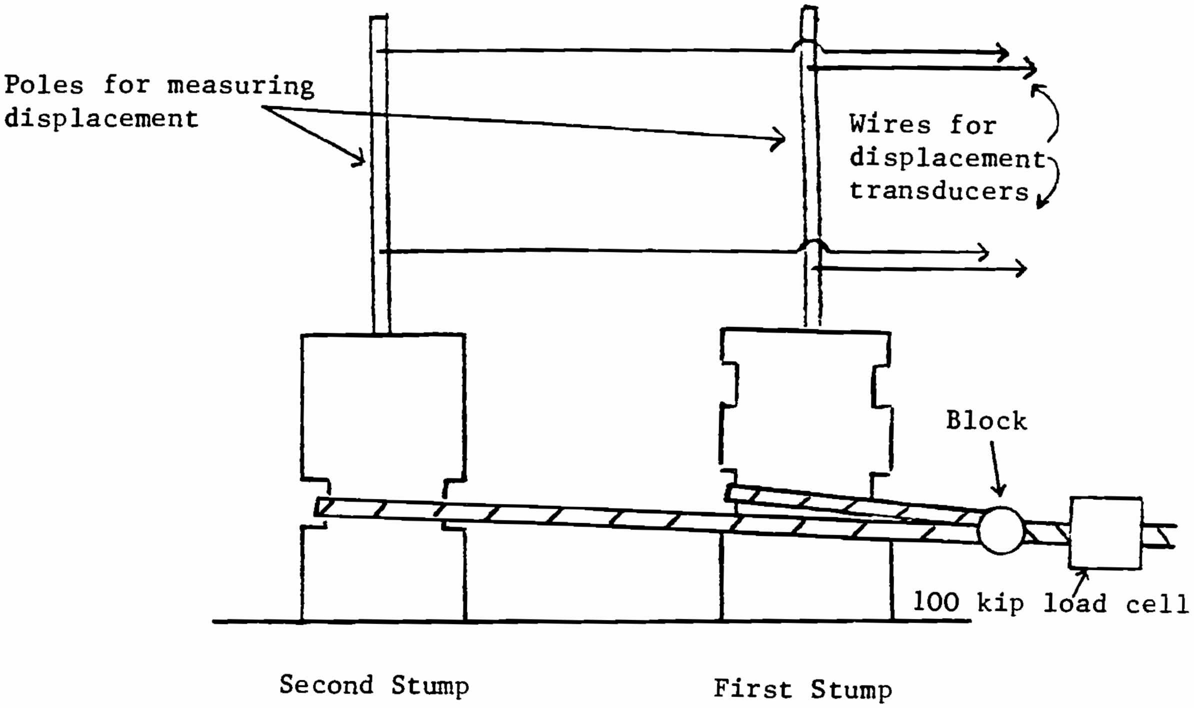


Figure 16

Schematic diagram of the data collection rigging configuration for the elevated tieback configuration.

SIDE VIEW



TOP VIEW

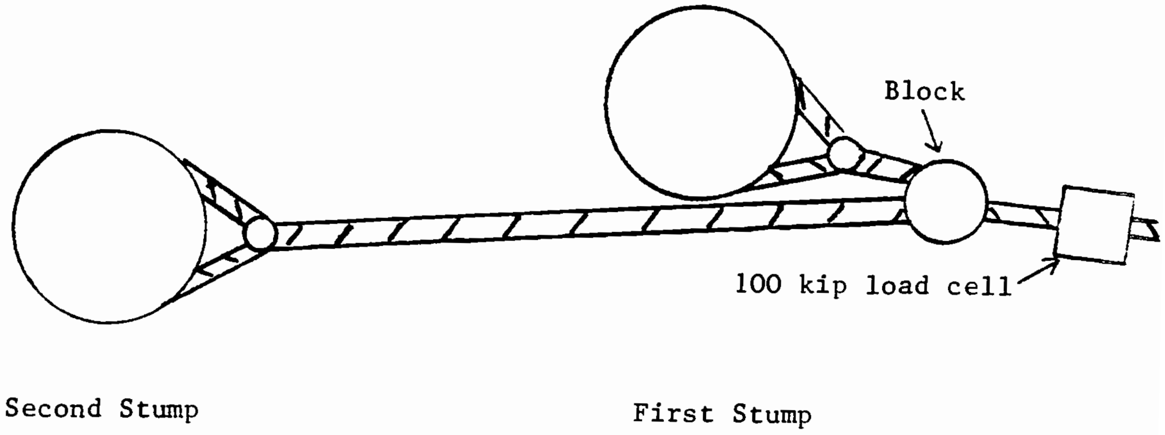


Figure 17

Schematic diagram of the data collection rigging configuration for the equalizer block configuration.

The testing order was: stump set 1 - series multiple, equalizer block, tieback, and elevated tieback; stump sets 2, 3, and 4 - equalizer block, tieback, elevated tieback, and series multiple.

Following the multiple stump tests, both stumps of anchor set four and the second stump of anchor set three were pulled until they failed. This was conducted in separate tests in order to construct the entire load-deformation curves for these three stumps.

D. Analysis

The procedure displayed in Figure 18 was used to determine stump and system displacement at one foot above the ground.

For the series multiple, tieback, and elevated tieback systems, the 100 kip load cell was located between the first stump and the yarder, and measured total system load. The 20 kip load cell, located between the two stumps, measured second stump load. First stump load was system load minus second stump load. The 100 kip load cell was the only load cell used in the equalizer block system, and was located between the block and the yarder. First and second stump loads were one half the system load since the stumps, block, and yarder were in line.

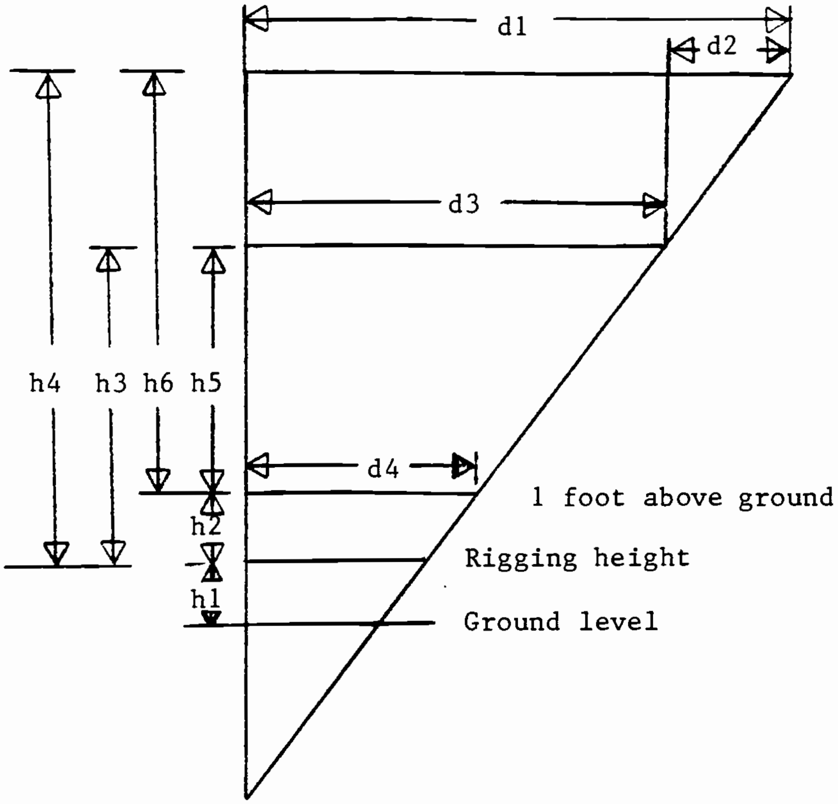


Figure 18

Diagram of geometry used to determine displacement at one foot above the ground surface, and the solution procedure.

h1 = Distance from ground level to rigging height.
h2 = Distance from rigging height to height of one foot above the ground surface.
h3 = Distance from rigging height to lower horizontal wire.
h4 = Distance from rigging height to upper horizontal wire.
h5 = Distance from 1 foot above ground surface to lower horizontal wire.
h6 = Distance from 1 foot above ground surface to upper horizontal wire.
d1 = Horizontal displacement of top wire point from initial position.
d2 = Difference in horizontal displacement between upper and lower wire points.
d3 = Horizontal displacement of lower wire point from initial position.
d4 = Horizontal displacement at one foot above ground surface.

Displacement determination procedure:

1. $d2 = d1 - d3$
2. $h2 = 1 - h1$
3. $h5 = h3 - h2$
4. $h6 = h4 - h2$
5. $d4 = d3 - (d2 \times h5 / (h6 - h5))$

Figure 19 illustrates a side view of the elevated tieback configuration. Loads were measured with the 20 kip load cell on the diagonal line between the two stumps. This force, which causes stump rotation, can be broken into its horizontal and vertical components. Since the diagonal line is inclined at a small angle, the vertical component of the diagonal force is very small in comparison to the horizontal force. The horizontal component is determined with equation 12.

$$HL = \text{Cos}\ (\text{Arctan}\ (h/D)) * (\text{20 kip load cell reading}) \qquad (12)$$

Where HL is the horizontal component of the load in the inclined line between the two stumps, and h and D are as shown in Figure 19.

HL is the load on the second stump. To determine the load on the first stump, HL is subtracted from the system load.

System displacement is first stump displacement for all rigging configurations except the equalizer block system. System displacement for the equalizer block configuration is the average of the first and second stump displacements.

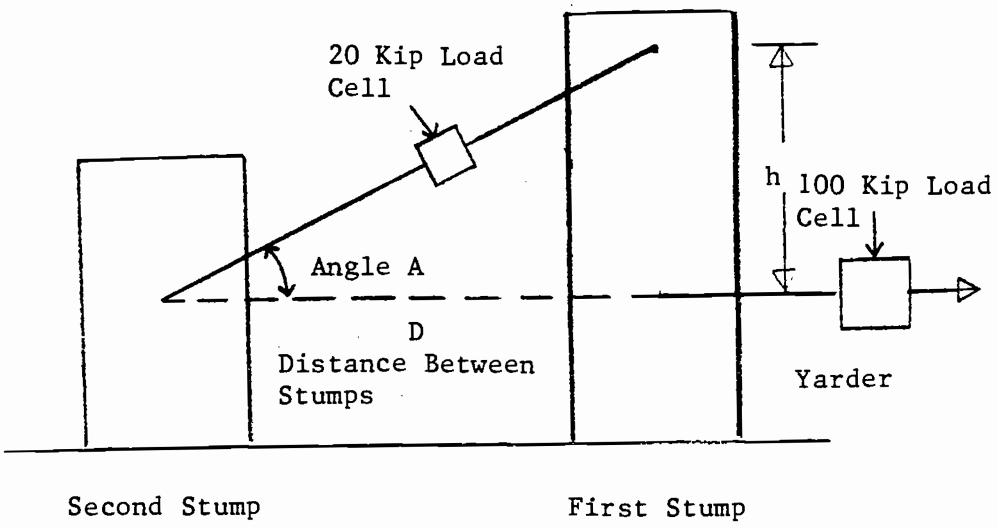


Figure 19

Illustration of the geometry used to determine the horizontal component of the 20 kip load cell reading.

