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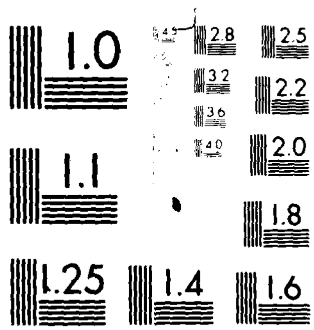

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In-House Report
January 1982

METHODS OF MEASURING AND ESTABLISHING CABLE TENSIONS IN GUYED STRUCTURES

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This report describes in detail, three methods of measuring cable tensions on guyed structures. The methods are sag, deflection tensiometer, and vibration. A field comparison of each method was made using the guyed structures at RADC's Stockbridge Test Site. The vibration technique was conceived several years ago for a previous effort and was verified as an accurate and practical method to measure guy cable tensions. Also included in this report is a complete documentation of the cables used on

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) all guyed structures at the Stockbridge Test Site and the results of the cable tension measurements performed for this effort.

PREFACE

This report describes, with considerable technical detail, several techniques for measuring the tension in cables used for guyed structures. These methods were applied to several guyed structures used at Rome Air Development Center's Stockbridge Antenna Test Site. This report includes all analytical computations and guy cable data necessary for all of the guyed structures at Stockbridge. Also included are advantages, disadvantages, and comparisons of several techniques of measuring cable tensions. This work was accomplished under Job Order No. 21140601 and was performed during the time period from May 81 to Sep 81. Mr. Nicholas Forlenza was employed by RADC under the Summer Engineering Aid Program. The authors wish to thank Mr. Theodore Prossner for his advice and the use of his optical equipment.

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I INTRODUCTION

The Rome Air Development Center uses numerous guyed structures for communication, radar, and antenna test programs performed at several site locations. At the Stockbridge Antenna Test Site, for example, 12 guyed structures are used for the Computer Controlled Antenna Measurement System (CCAMS). Included is a guyed jib crane structure 250 feet high with a 210 foot horizontal boom, two 180 foot interconnected steel towers, plus several guyed steel and wood structures. See frontispiece. The guy cables are the critical support members for these structures. Structural deflections, stability, and the survival of these structures when subjected to loading situations depend upon the initial, or pretension, cable tensions. These prescribed tensions must be periodically checked and adjusted if necessary. In several past efforts guy cables were checked by removing and resetting the tension with an in-line force gage. A length of cable, with a force gage and turnbuckle in line, was connected several feet above the ground anchor to the cable being reset. This new cable was then tensioned to the desired pretension value while the lower portion of the tower cable went slack. The tower cable was then adjusted using its turnbuckle until the needle of the force gage in the added short length of cable just began to drop. At this time the added cable would be untensioned and removed. This procedure was very time consuming, particularly with large diameter cables. During the 1974 and 1975 time period, a vibration technique was developed and tested at RADC's Ava Test Site with good results. When the requirement to check all of the guyed structures used for the Computer Controlled Antenna Measurement System at Stockbridge was made, it was decided that alternate techniques, particularly the vibration method, should be investigated. The original cable tensioning efforts at Stockbridge were made using the "sag method" for some cables and a clamp on tensiometer for others. Both methods have disadvantages that are discussed in this report. Appendix I of this report contains a complete documentation of the guy cable data for the guyed structures of the CCAMS. The installation tensioning methods and required cable data are documented in addition to the field data collected and analyzed for this present effort.

II THE SAG METHOD

Of all the methods described in this report, the sag method is the only one that does not deform the cable to determine the tension. This eliminates any possibility of damage to the cable or towers. Sag is a widely accepted method of tensioning cables especially when a tensiometer cannot be used. Cable tensions measured by the sag method will be used as a standard to which the other methods will be compared.

The theory behind the sag method is based on the geometry of a cable hanging between end supports. Generally, a cable allowed to deform under its own weight will take the shape of a parabola, providing it is taut. If a scope is attached tangent to the cable, a point will be viewed under the end support at the tower as shown in Figure 1. The distance from the viewed point to the end support is known as the intercept. The intercept is a function of the distance between the end supports (L), the weight per unit length of the cable (W), and the tension (T). The distance (L) can be measured and the weight per unit length can be obtained from the cable manufacturer. Thus, the tension will be a function of the intercept. The relationship given in Reference 1 (Pg 110) is as follows:

$$T = \frac{WL^2}{2I}$$

Where

W = Weight per unit length (lbs/ft)

L = Length between the end supports (ft)

I = Intercept (ft)

T = cable Tension (lbs)

However, in practice, the above relationship cannot be directly applied due to two required corrections for the value of the intercept. The first correction is for scope displacement. The true intercept is found by the tangent to the cable taken from the cable center line. The line of sight of the scope is parallel to the tangent, however, and is displaced from the cable. To correct for this, a measurement must be made from the center line of the cable to the center of the eye piece of the scope as shown in Figure 2. This distance is a component of the vertical correction (S) which must be subtracted from the direct reading (R). The second correction is due to horizontal target displacement. If the intercept is read from a target in front of or behind the end support, a correction must be made to interpolate to the working point reference

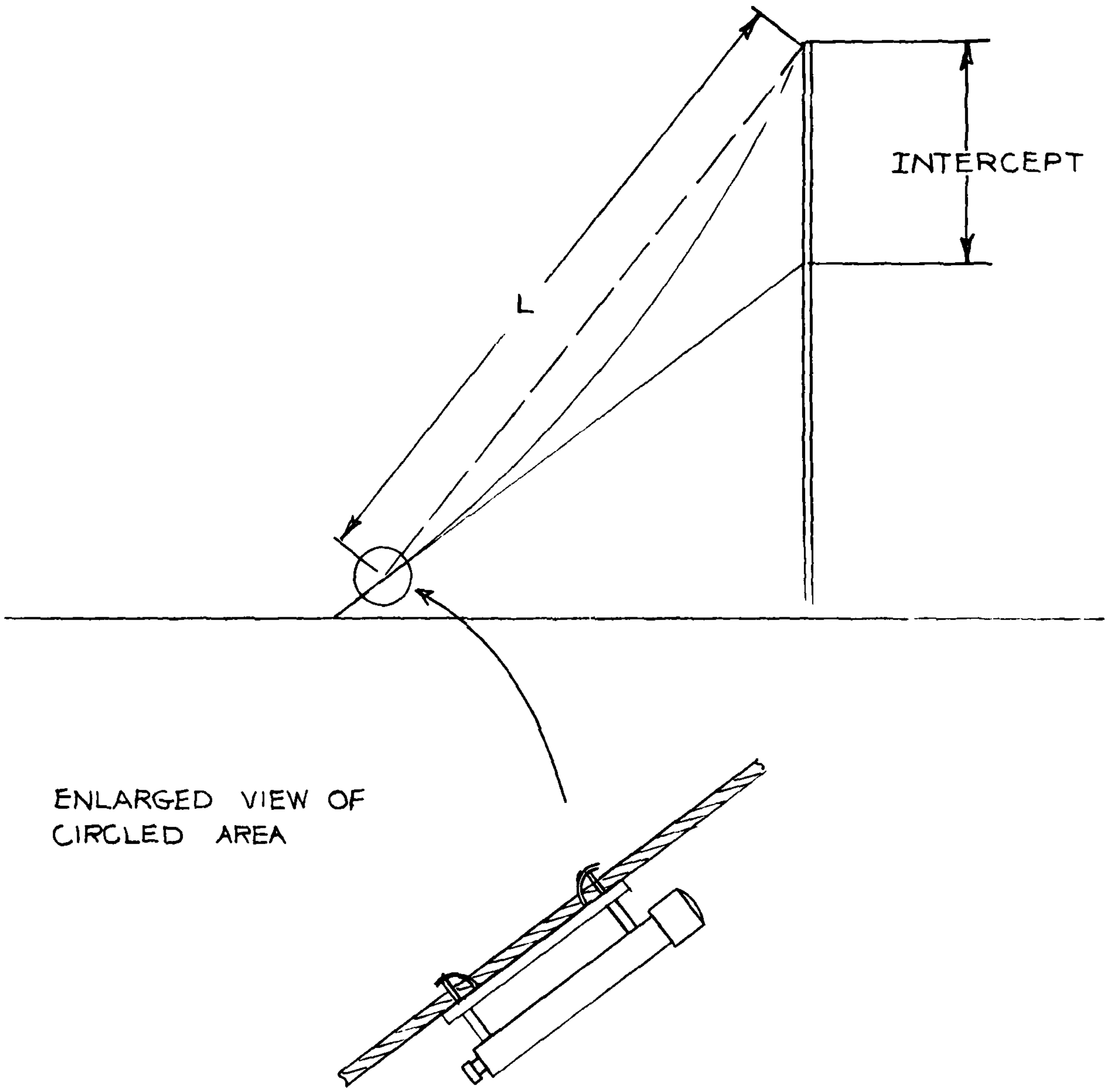


FIGURE 1
THE SAG METHOD

NOTE:
DIMENSION RELATING TO TRUE GUY TENSION IS DENOTED IN THE FOLLOWING DIAGRAM AS THE VARIABLE C. THIS ISN'T NECESSARILY THE ONLY CORRECTION