V. RESULTS

In this section, the results are organized in the categories of field results, model results, and a comparison of the two.

A. Field Results

One measure of multiple stump anchor effectiveness is the second stump load as a percentage of total system load. This transfer factor can be expressed as follows:

$$\text{Transfer Factor} = (\text{Second Stump Load}/\text{System Load}) * 100\% \qquad (13)$$

As the value for transfer factor becomes lower, more of the load placed on the system by the yarder must be resisted by the first stump. An example of an ideal multiple stump anchor system is one in which both stumps are able to resist equal load if they are the same strength. This is the principle behind the equalizer block system, where each stump is subjected to the same load.

The following table presents transfer factors for the series multiple, tieback, and elevated tieback systems. The percentages presented for each cycle in each test are averages of the transfer factors for every load increment in each cycle.

TABLE 2. Second stump load transfer as percentage of system load

Series Multiple			Tieback			Elevated Tieback		
Stumps Set	Cycle	Load Trans. %	Stump Set	Cycle	Load Trans. %	Stump Set	Cycle	Load Trans %
1	1	39	1	1	43	1	1	21
	2	36		2	38	2	1	41
	3	52		3	41		2	41
2	1	34	2	1	43		3	46
3	1	25		2	57	3	1	22
	2	13		3	36		2	34
4	1	28	3	1	34	4	1	22
				2	43		2	32
				3	54		3	32
			4	1	20			
				2	30			
				3	44			

Transfer factors range from 13 to 57 percent for all cycles for the three rigging configurations on all stump sets. It is not appropriate to average the transfer factors presented in the table because they were for several different pretensions. The stumps also had different abilities to resist loads which could have influenced the transfer factor. Consequently, the transfer of load from the system to the second stump is highly variable.

The system load-deformation curves constructed for each stump set are shown on Figures 20 through 23. They show the curves for the cycles within each of the rigging configurations. With the exception of the series multiple system, the loads and displacements shown for all systems are low due to the attempt to conduct nondestructive sampling. Because load-deformation curves for all systems are not available at high loads, it is not clear what the relationships between the four systems as tested in the field might be at loads higher than those plotted on Figures 20 through 23. The equalizer block curves are higher than the others in terms of higher loads per displacement. This could be due the shape of the system load-deformation curves. In the model, the series multiple, tieback and elevated tieback systems show "S" shaped load-deformation curves due to the addition of the individual stump load-deformation curves. This "S" shape for the field data is apparent on Figure 22 which illustrates the curves for stump set 3. Because of the way the individual stump load-deformation curves are combined for the equalizer block system, the curve is not "S" shaped. Consequently at low loads the equalizer block system curve can be expected to be higher than the other curves. This is the behavior shown on Figures 20-23. At higher loads than those measured in these tests, the position of the equalizer block curves may not be the highest.

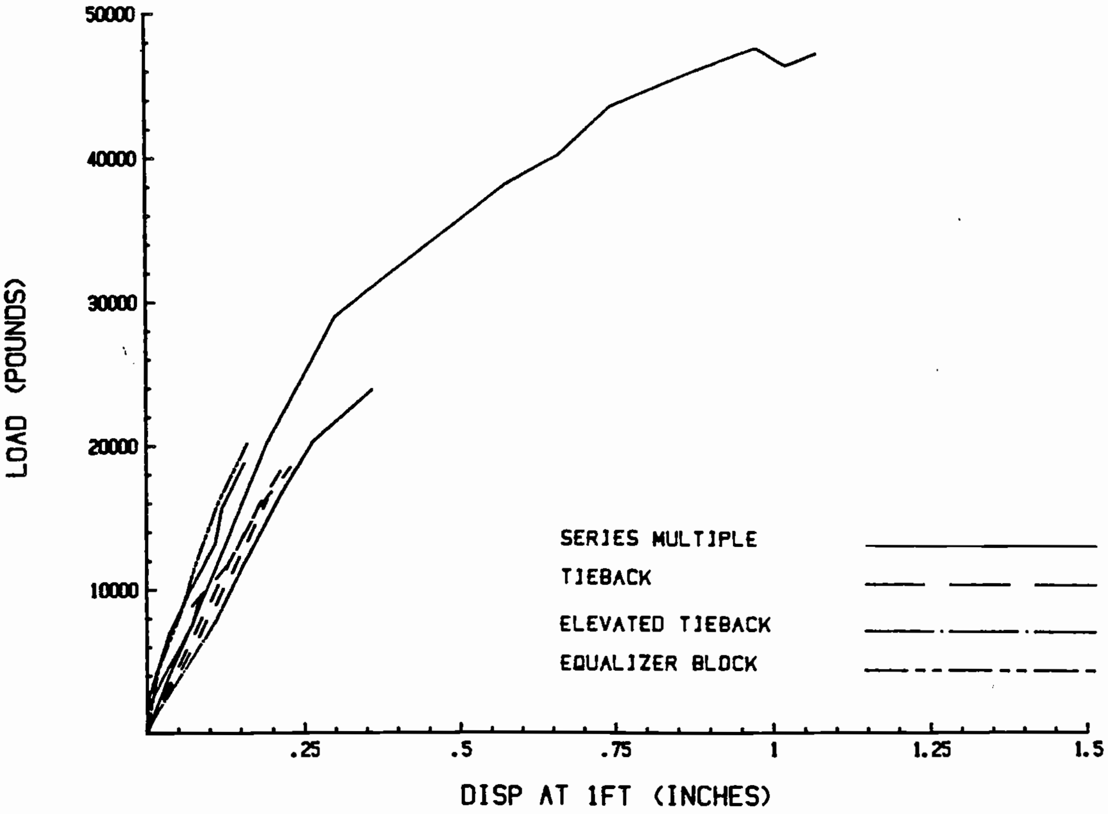


Figure 20

Stump set 1 load deformation curves for all rigging configurations. First stump diameter was 12.7 inches. Second stump diameter was 12.2 inches.

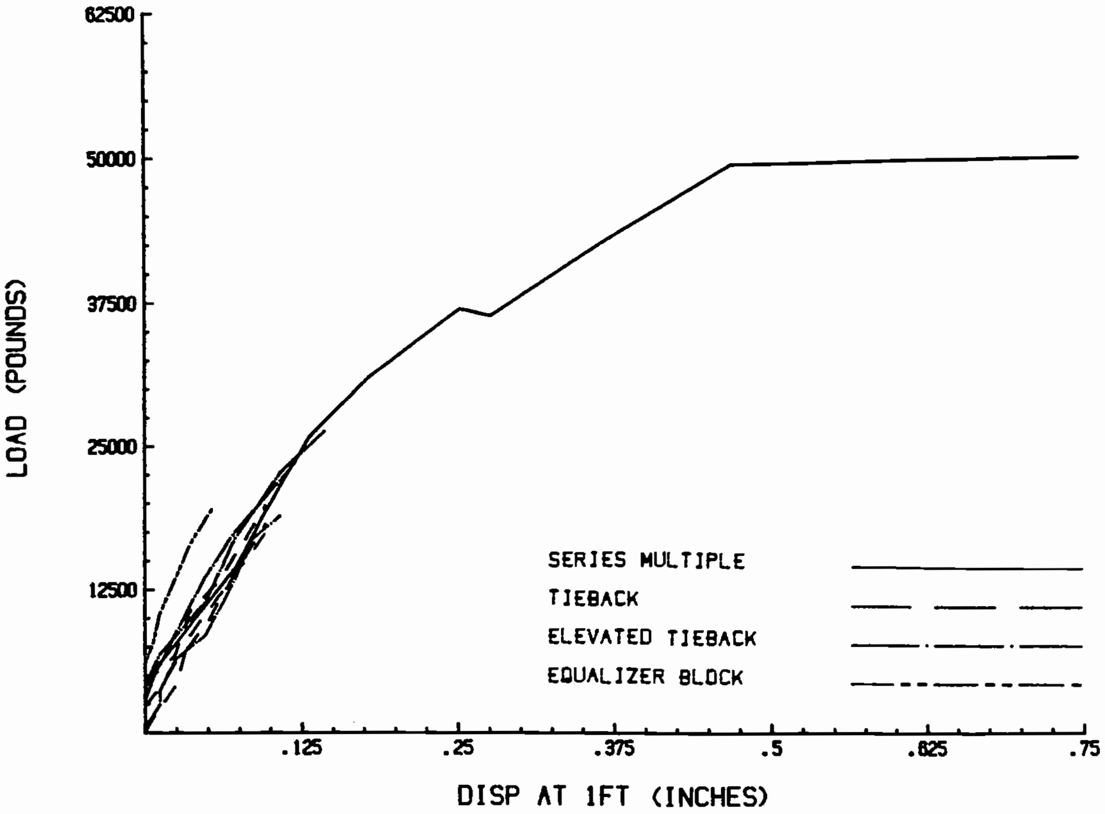


Figure 21

Stump set 2 load deformation curves for all rigging configurations. First stump diameter was 14.3 inches. Second stump diameter was 12.9 inches.

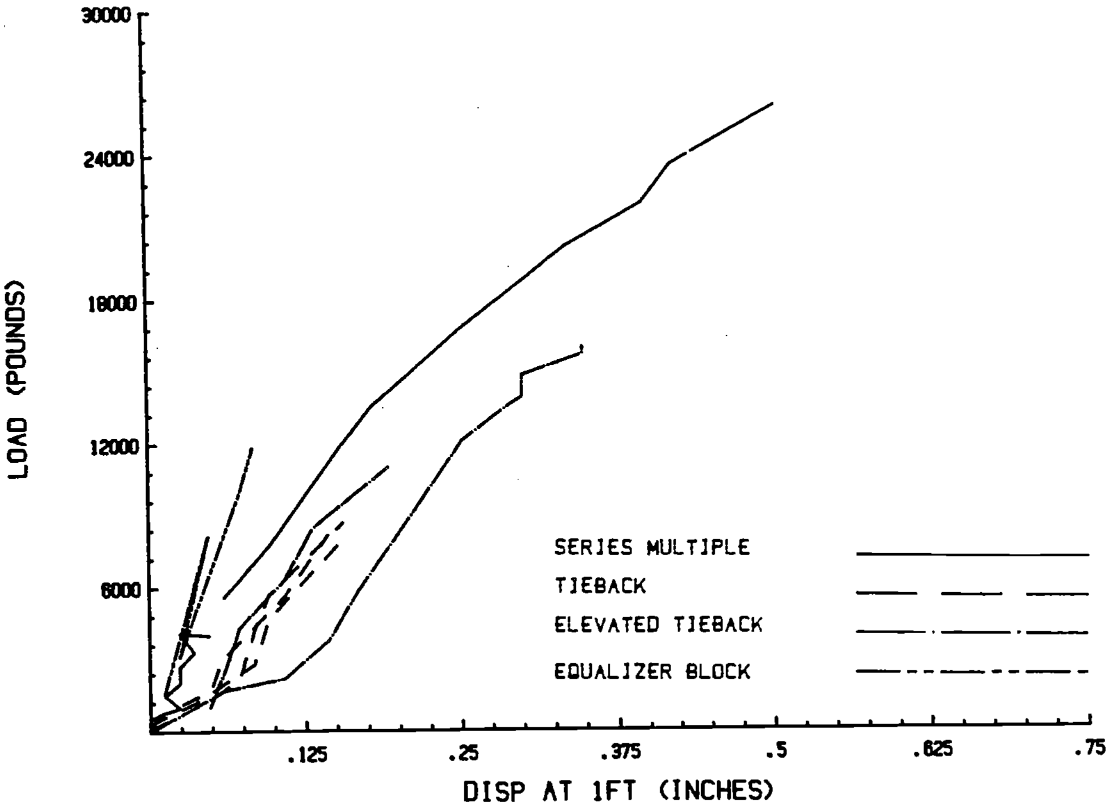


Figure 22

Stump set 3 load deformation curves for all rigging configurations. First stump diameter was 10.5 inches. Second stump diameter was 10.5 inches.

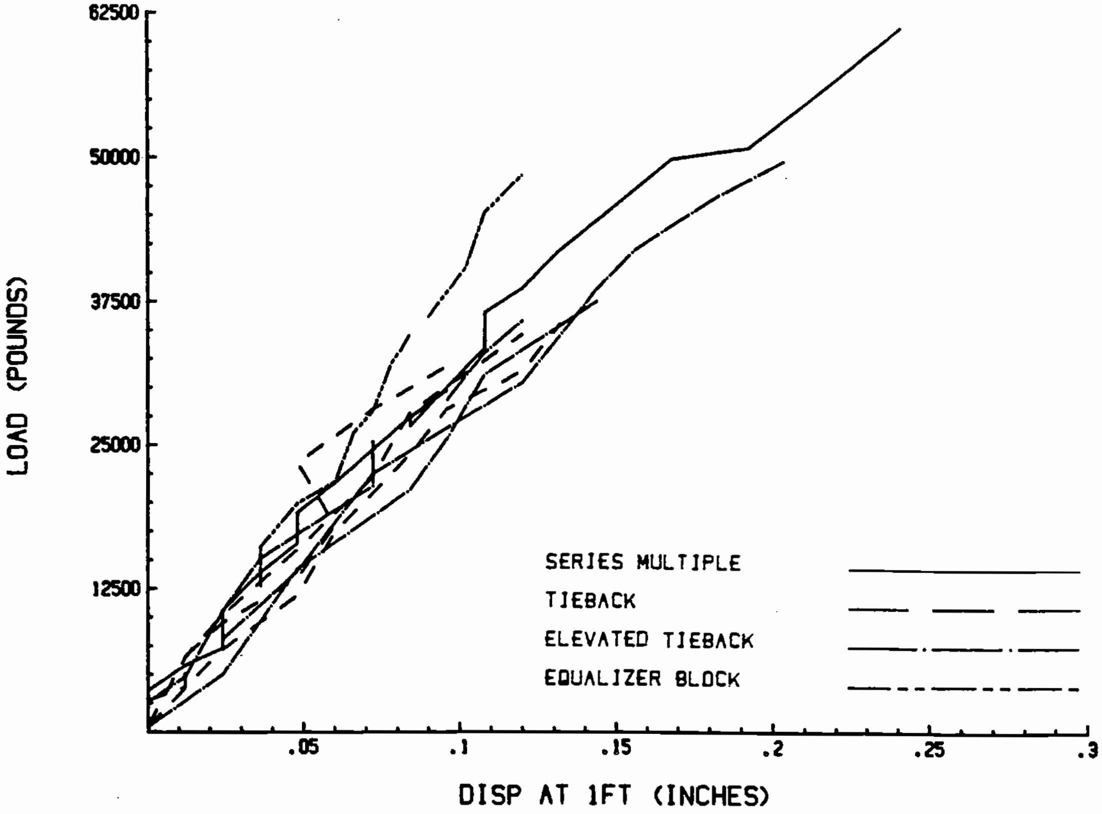


Figure 23

Stump set 4 load deformation curves for all rigging configurations. First stump diameter was 14.2 inches. Second stump diameter was 18.0 inches.

Three stumps were pulled to failure, the results of which are shown on the load-deformation curves in Figure 24. The first stump of anchor set four, which was 14.2 inches in diameter is the highest curve in the figure. The 18 inch diameter second stump of anchor set 4 is the next lowest curve, followed by the lowest curve which is the 10.5 inch diameter second stump of anchor set 3. The fact that the largest stump was not the strongest, since its curve was not the highest on the figure indicates that stump size is not necessarily the only indicator of strength that should be used to evaluate the strength of a stump anchor.

B. Model Results

Figures 25 through 30 show the model results for a range in stump anchor systems. The diameters and pretensions are listed in the figures. Strengths are represented by diameters in the model. In order to evaluate the effect of maximum strength differences between the two stumps, a large difference in diameters was selected for use in the model----12 and 18 inches. To evaluate the effect of equal stump strength, a 14 inch stump diameter was selected. With the exception of the lower portions of these load-deformation curves, some of the system curves are graphed on top of other load-deformation curves. This makes it difficult to see the differences between the four system curves. Even if the curves for some of the systems appear

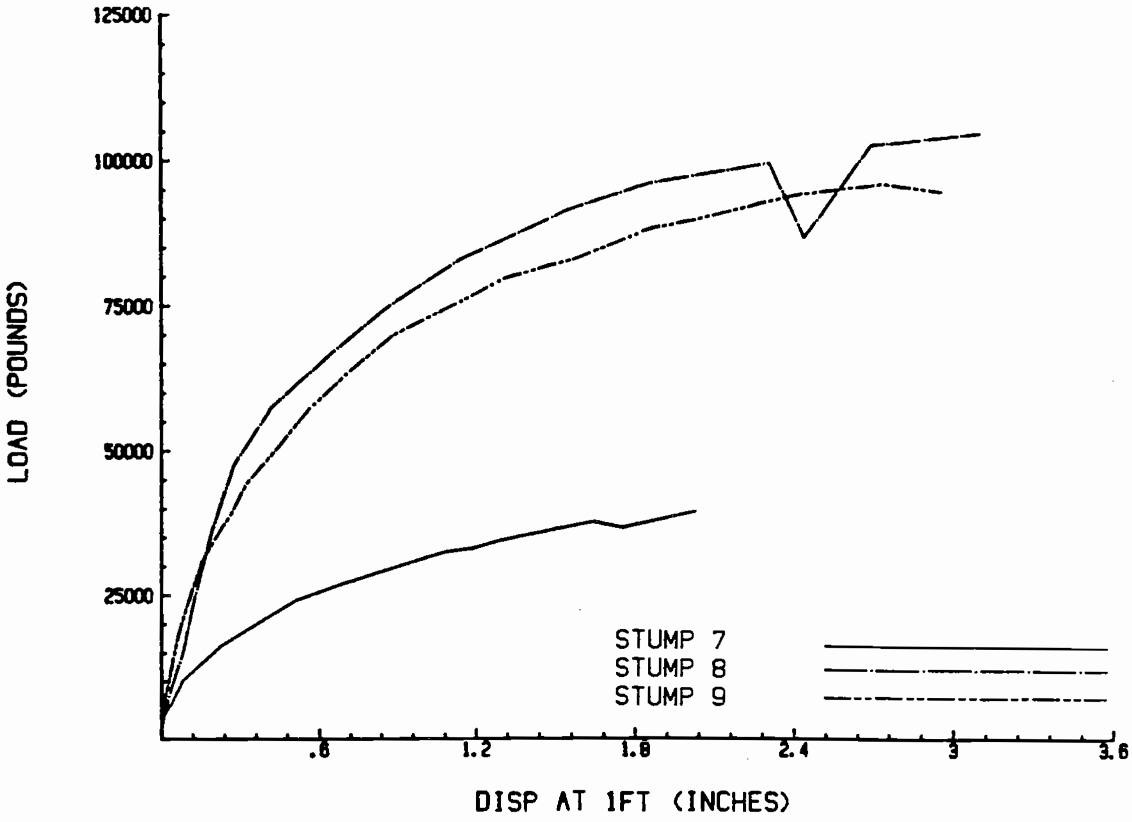


Figure 24

Load deformation curves for the three individual stump pull to failure tests. Stump 7 diameter was 10.5 inches, stump 8 diameter was 14.2 inches, and stump 9 diameter was 18.0 inches.

Stump 7 - Second stump of set 3
Stump 8 - First stump of set 4
Stump 9 - Second stump of set 4

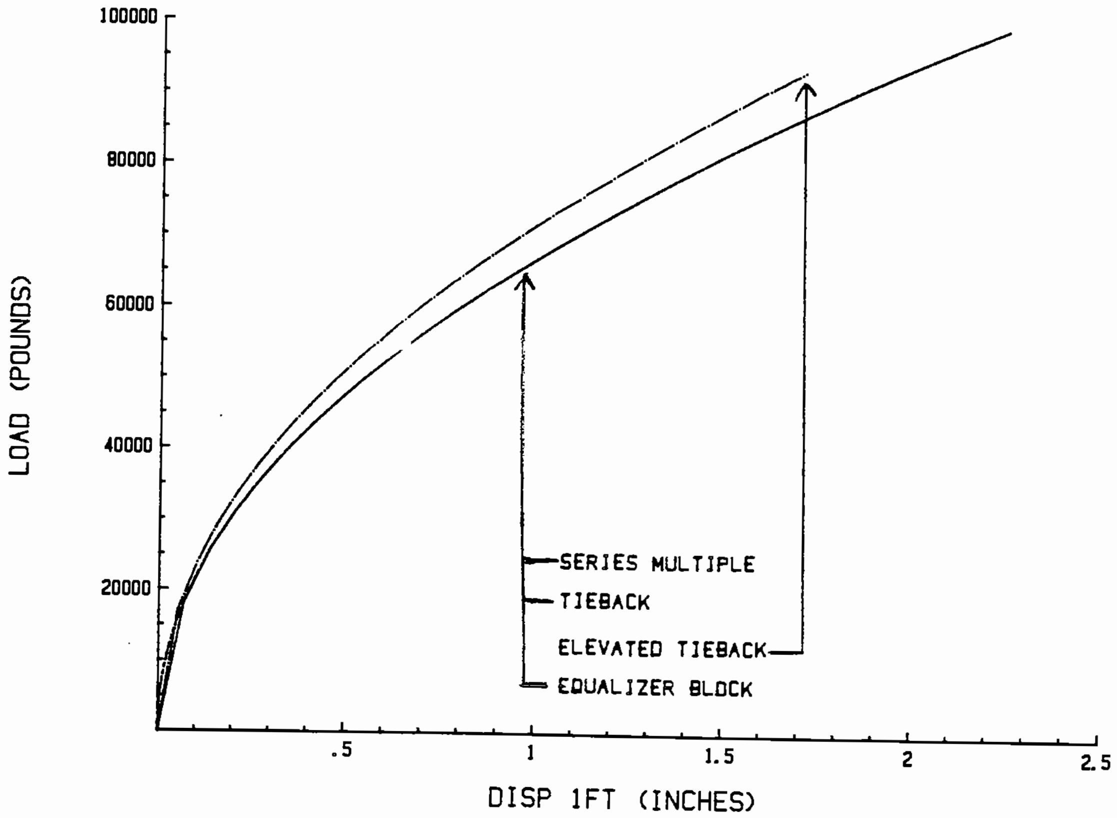


Figure 25

Model load deformation curves for the four rigging configurations. The curves end at the load where system failure occurs. Some curve portions might coincide with other curves.