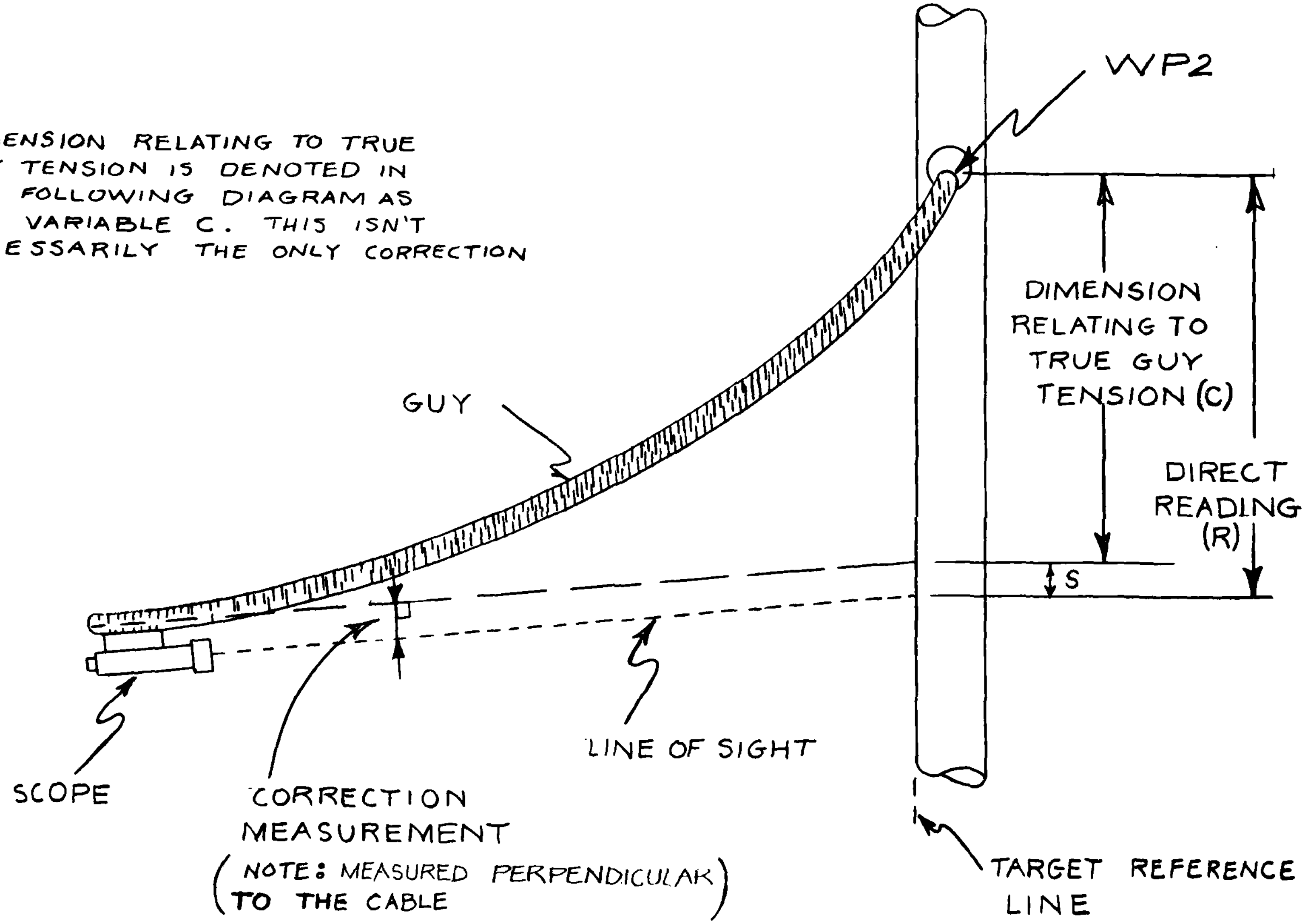


FIGURE 2 CORRECTION ANALYSIS FOR SCOPE DISPLACEMENT

line. Examples of target displacement can be seen in Figures 3 and 4.

It should be noted that a third correction is needed when the scope cannot be placed directly on the lower work point. The distance between the scope and the work point (D) must be subtracted from the length (L). This effectively places the scope at the lower point.

PROCEDURE

1. Follow the procedure for leveling the scope described later.
2. Choose a location on the cable close to the lower work point where there are no cable attachments or wrappings. (To reach this point, a ladder may be needed).
3. Measure the distance from the scope to the lower work point (D).
4. Clamp the cable holder to the cable making sure not to exert any external forces on the apparatus.
5. Look through the scope and rotate until the target can be seen. Record the target reading intercepted by the horizontal cross hair.
6. Using a ruler, measure the perpendicular distance from the center of the eye piece to the center of the cable.
7. Acquire values for length (L), weight per length of the cable (W), angle of inclination (α), and detailed geometry of the end supports.

SAMPLE CALCULATION

Referring to Figure 5

Given Data:

D = 10 ft

L = 175 ft

W = .517 lb/ft

M = 2.5 inches

$\alpha = 42^{\circ}$

Recorded Data:

Direct scope reading (C) = 2'7" = 2.625'

Perpendicular scope correction (F) = 2.75" = .229'