First stump diameter	14 inches
Second stump diameter	14 inches
No pretension	

System	Load at Failure (pounds)
Series Multiple	99,338
Tieback	99,338
Elevated Tieback	93,101
Equalizer Block	99,338

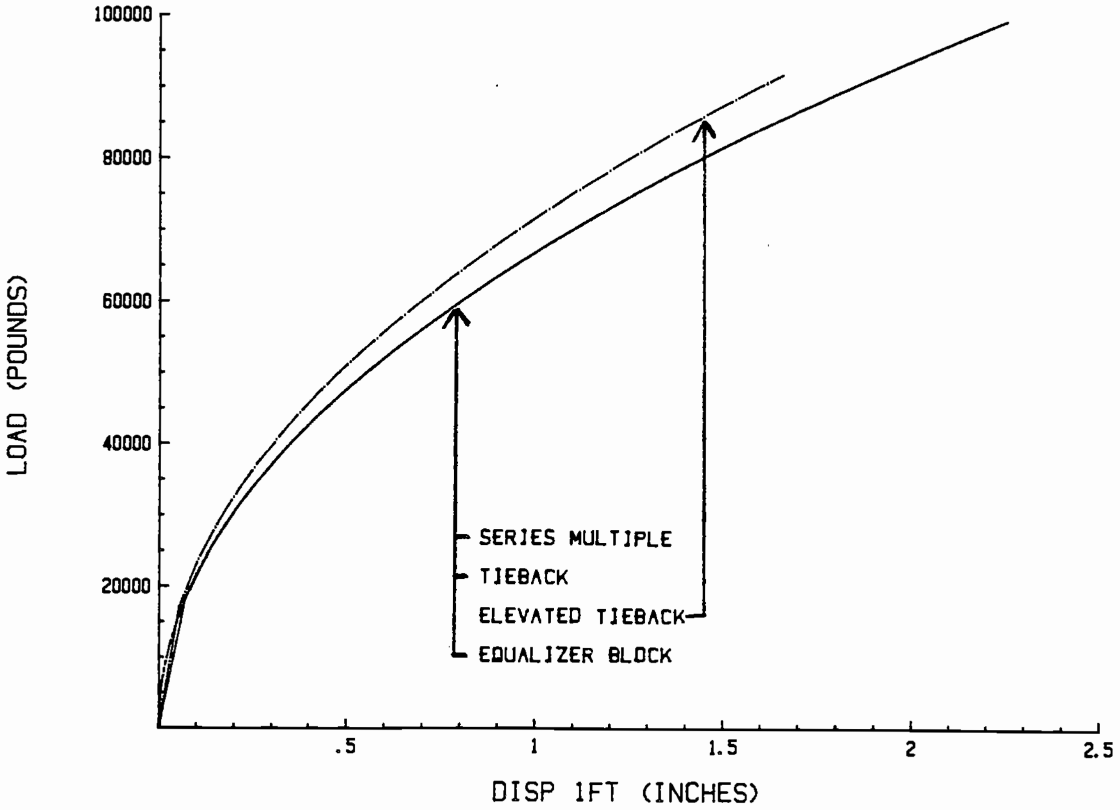


Figure 26

Model load deformation curves for the four rigging configurations. The curves end at the load where system failure occurs. Some curve portions might coincide with other curves.

First stump diameter	14 inches
Second stump diameter	14 inches
Pretension	2000 pounds

System	Load at Failure (pounds)
Series Multiple	99,338
Tieback	97,805
Elevated Tieback	91,659
Equalizer Block	99,338

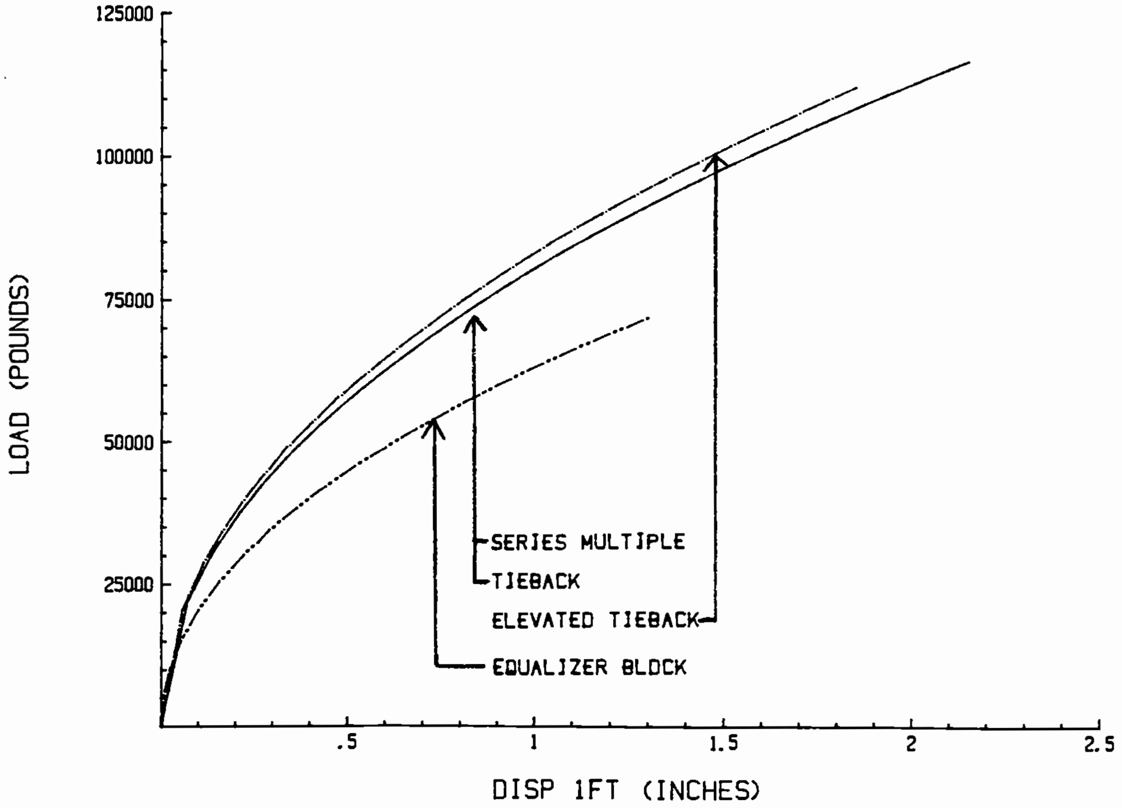


Figure 27

Model. load deformation curves for the four rigging configurations. The curves end at the load where system failure occurs. Some curve portions might coincide with other curves.

First stump diameter	18 inches
Second stump diameter	12 inches
No pretension	

System	Load at Failure (pounds)
Series Multiple	116,715
Tieback	116,715
Elevated Tieback	112,109
Equalizer Block	71,662

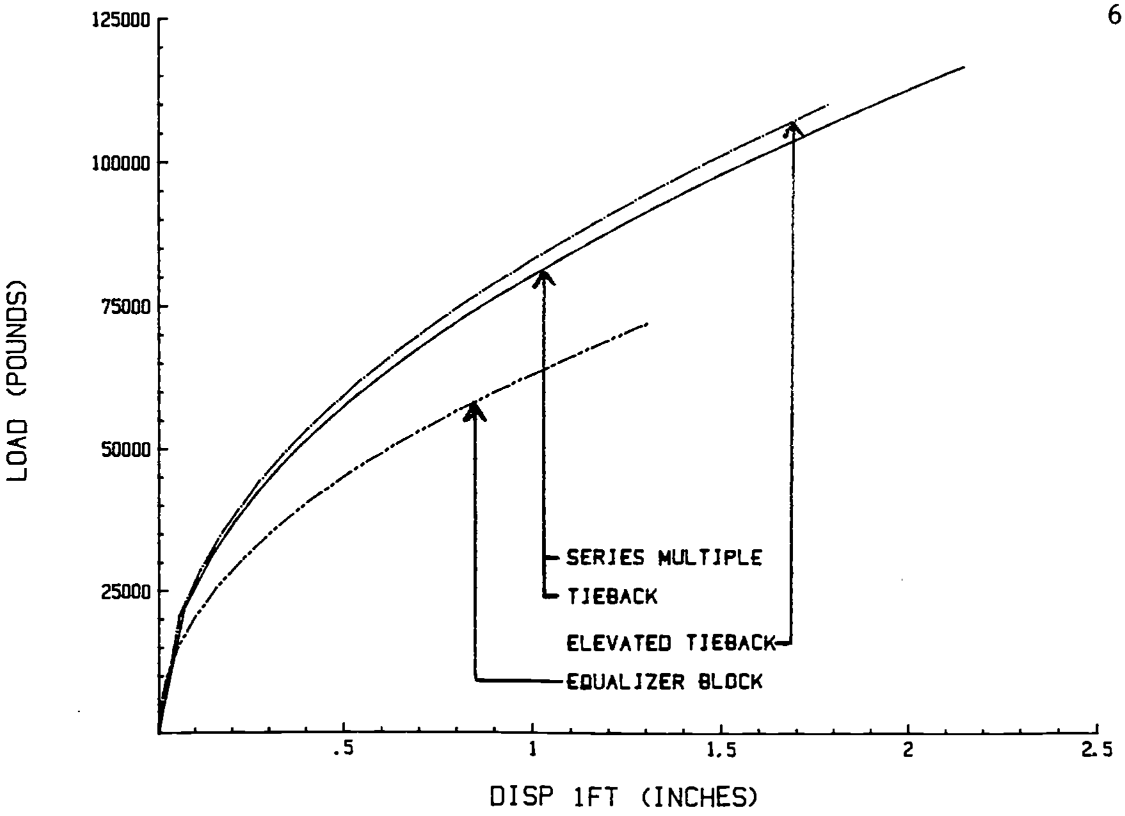


Figure 28

Model load deformation curves for the four rigging configurations. The curves end at the load where system failure occurs. Some curve portions might coincide with other curves.

First stump diameter	18 inches
Second stump diameter	12 inches
Pretension	2000 pounds

System	Load at Failure (pounds)
Series Multiple	116,715
Tieback	116,743
Elevated Tieback	110,403
Equalizer Block	71,662

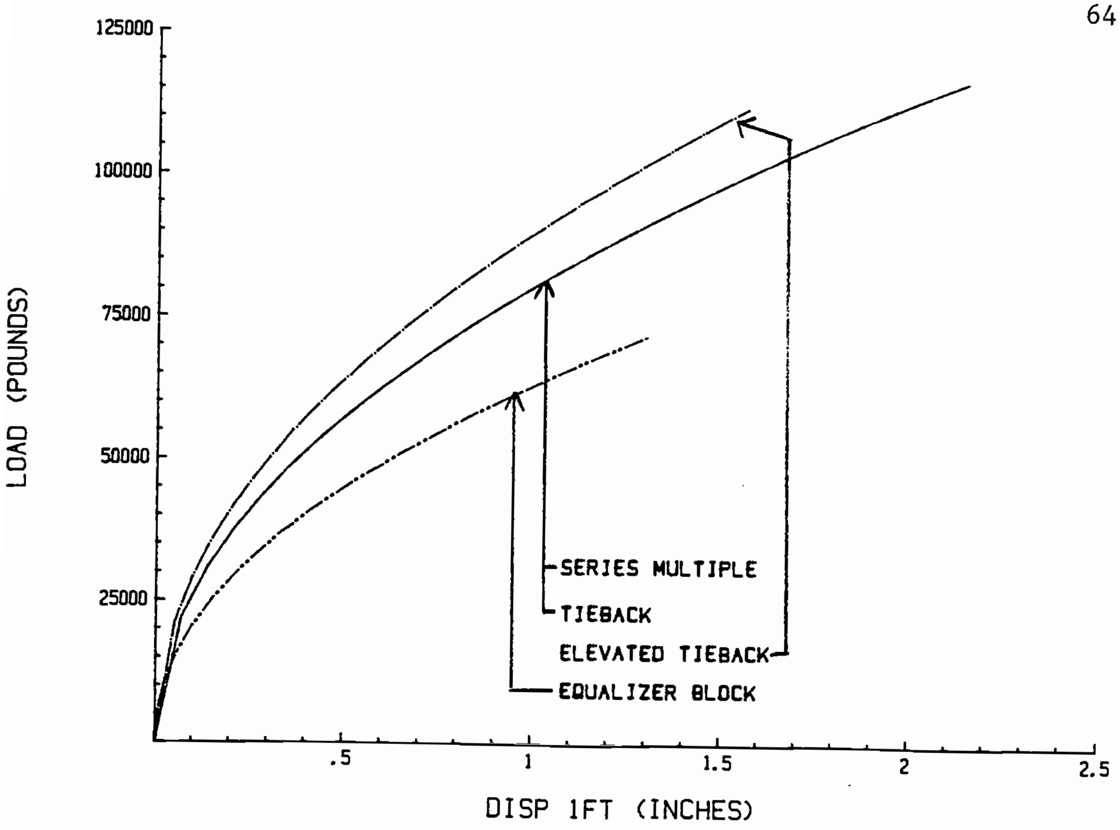


Figure 29

Model load deformation curves for the four rigging configurations. The curves end at the load where system failure occurs. Some curve portions might coincide with other curves.

First stump diameters	12 inches
Second stump diameter	18 inches
No pretension	

System	Load at Failure (pounds)
Series Multiple	116,715
Tieback	116,715
Elevated Tieback	111,642
Equalizer Block	71,662

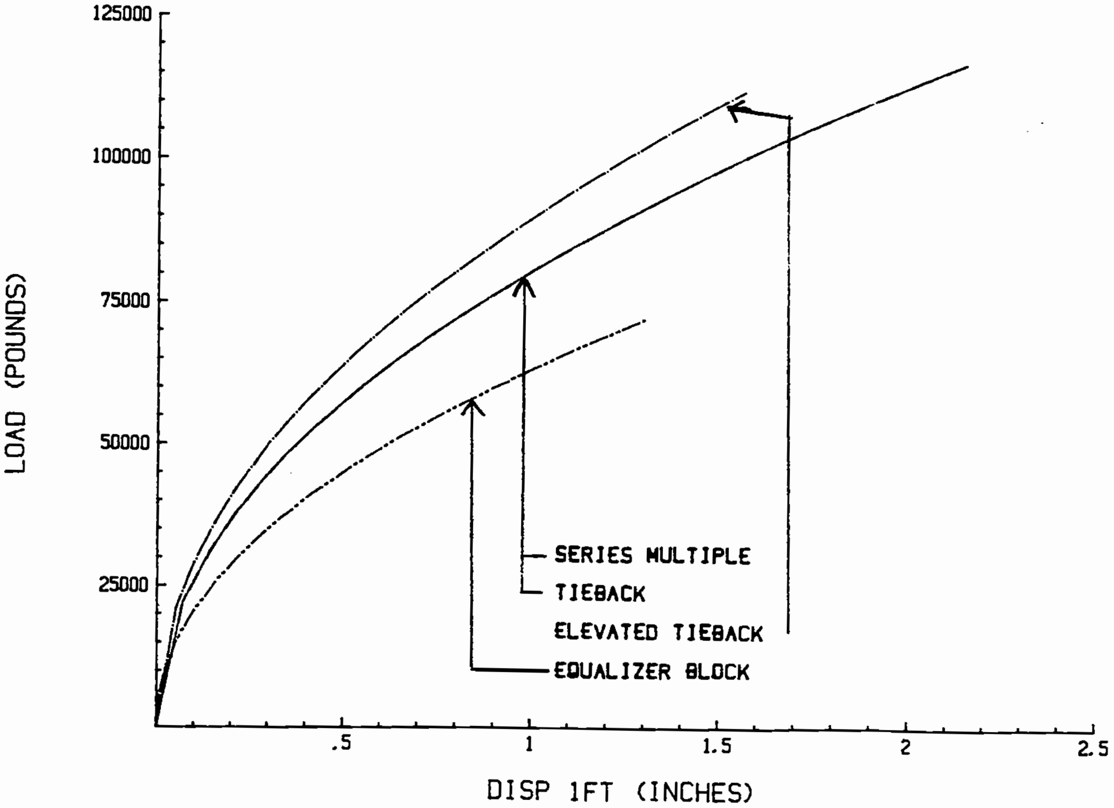


Figure 30

Model load deformation curves for the four rigging configurations. The curves end at the load where system failure occurs. Some curve portions might coincide with other curves.

First stump diameter	12 inches
Second stump diameter	18 inches
Pretension	2000 pounds

System	Load at Failure (pounds)
Series Multiple	116,715
Tieback	116,686
Elevated Tieback	111,606
Equalizer Block	71,662

similar, they do differ in two ways: (1) The lower portions of the curves differ because the low loading shape of the four load-deformation curve types differ. They differ due to the "S" shape caused from the individual curve combination for the tieback systems. (2) The curve endpoints represent the point at which load on one of the stumps has exceeded its ultimate load, causing system failure. The load at failure is listed on the figures.

If strength between the two stumps in a multiple anchor system differ, then the equalizer block configuration fails at a lower total system load that do the other configurations. Specifically, it fails when the strength of the weakest stump is exceeded. The model assumes that the two stumps, the block, and the yarder are all in line. If they were not, then system load at failure for the equalizer block system would be lower than presented here.

It appears that pretensioning the line between the two stumps has little effect on total system load. The tieback configuration results are not much different than the series multiple configuration results. The reason for this could be that the two systems may actually be similar, especially at higher pretensions. When loads are increased, the skyline in the series multiple system moves around the first stump towards the yarder causing an increase in the linkage tension. Some of this movement occurs before much first stump displacement has occurred. As the load between the stumps increases for the series multiple system, the first stump does not displace backwards as it does during pretensioning in the tieback systems. The behavior of the tieback systems can be expected to be different from the series multiple system at low loads when first stump displacements differ for the two rigging types. At higher loads, both stumps displace similarly so they can be expected to exhibit similar behavior.

The position of the strongest stump (first or second) does not seem to affect the ultimate system load. This conclusion is dependent on an assumption used to develop the model; the length of the line between the two stumps does not change.

In a real situation, the length of line between the two stumps is likely to change during loading increases due to line stretch, line travel, and wood crushing. In terms of being able to affect calculated model results, all three factors apply to the series multiple system, stretch and wood crushing apply to the two tieback systems, and none of the factors apply to the equalizer block system. Wire rope stretches when it is subjected to tension. When this stretching occurs in the linkage between the two stumps, it increases the linkage length. For the series multiple system, the skyline is likely to move around the first stump towards the yarder when load is applied. It is not clear whether or not this movement takes place at low loads before much crushing has occurred, or at high loads. The effect is a decrease in the linkage length. Wood crushing can occur on both stumps. Most of the wood crushing will occur on the back of the first stump although some will occur on the front, causing no increase in the linkage length. Some crushing will occur on the back of the second stump which will increase the linkage length. It is not clear what the cumulative effect of these three factors is likely to be on linkage length. When the linkage length is changed during load increase, one of the stumps is able to displace more than the model indicates. The result is that one of the stumps may reach its ultimate load before it would if the linkage length were not changing. The ability to assess the total impact of these three factors is beyond the scope of this project.

C. Comparison of Field and Model Results

The objective for this section is to compare the field and model load-deformation curves. Table 3 presents the results of a comparison for each stump set. In general, the model predicted a larger load at a given displacement than was measured in the field. Measured and predicted loads for the highest measured displacement common to all tests for

Table 3. Predicted and measured loads for the highest measured displacement for each stump set.

Stump Set 1	Rigging System 2	Pretension (pounds) 3	Measured Loads (pounds) 4	Predicted Loads (pounds) 5	Ratio 6	
1	Series Multiple		9400	15600	0.60	
	Tieback	3420	7700	15700	0.49	**Average = 0.52**
		4200	9500	15500	0.61	
	Elevated Tieback	1860	6100	15600	0.39	
	Equalizer Block		12500	15500	0.81	
2	Series Multiple		11300	14500	0.78	
	Tieback	4100	10600	14700	0.72	
		5520	12200	14800	0.82	**Average = 0.78**
	Elevated Tieback	2120	8900	14700	0.61	
		3800	13900	14800	0.94	
		5280	11900	14800	0.80	
	Equalizer Block		18900	14000	1.35	
3	Series Multiple		7000	11000	0.64	
	Tieback	880	2800	11000	0.25	
		2060	4400	11100	0.40	
		2780	4200	11000	0.38	**Average = 0.38**
	Elevated Tieback	1000	5000	11000	0.45	
		2020	2000	11000	0.18	
	Equalizer Block		11800	11000	1.07	
4	Series Multiple		29700	28500	1.04	
	Tieback	1480	31800	28900	1.10	
		4000	30100	28700	1.05	
		6940	28100	27700	1.01	**Average = 1.01**
	Elevated Tieback	3000	28900	28600	1.01	
		4100	25500	28500	0.89	
		8680	26500	27000	0.98	
	Equalizer Block		38250	26200	1.46	

each stump set are listed in columns 4 and 5. This provides a common basis for comparison of predicted and measured values for all tests in each stump set.

The ratio of measured to predicted loads for each test (column 6) shows that the predictions in relation to the measured values are highly variable. The ratio of measured to predicted loads for the series multiple and the two tieback systems is less than the ratio for the equalizer block systems. This difference may be due to the influence of line stretch, line travel, and wood crushing. These three factors influence the behavior of the series multiple system while only line stretch and wood crushing affect the two tieback systems. The equalizer block system is not influenced by any of these factors.