Calculation of Proper Intercept

$P = M \tan \alpha$

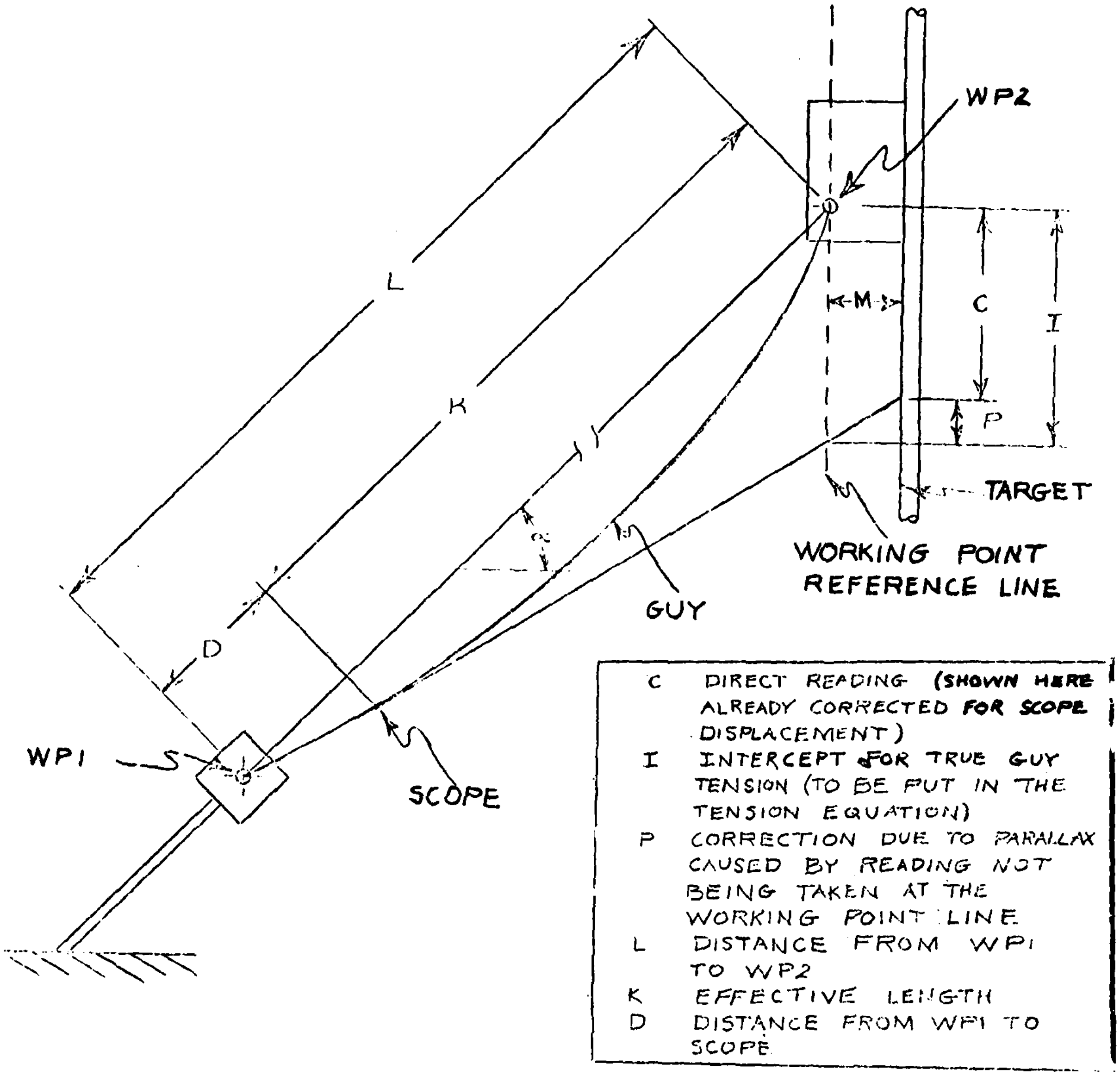


FIGURE 3

TARGET DISPLACEMENT M BEHIND WORK POINT

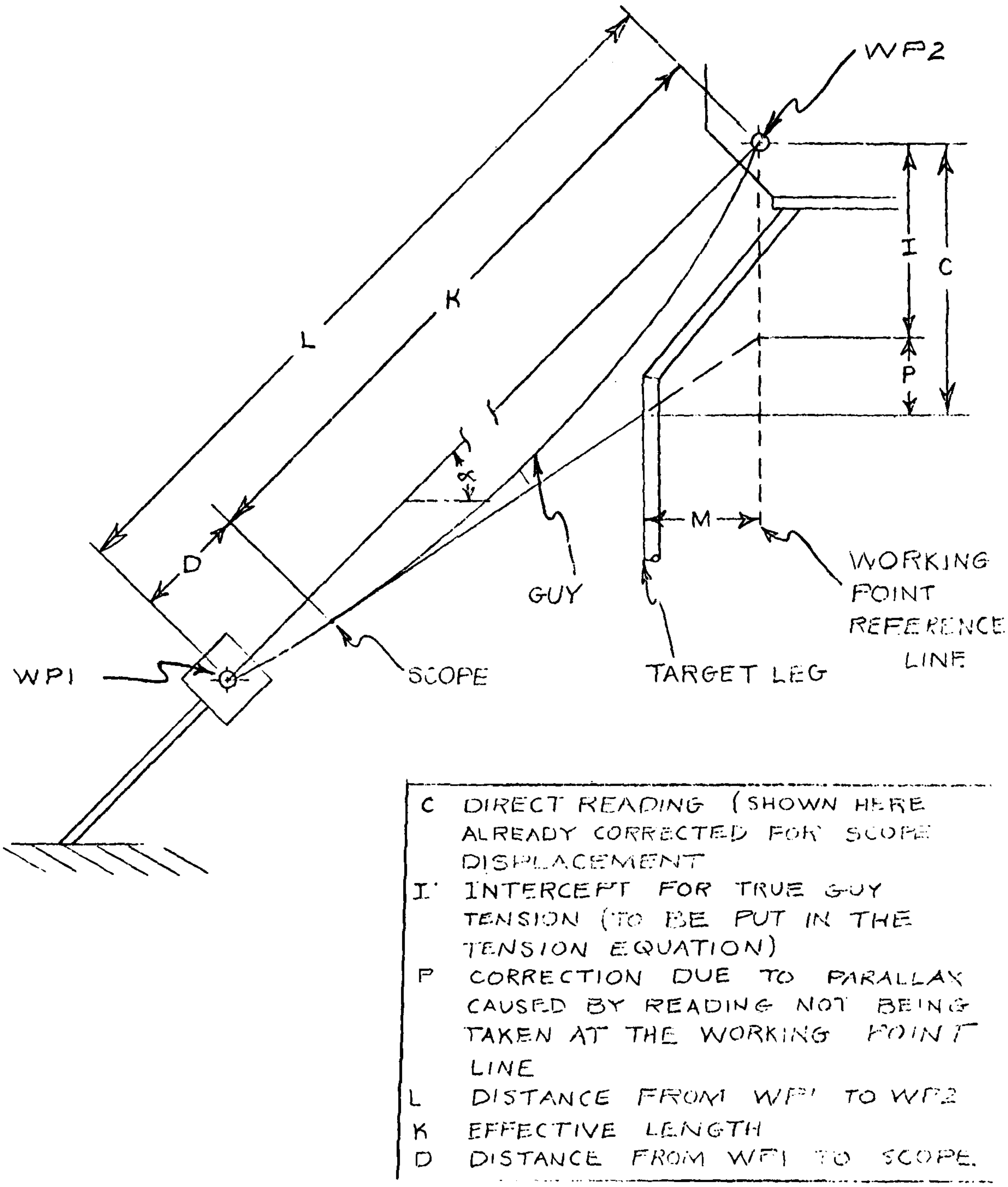


FIGURE 4
TARGET DISPLACEMENT M IN FRONT OF WORK POINT

Vertical scope correction $(G) = \dfrac{F}{\cos\alpha}$

$I = C \pm P - G$

(Note: P is Positive if work point is in front of target leg, Figure 3
P is negative if work point is in back of target leg, Figure 4)

For Figure 5

$I = C + P - G$

$I = C + M \tan\alpha - \dfrac{F}{\cos\alpha}$

$I = 2.625' + \dfrac{(2.5)}{(12)} \tan 42^o - \dfrac{.229}{\cos 42^o}$

$I = 2.50$ ft

Calculation of Effective Length

$K = L-D$

$K = 175 - 10$ ft

$K = 165$ ft

Calculation of Tension

$T = \dfrac{WK^2}{2I} = \dfrac{(.517 lb/ft)(165ft)^2}{2(2.50ft)}$

T = 2,809 lbs

FIELD OBSERVATIONS

The sag method is an effective way to measure guy cable tension. It is recommended for use on long cables with large sag. However, for large numbers of guy cables, the sag method becomes very time consuming. For each cable, several necessary steps are required. Separate targets must be properly mounted at the upper end support of each cable. Placing targets requires climbing the towers and working at difficult and awkward locations. Through analysis of the sag equation, it is noted that the length (L) is a critical parameter due to its squared relationship with the tension. Thus, it is imperative to have accurate lengths. To correct for the problem of target displacement, a detailed sketch and dimensions of the upper work point of each cable is required as well as the cable angle (α).

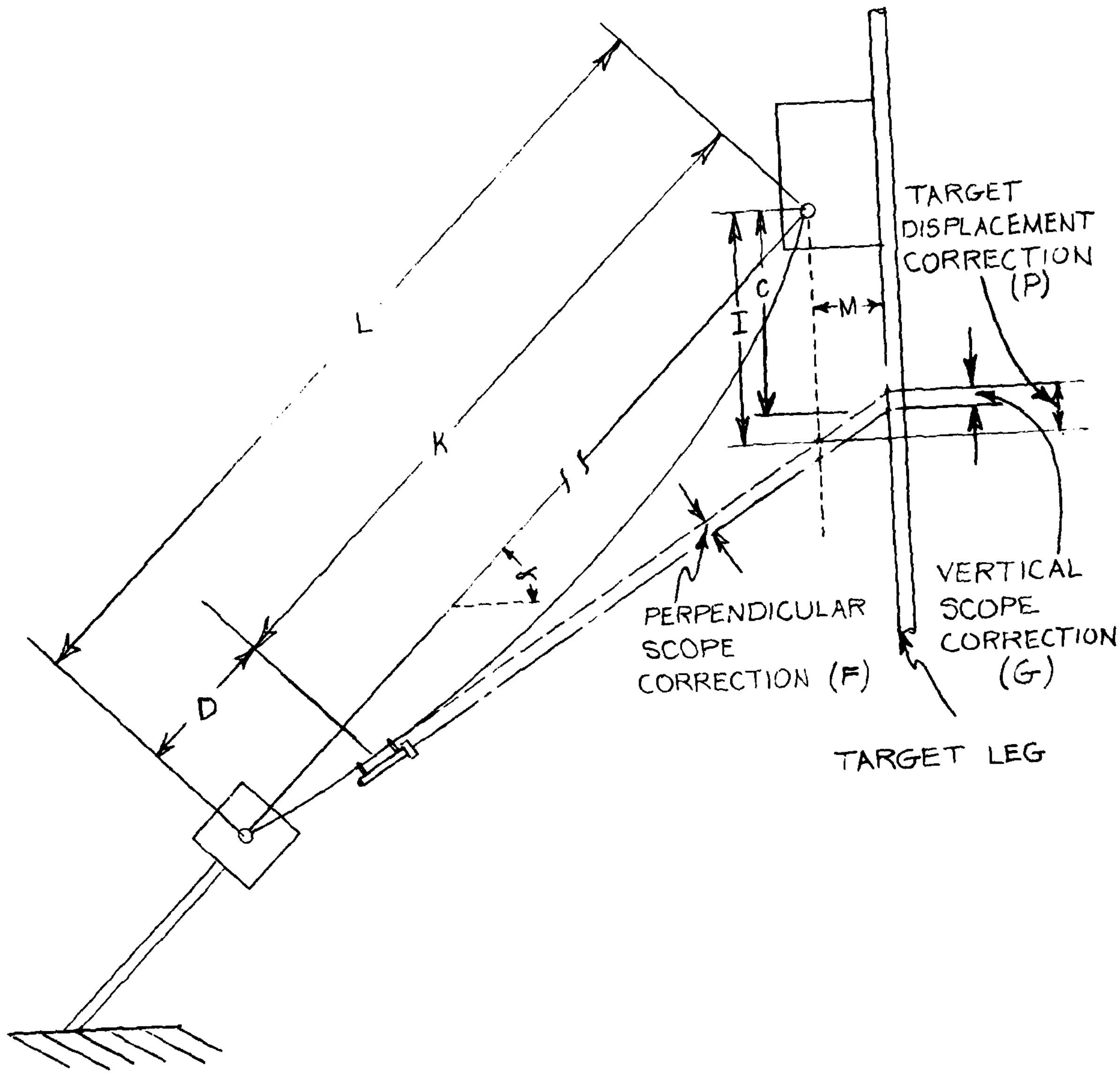


FIGURE 5

SAG METHOD CORRECTIONS

Prior to the measuring of any sag data, the scope should be leveled to insure that the line of sight is parallel to the cable tangent. It is noted that when the scope is repeatedly placed on a cable in approximately the same position, multiple readings will be obtained. It is advisable that, for each cable, several readings be taken and the most probable intercept value be chosen for the calculations. Also, high winds cause large fluctuations in the scope readings. It is advisable to choose a day with proper weather conditions.