The measured to predicted load ratios for the series multiple system are generally higher than the ratios for the two tieback systems for all stump sets. This behavior is reasonable because of the physical operation of the three factors of linkage line stretch, line travel around the first stump for the series multiple system, and wood crushing. In the series multiple system, line stretch, and wood crushing will increase the linkage length. However, line travel will occur with this system causing the linkage length to decrease. The cumulative effect may be to reduce the influence of these three factors on the series multiple system. The measured and predicted values may then match better with the series multiple system than with the two tieback systems.

A detailed comparison of the load-deformation behavior of stump set two follows along with a discussion of the causes for differences between the field and model load-deformation curves for all stump sets.

Stump set two had a first stump diameter of 14.3 inches and a second stump diameter of 12.9 inches.

Figures 31 through 37 show the model and field load-deformation curves for cycles in each rigging configuration. The pretensions for the tieback systems and initial loads for the series multiple system are shown in the figures. In some figures, the model and field load-deformation curves seem well matched, in others they do not. There are at least two explanations for the differences between the model and field curves: (1) the variability in the single stump model, and (2) the model does not include the effects of wood crushing, line travel, or line stretch.

There are two components of variability in the single stump model which may result in variability in the multiple stump model. One is variation associated with the shape of the load-deformation curves, and the other is variation associated with the normal load Ax.

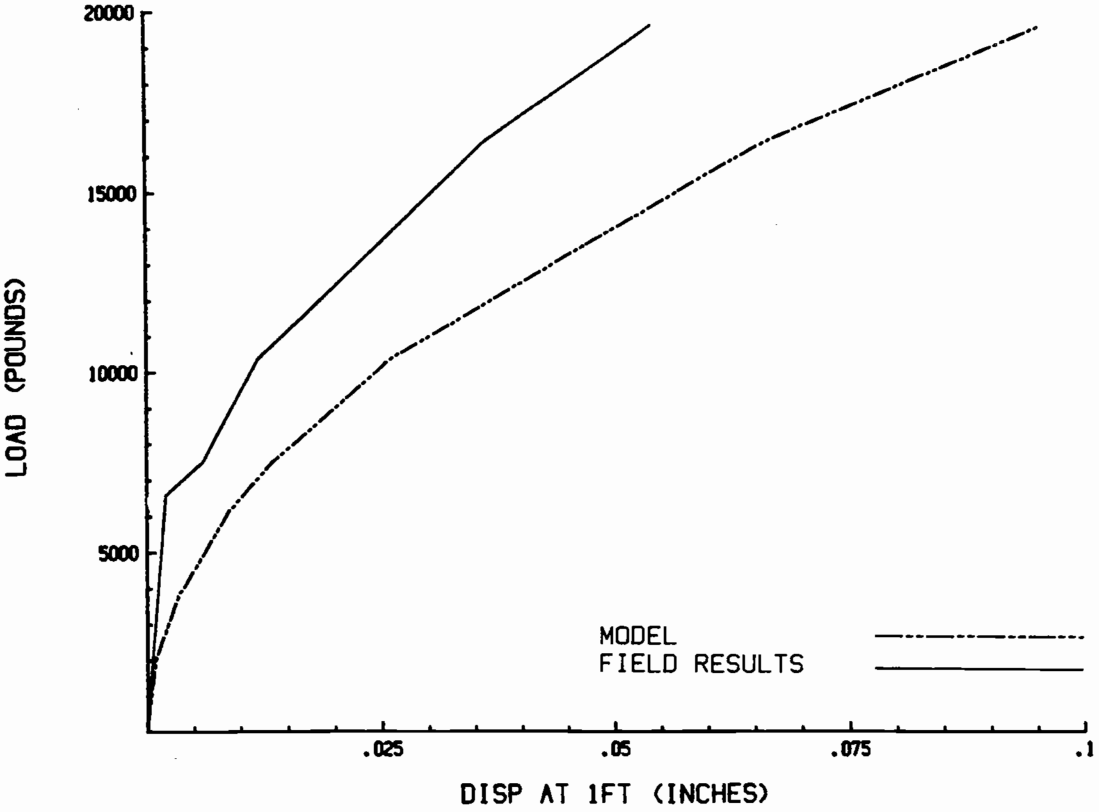


Figure 31

Load deformation curves for the model and field results for the equalizer block configuration of stump set 2.

Stump	Diameter	Pretension
First	14.3 inches	None
Second	12.9 inches	

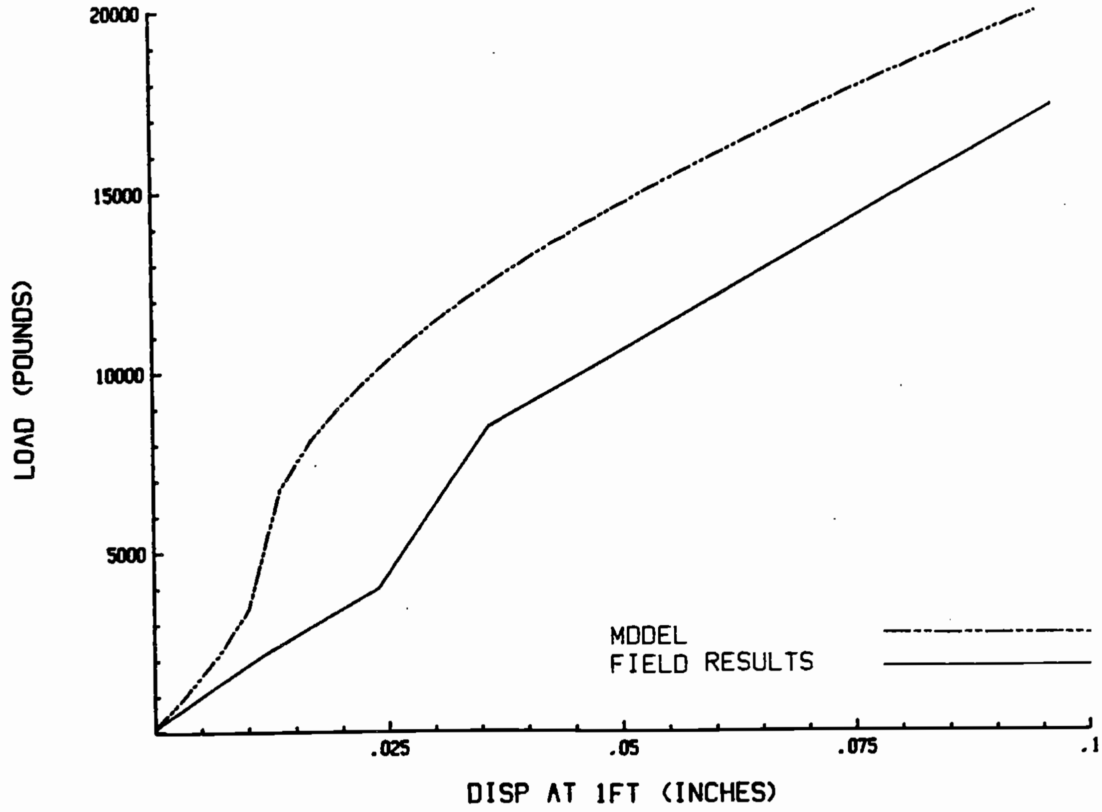


Figure 32

Load deformation curves for the model and field results for a cycle of the tieback configuration of stump set 2.

Stump	Diameter	Pretension
First	14.3 inches	4100 pounds
Second	12.9 inches	

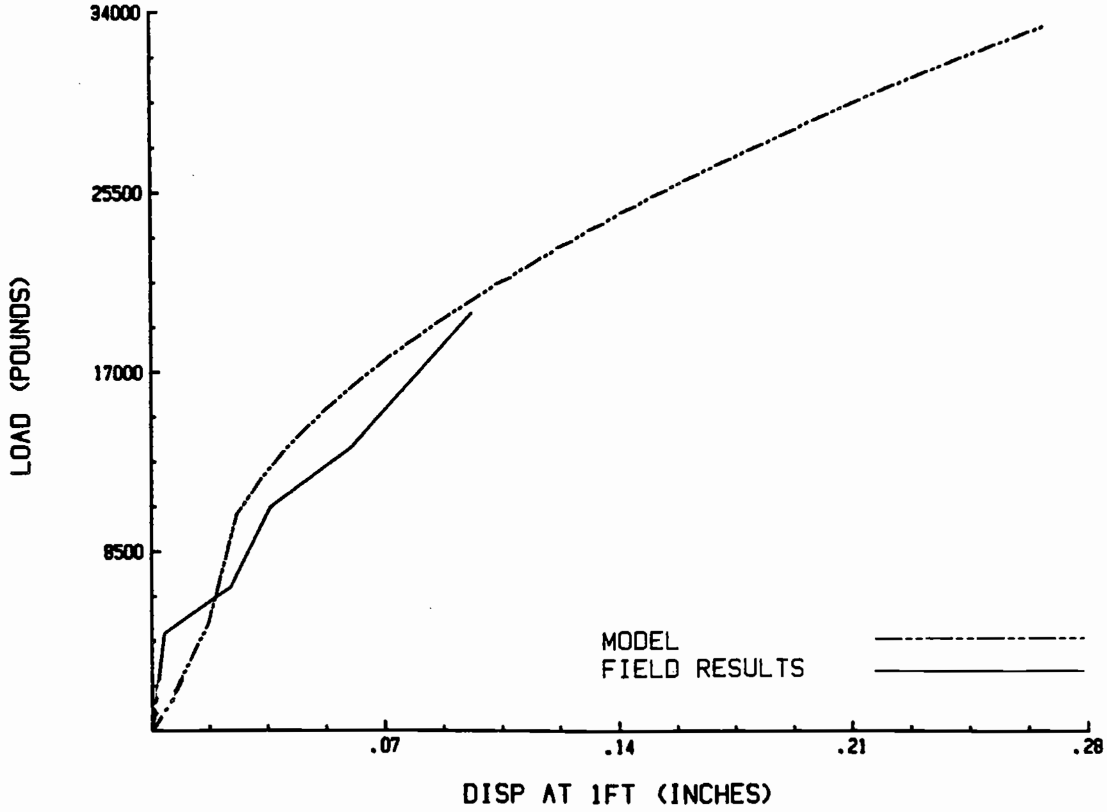


Figure 33

Load deformation curves for the model and field results for a cycle of the tieback configuration of stump set 2.