Although the sag method is accurate for most applications, it requires a great deal of preparation. For this reason, alternate methods of measuring guy cable tensions are addressed in this report.

LEVELING THE SCOPE

To level a scope for use in the sag method, it is imperative that the cable holder is parallel to the line of sight of the scope. The parallel adjustment of the scope and holder is shown to be critical by an analysis which follows. The analysis shows large deviations in tension for small errors. The adjustment can be accomplished with the aid of a bubble level which is attached directly to the scope. The bubble level is used only to insure that the line of sight of the scope is parallel to the cable. However, before this can be done, the bubble level must be adjusted. Basically the overall procedure is as follows:

1. Adjust the bubble level to the line of sight.
2. Level a short length of the appropriate cable.
3. Place the scope and cable holder over the leveled cable and adjust the holder until the bubble is centered.

The adjustment of the bubble level attached to the scope as shown in Figure 6 is the most difficult step. The proper order of the process is to level the line of sight and then adjust the bubble level to indicate this. To level the line of sight another reference is required. Although a floor may appear to be level it is not accurate enough for this experiment; thus, no reference assumption can be made from it. There are several ways to bring the line of sight to level and all require an adjustable tripod. It should be noted that for ease of adjustment, the tripod should be set up so that the diagonal of the square connecting the adjusting screws lies on the line of the targets. An arrangement of this kind allows adjustment to affect only one dimension of the scope's view. The leveling methods are:

1. Mirror Reflection
2. Level Plate
3. Two Targets

(Note: For all methods, see Figure 6)

1. Mirror Reflection Method

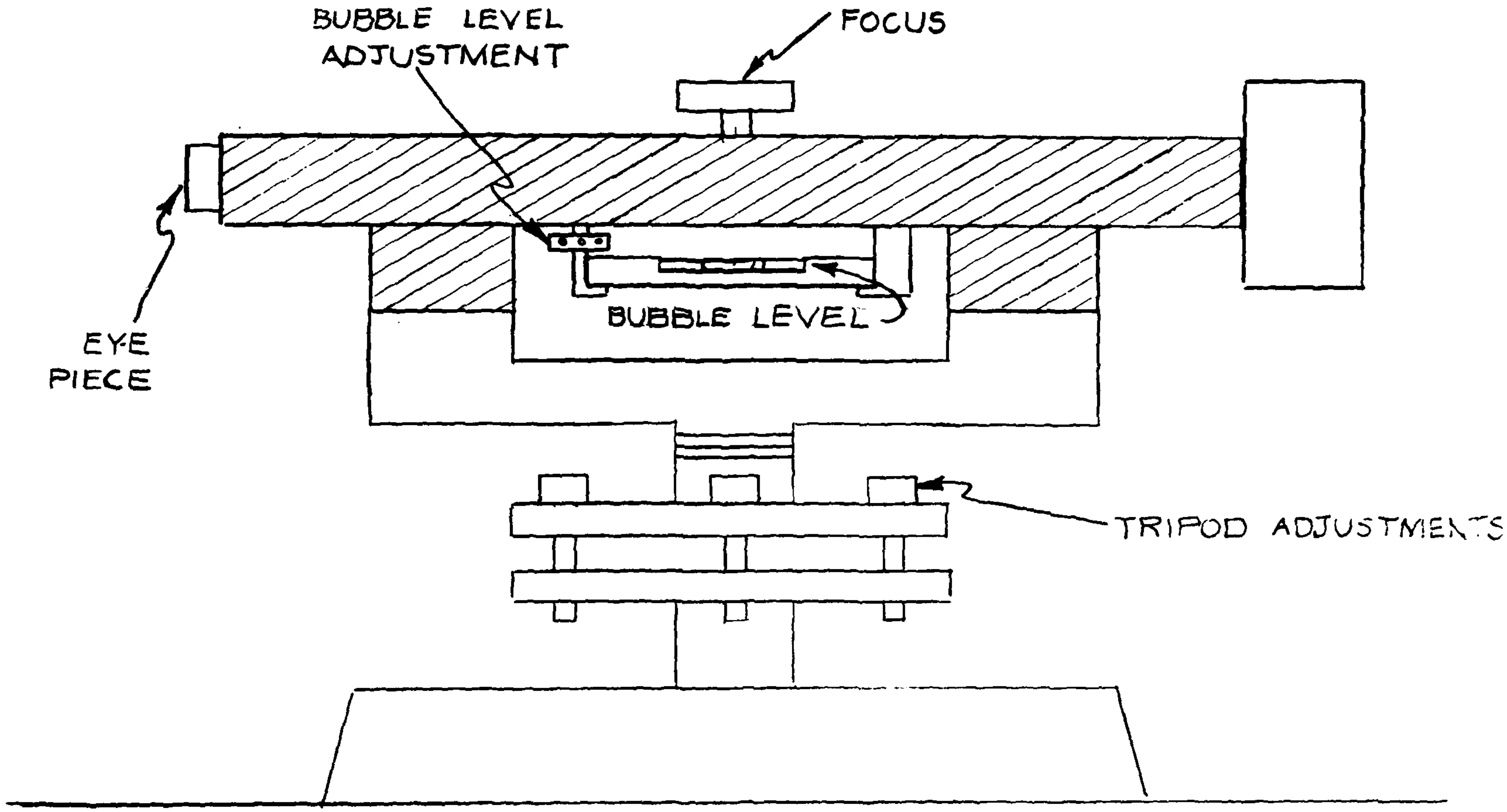
If a mirror is placed on a wall and adjusted to lie perfectly vertical at approximately the same height of the scope, it will be possible to get the line of sight parallel to horizontal. Shooting the scope at the mirror and lining the crosshairs with the reflection of the center of the scope will bring it into level. The greater the distance between the scope and the mirror, the greater the accuracy. After the scope is horizontal, the bubble can be centered. The difficulty with this method is the time required to accurately level a mirror at the proper height on the wall.

2. Level Plate Method

A screw adjustable plate can be brought to level by trial and error adjusting using a precision level. Once completed, place the scope and tripod on the plate and attach a target to the wall a reasonable distance from the scope. Focus the scope and take a target reading. Now rotate the base 180^{o} and take another reading keeping the scope in the same direction. Adjust the tripod and keep on taking readings until identical readings are achieved. Center the bubble and the process is complete.

3. Two Target Method

The two target method is convenient since no level or vertical surface is required. Instead of using a level surface, this method uses two points at the same elevation to level the line of sight. To find these supplementary points, the scope and tripod are placed on a table equal distance from two targets so that the tripod and the targets lie in a straight line (Figure 7, Position 1). The targets should be as far apart as reasonably possible. The next step is to level the tripod in all directions which can be done by adjusting it so that the bubble is centered and remains centered after a scope rotation of 180^{o}. This is achieved by trial and error adjusting both the tripod and the bubble level.



NOTE: THE SCOPE IS SHADED TO DISTINGUISH IT FROM THE TRIPOD

FIGURE 6 SCOPE WITH BUBBLE LEVEL AND TRIPOD

When this condition is achieved, it cannot be assumed that the line of sight is level; however, it will have the same slope when rotated 180^{o}. Since the scope is equidistant from the targets and the slope of the line of sight is a constant, the readings viewed on the targets will be at the same elevation (reference points). Next, place the scope and tripod setup to a point still in line with the targets but not between them. A favorable position would be where one of the targets is equidistant from the other target and the scope (Figure 7, Position 2). Aim the scope at the targets and lock it from rotation. Slowly turn the tripod so the scope view moves only in the vertical direction. Adjust the view so the horizontal crosshair is the same distance above or below each reference marker on their respective targets. This distance is denoted by the variable D in Figure 7. This will occur only when the scope is level and the bubble is centered. If the bubble is not centered, adjust it with a steel pin. The scope can now be leveled by simply centering the bubble.

The procedure can be checked by moving the tripod to an arbitrary position. From this position, view both targets to make sure that the readings are equidistant from the reference markers. If this situation occurs, the procedure was done correctly.

Leveling the Cable Holder (Figure 8)

There are many design possibilities for the cable holder. This makes a standard leveling procedure nearly impossible; however, there is a general approach. Acquire an appropriate length of cable and clamp it to a chair. By trial and error adjusting of its ends, level the cable with a precision level. Remove the scope from the tripod and attach it to the cable holder. Most cable holders will attach to the scope in two places, both of which allow for adjustment. To prevent problems from occurring , tighten one adjustment so that the slope of the scope is only dependent on the other adjustment. Place the apparatus on the leveled cable and adjust until the bubble level is centered. Now tighten the cable holder.

An error analysis was performed to determine the effect of the scope adjustment on the calculated tension. The analysis was carried out as follows. The sag method is applied to a cable with a known tension. The analysis calculates the intercept and the angle of the scope with respect to the horizontal. Then the tension is recalculated deviating the scope angle (by 1^{o} and $.1^{o}$) from the proper angle.

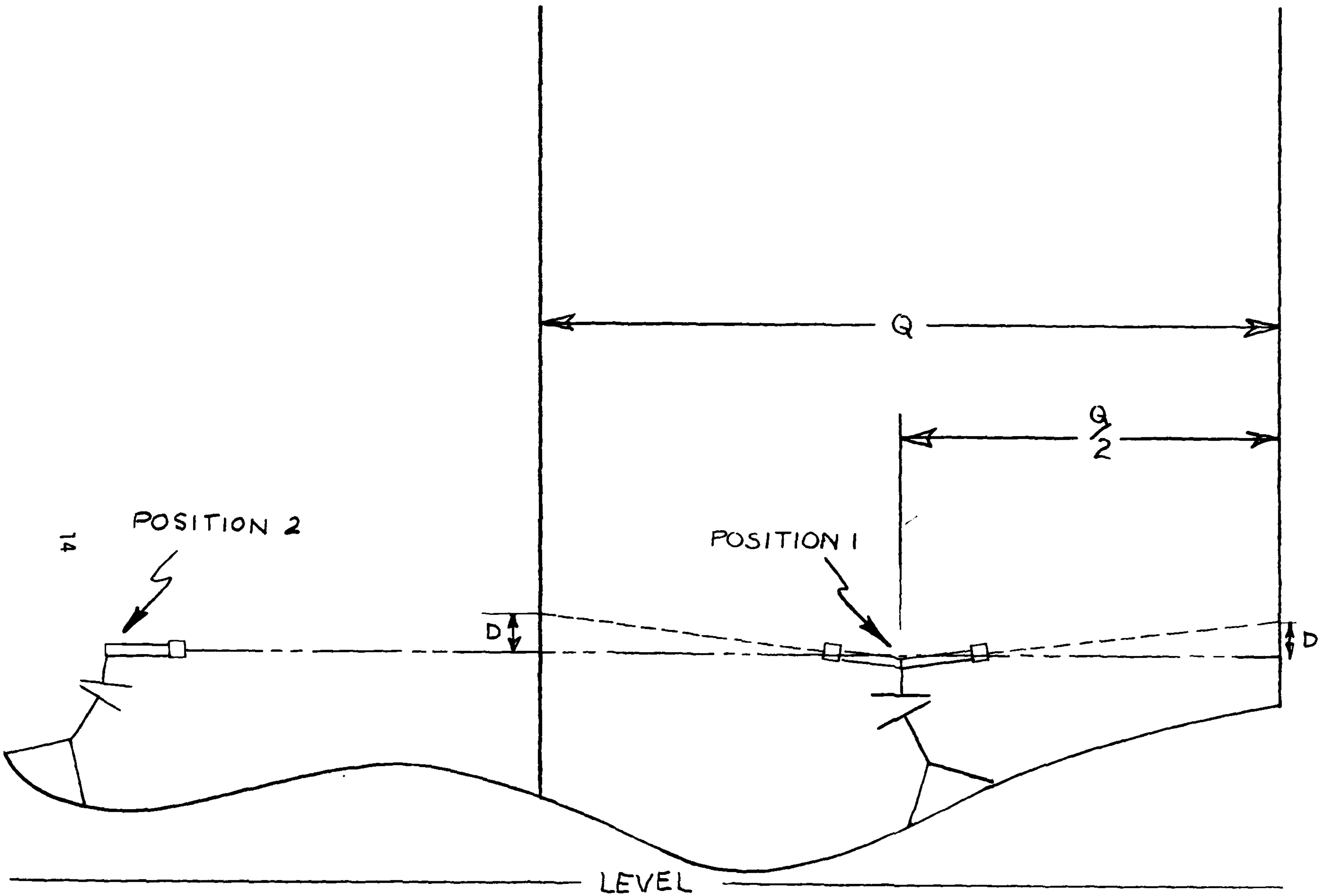


FIGURE 7 TWO TARGET METHOD

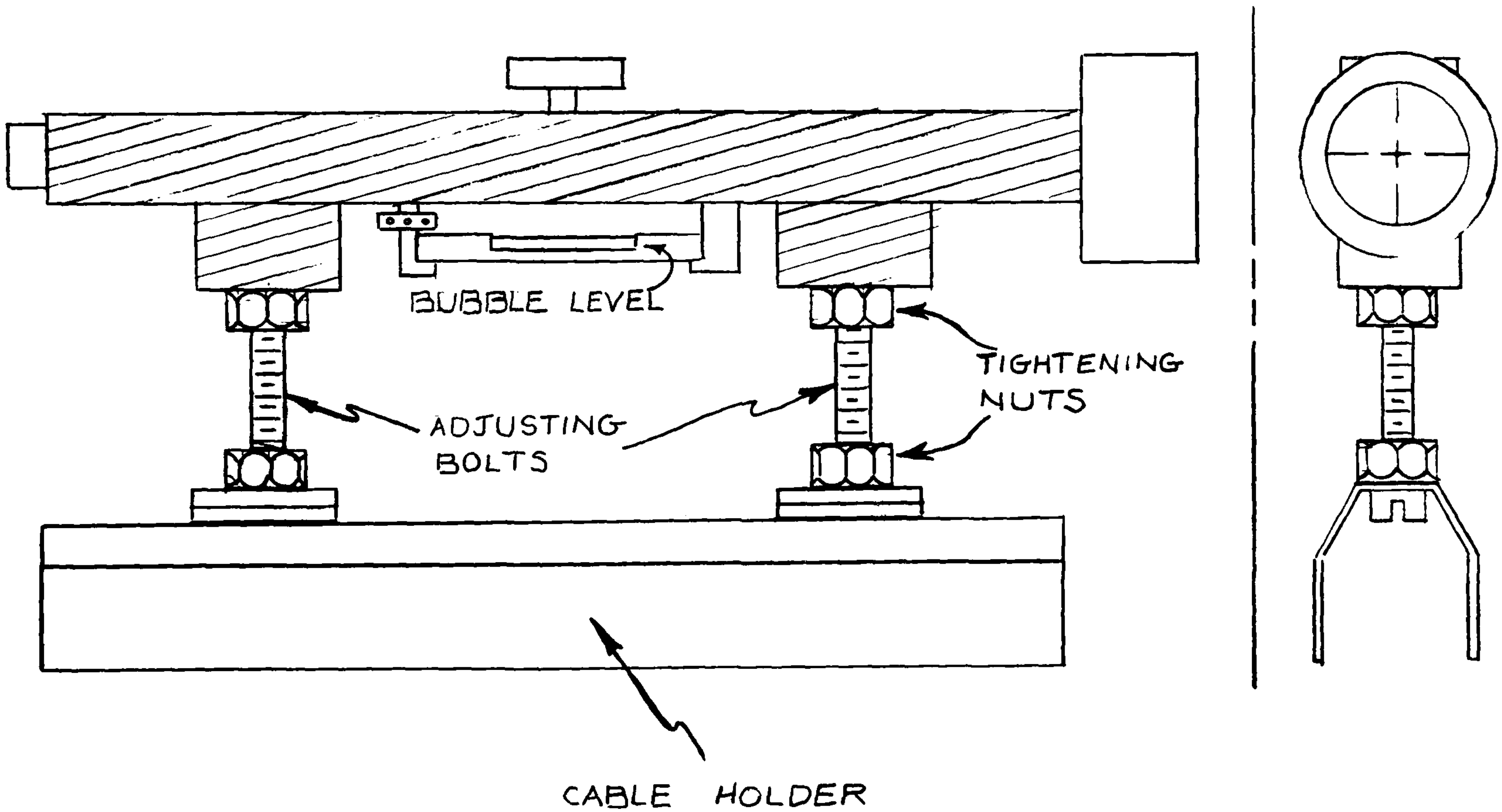
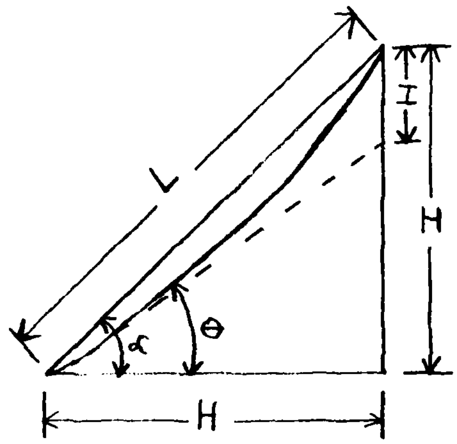


FIGURE 8 SCOPE WITH CABLE HOLDER

The values of tension for both cases will be compared to the proper value to illustrate the importance of the scope adjustment.