Stump	Diameter	Pretension
First	14.3 inches	5520 pounds
Second	12.9 inches	

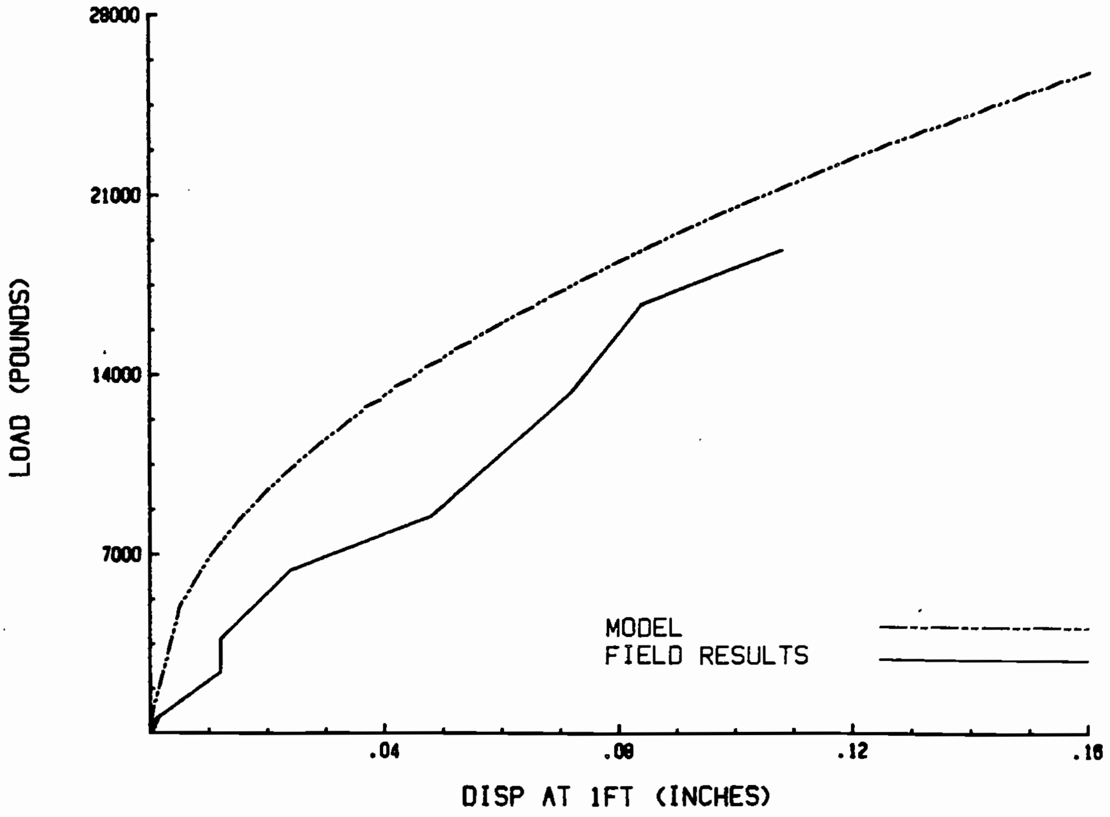


Figure 34

Load deformation curves for the model and field results for a cycle of the elevated tieback configuration of stump set 2.

Stump	Diameter	Pretension
First	14.3 inches	2120 pounds
Second	12.9 pounds	

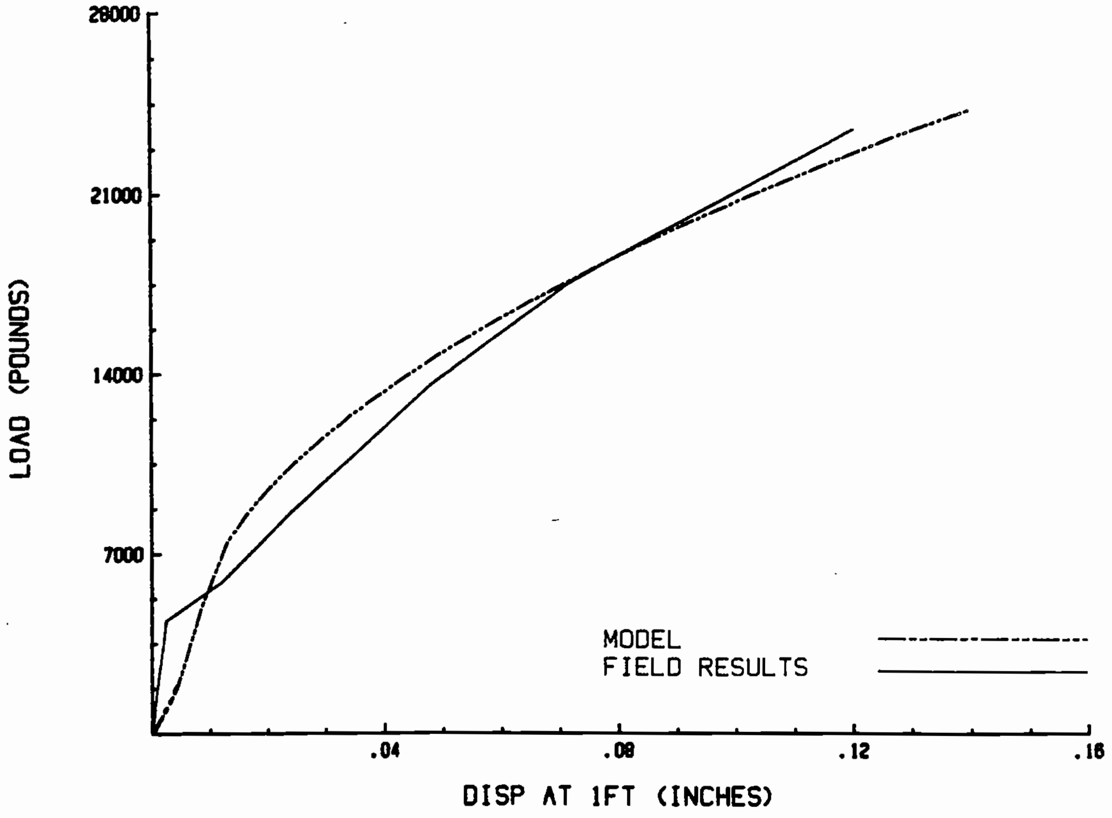


Figure 35

Load deformation curves for the model and field results for a cycle of the elevated tieback configuration of stump set 2.

Stump	Diameter	Pretension
First	14.3 inches	3800 pounds
Second	12.9 pounds	

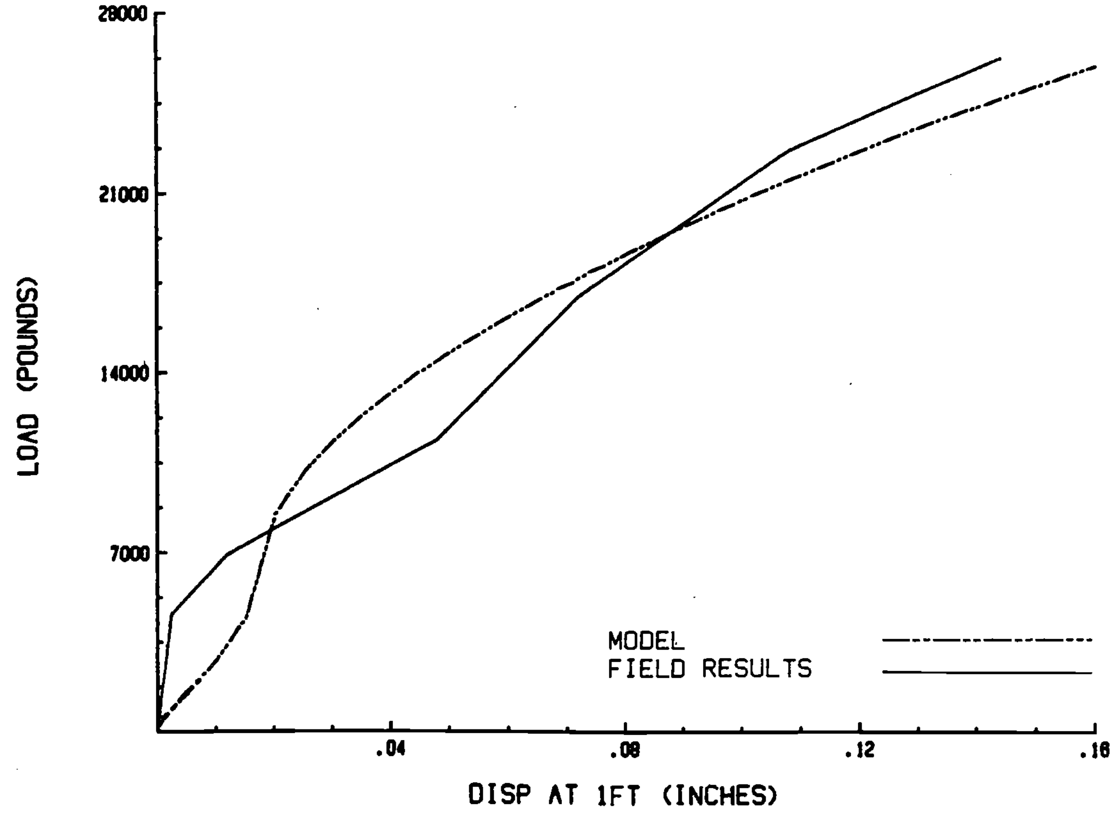


Figure 36

Load deformation curves for the model and field results for a cycle of the elevated tieback configuration of stump set 2.

Stump	Diameter	Pretension
First	14.3 inches	5280 pounds
Second	12.9 pounds	

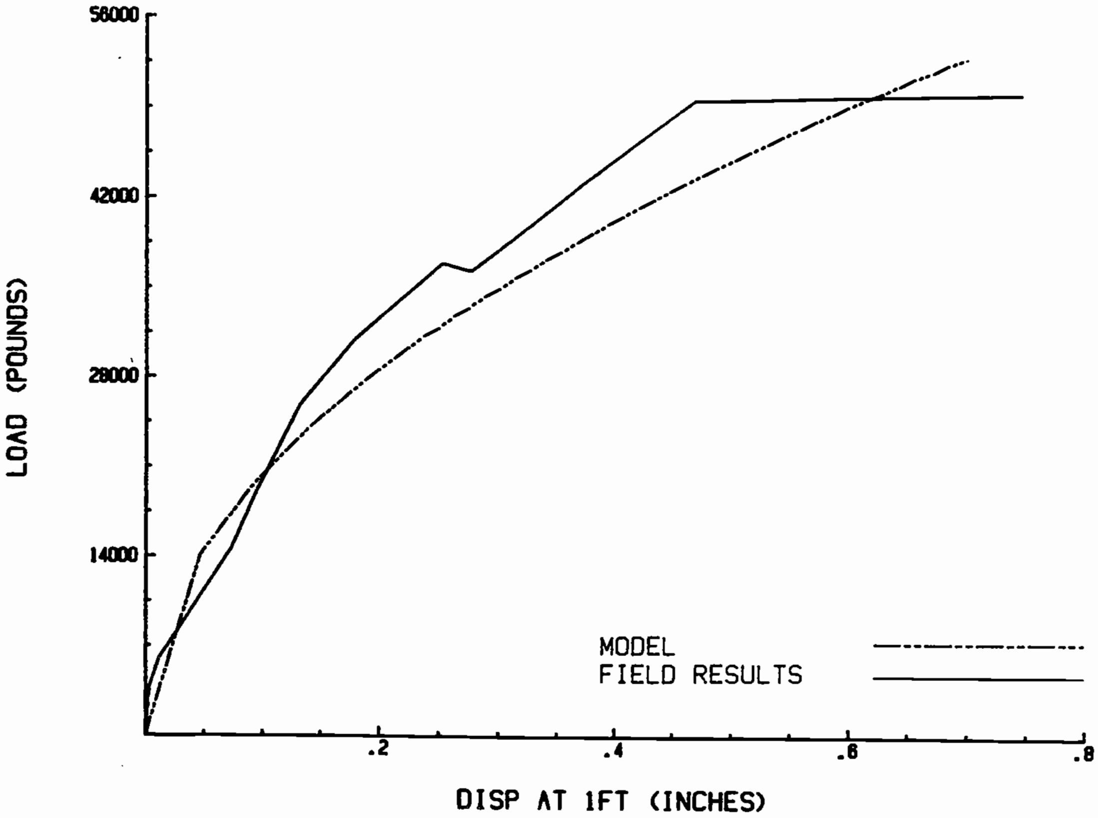


Figure 37

Load deformation curves for the model and field results for the series multiple configuration of stump set 2.