Tension Error Caused By Scope Error

Consider a typical tower application



First calculate the proper intercept

$$T = \frac{WL^2}{2I}$$

Therefore $I = \frac{WL^2}{2T}$

Let L = 347.89 ft

H = 246 ft

W = 4.73 lb/ft

T = 68,000 lbs

$$I = \frac{(4.733\,lb/ft)(347.89ft)^2}{2(68,000\ lbs)}$$

I = 4.21ft — Proper intercept reading for designated 68,000 lbs pretension

Calculating θ for above I:

$$\theta = \tan^{-1} \frac{(H-I)}{H}$$

$$\theta = \tan^{-1} \frac{(246-4.21)}{246}$$

$\theta = 44.51^{o}$ (for a tension of 68K)

Suppose the scope was one degree (1^0) from parallel with the tangent to the cable, the new angle will be called θ'

$\theta' = 44.51 - 1 = 43.51^0$

$\text{Tan } 43.51 = \dfrac{246 - I'}{246}$

$I' = 12.51$ ft

Now calculating the corresponding tension using I':

$T' = \dfrac{WL^2}{2I} = \dfrac{(4.73 \text{lb/ft})(347.89 \text{ft})^2}{2(12.51 \text{ ft})}$

$\underline{T' = 22{,}881 \text{ lbs}}$

Now performing the same calculation with an error of $.1^0$

$\theta' = 44.51 - .1 = 44.41^0$

$\tan 44.41 = \dfrac{246 - I'}{246}$

$I' = 5.01$ ft

Calculating the corresponding tension

$T' = \dfrac{WL^2}{2I'} = \dfrac{(4.73 \text{lb/ft})(347.89 \text{ft})^2}{2(5.01 \text{ft})}$

$\underline{T' = 57135 \text{ lbs}}$

Results:

Proper Tension With No Error	68,000 lbs
Tension With 1^0 Error	22,881 lbs
Tension With $.1^0$ Error	57,135 lbs

A second example for a shorter tower:

W = 2.10 lb/ft

H = 103.69 ft

L = 146.64 ft

T = 28,000 lbs (proper)

$I = \dfrac{WL^2}{2T} = \dfrac{(2.10 \text{ lb/ft})(146.64 \text{ft})^2}{2(28{,}000 \text{ lb})}$

$I = .806 \text{ ft} = 9.68 \text{ in}$

$$\theta = \tan^{-1} \frac{(H-I)}{(H)} = \tan^{-1} \frac{(103.69-.806)}{103.69}$$

$\theta = 44.78^{0}$

With 1^{0} error

$\theta' = 43.78$

$$\tan 43.78 = \frac{(103.69 - I')}{103.69}$$

$I' = 4.34 \text{ ft}$

$$T' = \frac{(2.1)(146.64)^{2}}{2(4.34)}$$

$\underline{T' = 5206 \text{ lbs}}$

With $.1^{0}$ error

$\theta = 44.68$

$$\tan 44.68 = \frac{(103.69-I')}{103.69}$$

$I' = 1.15 \text{ft}$

$$T' = \frac{(2.1)(146.64)^{2}}{2(1.15)}$$

$\underline{T' = 19602 \text{ lbs}}$

Results:

Proper Tension with no Error	28,000 lbs
Tension with 1^{0} Error	5,206 lbs
Tension With $.1^{0}$ Error	19,602 lbs

The results of this analysis show the need of having a properly adjusted scope. An angular error of only $.1^{0}$ results in a tension error of 20 percent. It is concluded that sufficient care must be taken when adjusting the scope.

III CLAMP ON DEFLECTION TENSIOMETER METHOD

One of the major considerations for measuring guy cable tensions is the ease and quickness of taking the readings. This becomes more important with large numbers of cables. It is also desirable not to require steel construction workers to climb the towers to place targets or make physical measurements. The clamp on tensiometer is an attractive method. It does not require climbing towers or making special preparations. Once the tensiometer has been calibrated, readings can be taken as quickly as the tensiometer can be clamped onto the cable.

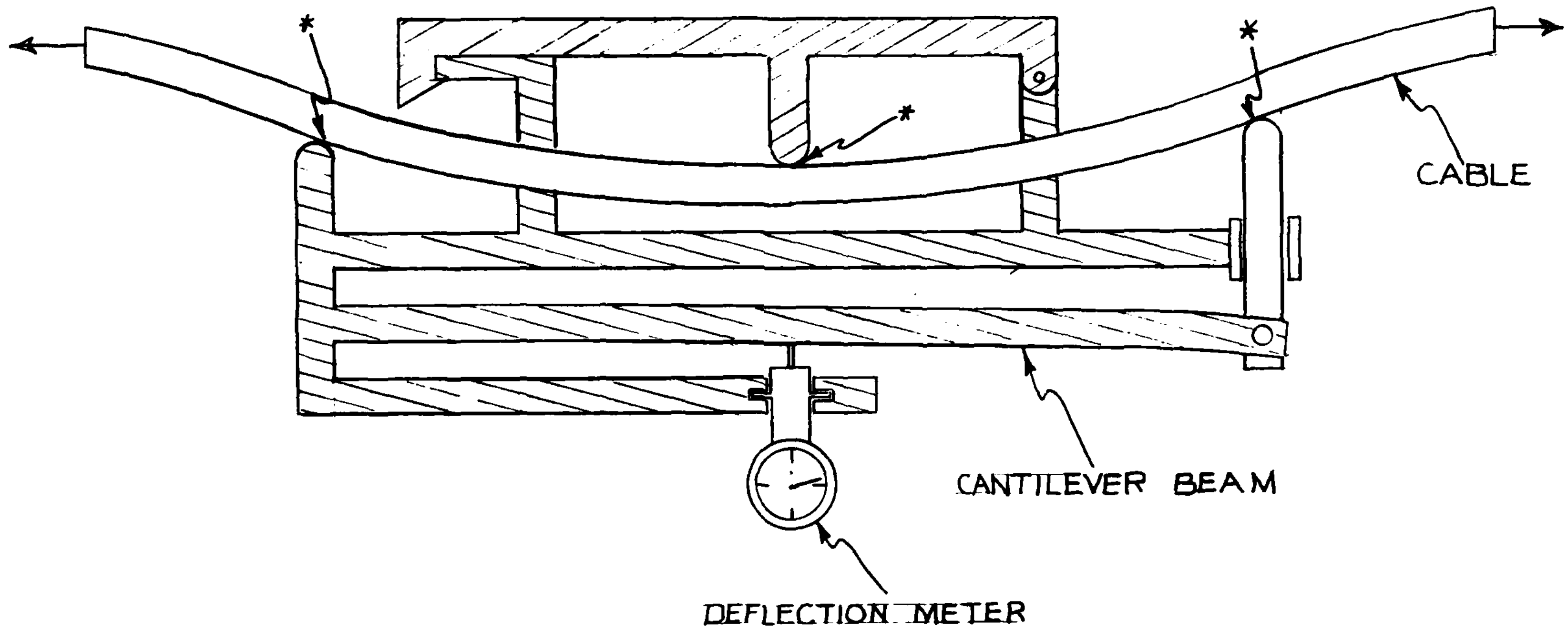
The tensiometer's theory is relatively simple. A known deflection is put in the cable by three forces which are applied in the same plane, perpendicular to the nondeflected center lines. A single meter reading determines the magnitude of these forces. Knowing these forces, the deflection, and the cable geometry, a tension can be found by force resolution of a cable segment.

A practical method of determining the magnitude of the applied force normal to the cable is shown in Figure 9. One of the positions of force application is attached to a cantilever beam which creates a small displacement. The displacement is measured and used to calculate the applied force through a cantilever deflection equation. The displacements are linearly related to the force applied.

CALIBRATION OF THE TENSIOMETER

DIRECT METHOD:

The most obvious and practical way to calibrate the tensiometer would be to attach it to cables with known tensions and then develop a graph of tension versus cantilever beam deflection. This would be very accurate, but it does pose some practical problems. A lab calibration requires the availability of proper testing equipment. This case would involve a tensile testing machine able to stretch long cable specimens. The tensiometer could have a length of approximately two feet. Many tensile machines can only test specimens of a few inches in length. Also, the end connections of the cables must be compatible with the tensile testing machine mounts which are usually threaded. An important consideration is that each size and type of cable be calibrated individually. This results in a different table and calibration for each type of cable. It is also possible to have cables in the field which are tensioned to known values using an in-line force gage. With the known tensions, a calibration can then be performed for that type of cable. If there is not an opportunity to directly calibrate the tensiometer, then an analytical method may be used.



NOTE: * REFERS TO POSITION OF APPLIED FORCE

FIGURE 9 SCHEMATIC OF TENSIOMETER

ANALYTICAL METHOD:

The analytical approach is to determine tension by force resolution. This requires knowledge of the geometry of the deflected cable. In all cases, prior to attaching the tensiometer, we will assume a short segment of the cable under tension to be straight. Since we are using a relatively small deflection compared to the test length of the cable, we can also assume the cable remains straight a small distance outside the end clamps of the tensiometer. Between the clamps, the cable can take the shape of a string or a beam depending upon the bending strength of the cable. Once the geometry is known, the forces are resolved about either end point of the tensiometer (Figure 10). Neither the magnitude nor the direction of the end forces are known; however, we do know the vertical component would be equal to $\frac{P}{2}$. With the assumption that the cable is perpendicular to the central applied force, a critical parameter is the angle θ (Figure 10). θ is directly dependent on the cable properties and eventually will result in a major error consideration for the analytical method of tensiometer calibration.

Error Analysis When Using the Analytical Method To Measure Cable Tension

It is strongly emphasized that the most accurate measurements of cable tensions with a clamp on deflection tensiometer are obtained when the device has been calibrated with the exact size and type of cable under known tensions. If direct calibration is not possible, then the analytical method of resolving forces at one of the end clamps of the tensiometer may be used. As previously indicated, the amount of beam-like properties of the short length of cable between the end clamps of the tensiometer will effect the accuracy of the force resolution. Referring to Figure 10, the angle θ for a fixed deflection would be larger for a stiff cable as compared to a cable behaving like a string. Also, it has been observed that clamping the tensiometer on a length of stiff cable that was completely untensioned results in a large meter reading.