Stump	Diameter	Initial Load
First	14.3 inches	480 pounds
Second	12.9 inches	

One approach to use to determine the influence of normal load variation in the multiple stump model, would be to determine the normal load equation for the upper and lower 95% prediction limits for the single stump model. The resulting Ax equations could then be used in the multiple stump model to obtain two load-deformation curves. One curve would be related to the upper 95% prediction limit, the other to the lower 95% prediction limit. These curves would then be compared to a complete system load-deformation curve developed from field data. Unfortunately, there were no complete multiple stump system load-deformation curves developed because it was not possible to apply enough load to fail the multiple stump system. However, it was possible to compare the prediction limits from Stoupa's single stump equations to the failure load tests conducted on single stumps in this project.

The procedure was to determine the normal load Ax for the upper and lower 95% prediction limits. The empirical equations used in the single stump model were then used to develop two load-deformation curves associated with the prediction limits. The field load-deformation curve from the second stump of anchor set three was then compared to the two prediction limit curves. Figure 38 illustrates the three curves. It is apparent from the figure that consideration of normal load variation in the single stump model results in a wide range of possible load-deformation

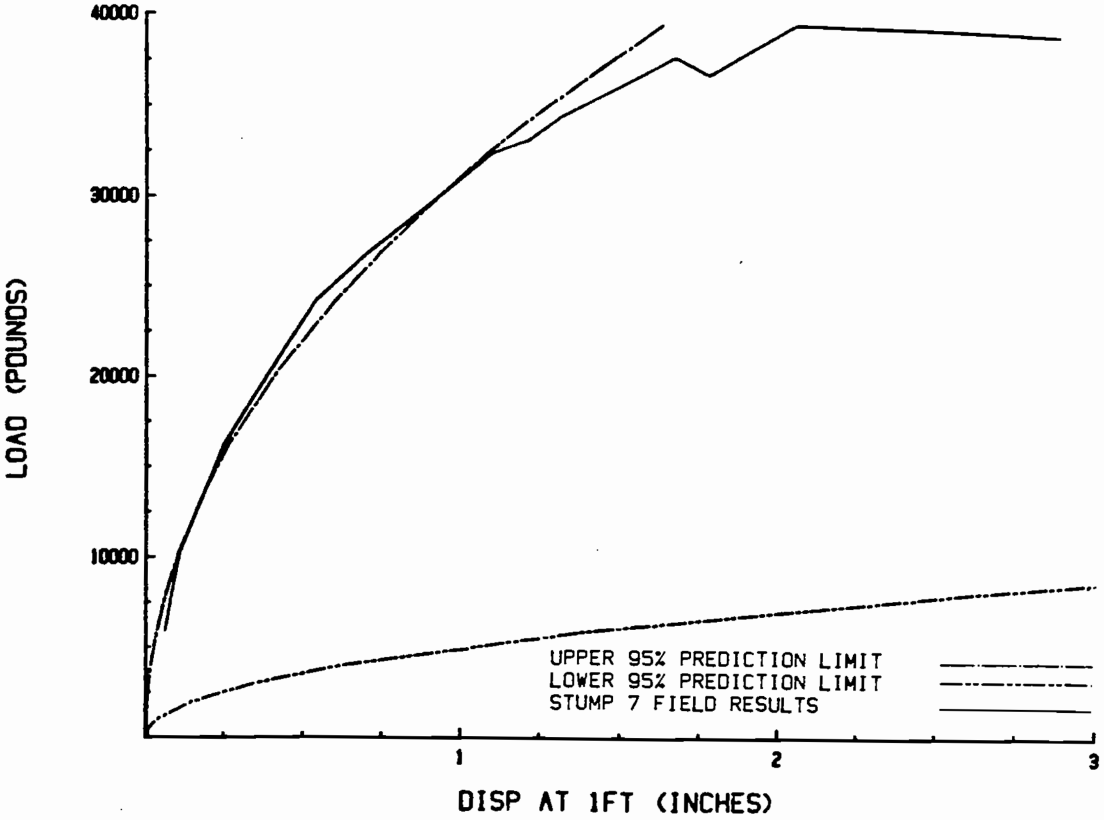


Figure 38

Comparison of load deformation curves for the second stump of set three (stump 7) and Stoupa's upper and lower 95% prediction limits on normal load Ax.

curve locations within the prediction limits. Additional variability associated with the load-deformation curve shape is not shown in Figure 38. The field curve is at the top of the range indicating that the model is predicting conservatively for this one case. Because there is a large amount of variation in the normal load portion of the single stump model, it should be expected that multistump load-deformation curves would also be quite variable. For this reason, a more detailed comparison of the model and field curves was not done.

One indication of the validity of the single stump model combination procedure to form the multiple stump model is the presence of "S" shaped system curves for the field data. This behavior is illustrated for the field load-deformation curves in Figure 22. Figures 21 and 23 also illustrate this behavior although it is more pronounced in Figure 22. If there is an initial tension in the linkage between the stumps for the series multiple or the two tieback systems, the single stump models for each stump when added together to form the multiple stump model result in an "S" shaped system curve. This "S" shaped system curve is illustrated for the model results in Figures 32 through 37.

The multiple stump model is not designed to include the effects of wood crushing, line travel around the first stump in the series multiple system, or line stretch between the stumps. These three factors are likely to influence the linkage length between the two stumps as load is applied to the system, for all configurations except the equalizer block. It is not clear how these three factors will operate in the system, consequently their effect on the model is not apparent. If the linkage length changes as system load is varied then the method of single stump model combination to form the multiple stump model needs to be revised. If wood crushing, line travel, or stretch were included in the model, then the stumps would displace at different rates relative to each other as the applied load varied. The result would be a different system load-deformation curve, perhaps one closer to the field curves.

VI. APPLICATION OF RESULTS

The multiple stump model can be used to determine system load-deformation characteristics and to predict failure of a multiple anchor system. However, it is important to recognize its limitations. It does not consider line stretch, line travel around the first stump in the case of the series multiple system, or wood crushing. Therefore, the model can not characterize an actual multiple stump anchor system as accurately as it might be able to do if these three factors were incorporated in it.

There is variation associated with the single stump model. Since the multiple stump model is a combination of two single stump models, there is variation associated with the multiple stump model. The combined effect of model variation and the influence of the three factors discussed in the previous paragraph may result in a predicted anchor capacity different from the actual capacity.

Field load-deformation curves developed for this study used stumps located on the Oregon State University Macdonald Forest. Stumps grown in different environmental conditions are likely to have different system load-deformation behavior when used as multiple stump anchors because their root structure is likely to be different. Root structure influences resistance to stump pullout. The magnitude of load at system failure may change if a stump's resistance to pullout changes from site to site. However, the relationship between different rigging configurations is likely to remain the same. The reason for this is that regardless of the differences between sites, the four anchor system alternatives are all subjected to the same conditions on any one site.

All four systems have similar field load-deformation curves as illustrated in Figures 20 through 23. The model load-deformation curves for a two stump anchor system of equal strength, which in the model means equal diameters, are similar for all systems as illustrated in Figures 25 and 26. When stump strengths are changed in the model by changing from equal diameter stumps to unequal diameter stumps, the series multiple, tieback, and elevated tieback systems are still similar to each other. The equalizer block system is now different from the other systems because it fails at a lower total system load as illustrated in Figures 27 through 30.

The equalizer block system seems to be the least desirable system because it fails at a lower system load when stump strengths differ within the anchor system. The reason for this is related to stump displacement. In the equalizer block system, displacement of one stump does not influence the displacement of the other stump. In an extreme situation, one weak stump can displace to failure before the other stump displaces much at all. This causes the entire system to fail. For the other systems, displacement of one stump does influence the displacement of the other stump. Both stumps displace similar amounts so load at failure is higher for the series multiple and tieback systems than for the equalizer block system.

Within the model assumptions, the series multiple, tieback, and elevated tieback systems all have similar load-deformation behavior. Consequently, the preferable one to use is one which is the easiest to rig. The series multiple system requires the least amount of hardware to rig since the skyline is simply wrapped around the first stump and tied off on itself after being wrapped around the second stump. The tieback systems require the use of twisters. Based on this, the series multiple system appears to be the preferable system.

VII. OPPORTUNITY FOR FURTHER WORK ON MULTIPLE STUMP ANCHOR SYSTEMS

There are two major areas of incomplete understanding that limit how well the multiple stump model can predict the load-deformation characteristic of multiple stump anchor systems. These are the variability of the single stump model, the effects of wood crushing, line travel around the first stump in the series multiple system, line stretch, and soil moisture content.

Two types of variation are recognized in the single stump model; variation associated with the shape of the load-deformation curves, and variation associated with the normal load Ax. It is necessary to become more familiar with this variation in the single stump model. This will lead to a better understanding of the variation in the multiple stump model since it is a combination of two single stump models. In this way, it is hoped the multiple stump model will be able to provide an estimate of anchor capacity closer to what actually might occur.

It is apparent that wood crushing, line travel, and line stretch occur when multiple stump anchor systems are loaded. The actual mechanics of how these three factors operate is not clearly understood. Research on the behavior of these factors is necessary. When they are better understood, and incorporated in the multiple stump model, it will be able to more accurately predict the ultimate capacity of a multiple stump anchor system.

Varying soil moisture content might also cause the load-deformation characteristics of an anchor system to vary. When results of research on the effects of varying soil moisture content on the load-deformation characteristics of multiple stump anchor systems is built into the model, it will be able to more fully characterize anchor behavior in a variety of soil moisture regimes.

The multiple stump model was based on the single stump model which was developed from data collected on the Oregon State University MacDonald Forest. The model is then specific to young growth Douglas-fir stands in the same site type on the MacDonald Forest. A broader data base from young growth Douglas-fir stands throughout its range will make the model more applicable.

In order to conduct nondestructive sampling, each of the four stump sets had all four rigging configurations tested on it at low load levels. As a result of this testing procedure, only the low load portions of the system load-deformation curves are available for analysis. A more thorough comparison of the four rigging configurations would be possible if complete load-deformation curves were available for all rigging configurations.

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