To properly evaluate these errors, three cases are to be considered:

1. The cable behaves like a perfect string.
2. The cable behaves like a beam.
3. The cable behaves like a string with varying amounts of beam properties.

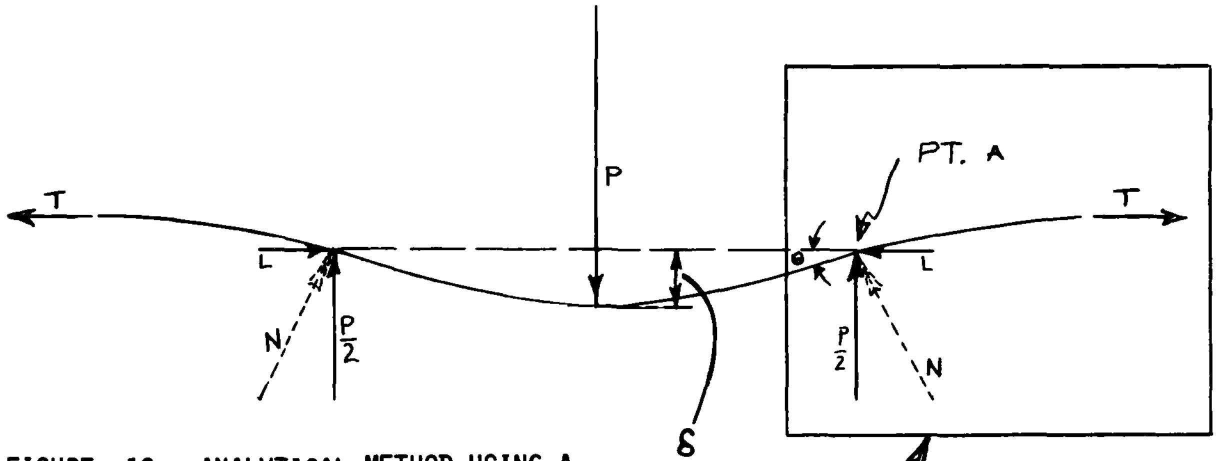


FIGURE 10 ANALYTICAL METHOD USING A TENSIOMETER

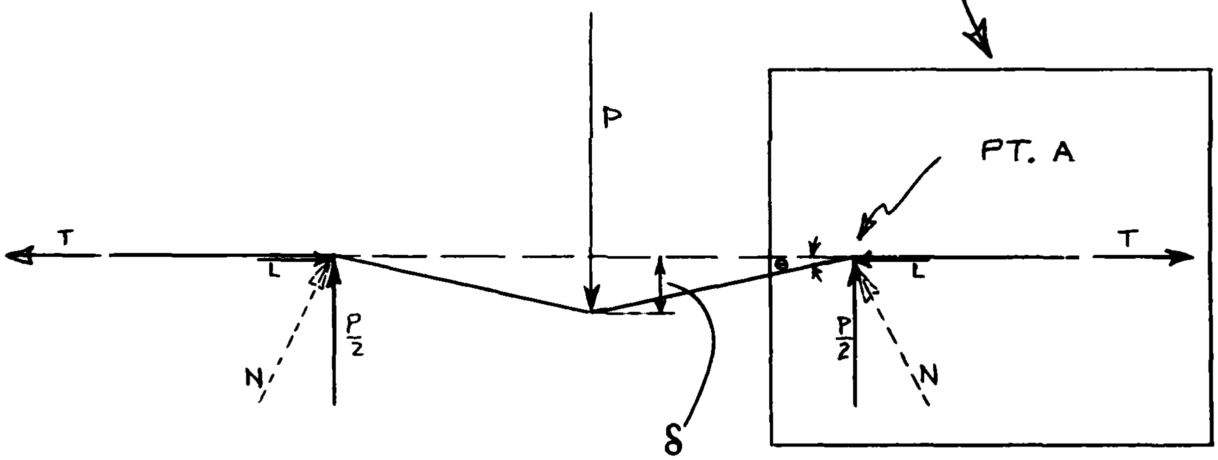


FIGURE 11 PERFECT STRING CASE

1. <u>The Perfect String</u>

Since a perfect string supports no bending moment, the cable will be straight between points of force application, as shown in Figure 11. This simplification eliminates all curves from the diagram and allows θ to be calculated from the geometry of the included right triangle.

$$\theta = \tan^{-1}\frac{\alpha}{L}$$

As previously stated, once θ is known the tension can be found by force resolution by the equation:

$$T = \frac{P}{2\sin\theta} \qquad \text{(Figure 12)}$$

2. <u>Cable As A Beam</u>

In the case of assuming the cable to behave as a beam, the angle θ becomes much more difficult to evaluate. Consider a beam on simple end supports with a concentrated center load. Without an axial load, the angle θ can be evaluated by the well known beam deflection equation:

$$\theta = \frac{w\ell^2}{16EI}$$

However, with an axial load applied, the relationships between deflections and lateral load become very complicated and include the unknown axial force as well. For example, a simply supported beam of length "ℓ", loaded by a concentrated load of magnitude "w" with an axial load in tension of "P" has a deflection "y" at the center of the beam given by the following:

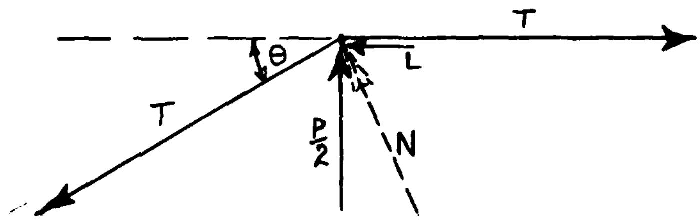
$$y = \frac{w}{P}\left(\frac{\ell}{4} - \frac{1}{2}\,j\tanh\frac{1}{2}U\right) \qquad \text{where}$$

$$U = \frac{\ell}{j}$$

$$j = \sqrt{\frac{EI}{P}}$$

tanh = hyperbolic tangent

Thus, since "P" is an unknown (the desired value of the cable tension), force resolution of a clamp on tensiometer becomes difficult for finding the axial tension in a beam. It should further be noted that "I", the bending moment of inertia, cannot be computed for a stranded cable because the cross section material is not homogeneous.



NOTE: THE NORMAL FORCE N (DASHED) HAS BEEN RESOLVED INTO P/2 AND L

FIGURE 12

SCHEMATIC FORCE ANALYSIS OF PT. A

3. String With Varying Amounts of Beam Properties

A further evaluation reveals a method to treat the cable as a string with varying amounts of beam properties. Figure 13 shows a free body diagram of a short length of cable with the applied forces from the tensiometer. We have now chosen to analyse the boxed in section of Figure 13 which has been enlarged and is shown in Figure 13a with all the forces acting on it. The cable exhibits two characteristics due to its beam properties. They are the shear force (s), acting perpendicular to the deflection of the cable, and the bending moment(M) which is created by the right cable tension force being displaced from the point of resolution by a distance (d). If these properties could be eliminated, the cable would act as a perfect string and could be evaluated as such. A reasonable approach would be to clamp the tensiometer on to a length of untensioned cable and record the meter reading. Then this value could be subtracted from readings taken on tensioned cables. Would this approach eliminate these beam properties? To do this we will analyze two cases, the tensioned and untensioned cases. Figure 13b shows the forces of the cable segment from Figure 13a summed about the point of the applied tensiometer force. To simplify the diagram we have displaced the tension to the point of resolution and applied a moment to compensate for it (Figure 13c). The moment created is equal but opposite to the bending moment.

$M = Td$

Now resolving the forces of Figure 13c in the vertical direction:

$$\frac{P}{2} = T \sin \theta + S \cos \theta \qquad \text{(tensioned cable)}$$

Now consider the case where the tensiometer is clamped on the same cable without tension. The force variables for the untensioned case will be designated by primed notation. Therefore, by resolving the force diagram (Figure 13d)

$$\frac{P'}{2} - S' \cos \theta = 0 \qquad \text{(untensioned cable)}$$

Rearranging terms:

$$\frac{P'}{2} = S' \cos \theta$$

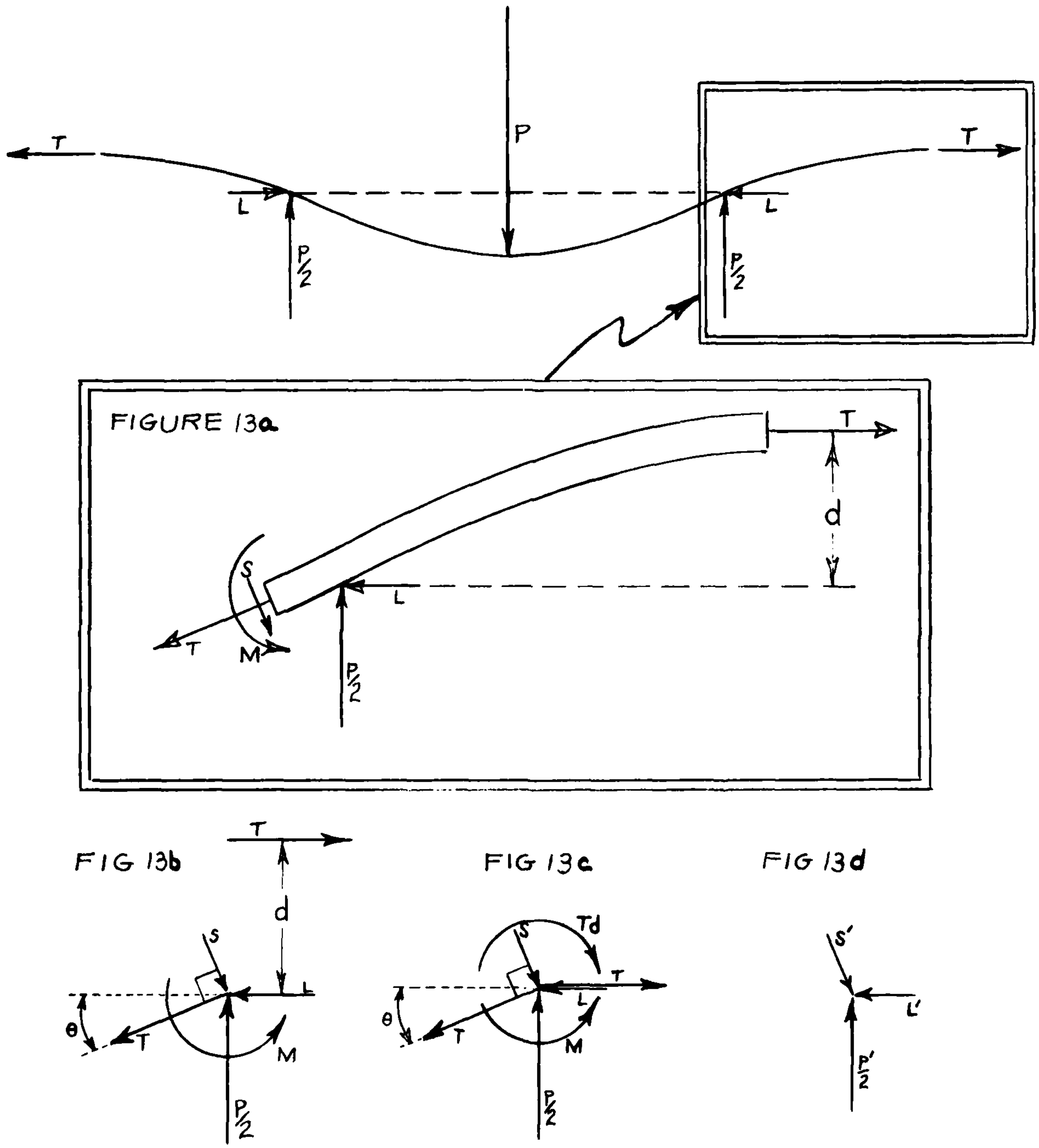


FIGURE 13

STRING WITH BEAM PROPERTIES

Now subtracting the equations for the tensioned and untensioned cases we get

$$\frac{P}{2} = T \sin \theta + S \cos \theta$$

$$\left(\frac{P'}{2} = S' \cos \theta'\right)$$

$$\frac{P}{2} - \frac{P'}{2} = T \sin \theta + S \cos \theta - S' \cos \theta'$$

It is noted that if the shear forces and angles for the tensioned and untensioned cables are equal, the last two terms of the above equation cancel out. This would result in tension as a function of a constant (sin θ) and the tensiometer applied forces, $\frac{P}{2}$ and $\frac{P'}{2}$. This would allow the tension to be calculated by subtracting the magnitude of the applied tensiometer forces for the tensioned and untensioned cases and solving as if the cable were a perfect string. However, shear is a function of the applied tensiometer force which varies with cable tension. Therefore, S and S′ will differ considerably. As a result, the equation is unchanged from above. Since S and S′ are not known, the tension cannot be solved. It can be concluded that a procedure which subtracts the applied force on an untensioned cable from a reading on a cable with tension to eliminate beam properties is incorrect.

It is important to realize that the analytical calibration applies only for flexible cables. The basic assumptions made do not apply to stiff cables. Thus, direct calibration is the only alternative for stiff cables. A reasonable limit of cable stiffness would be an untensioned reading of 10 percent of the tensioned reading. If it was desired to use a tensiometer on a relatively stiff cable, it would be advisable to make the tensiometer as long as possible. The longer the distance between tensiometer end clamps, the greater the string like qualities.

Sample Calculations

Find the tension in a ½ inch cable using the tensiometer in Figure 14. Suppose for a ½ inch flexible cable under tension, the meter reading equals 42.5 (42.5×10^{-3} inches). What is the cable tension?

Solution:

The problem can be approached by an analysis of a cantilever beam giving the relationship between the applied force and the deflection. Using the cantilever deflection equation:

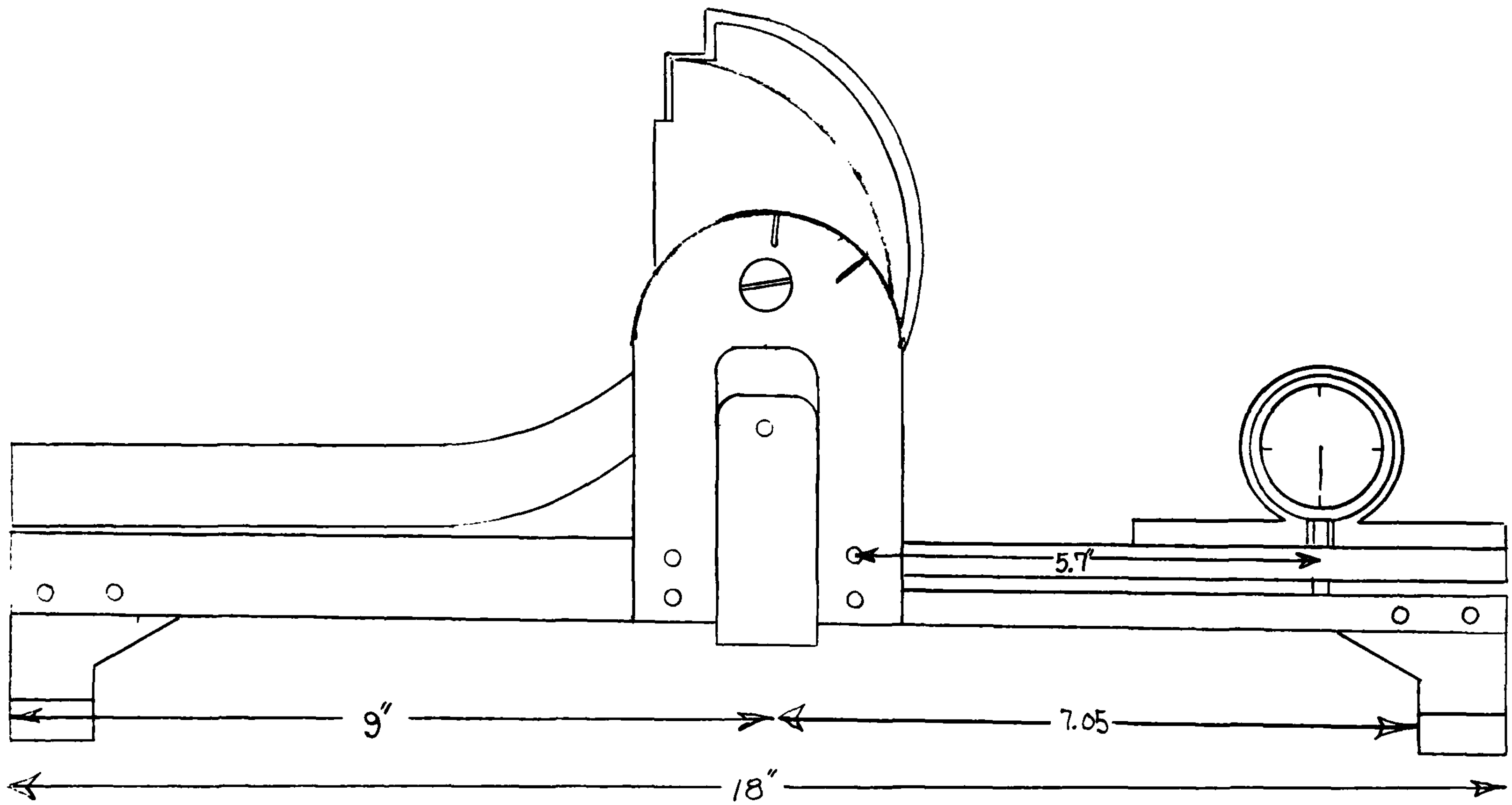


FIGURE 14 SAMPLE TENSIOMETER

$$y = \frac{\frac{(P)}{2}(3\ell x^2 - x^3)}{6EI}$$

$$I = \frac{bh^3}{12}$$

where

y = beam deflection at meter location

I = beam moment of inertia

Combining Equations

$$y = \frac{\frac{(P)}{2} 12 (3\ell x^2 - x^3)}{6Ebh^3}$$

$$y = \frac{2\frac{(P)}{2}(3\ell x^2 - x^3)}{Ebh^3}$$

From Figure 14, tensiometer dimensions are;

b = .5"

h = .6"

α = .335" (cable deflection)

ℓ = 7.05"

x = 5.7"

E = $3\text{x}10^7$ psi (steel)

Substituting data

$$y = \frac{2\frac{(P)}{2}\{3(7.05)(5.70)^2 - (5.70)^3\}}{(3\text{x}10^7)(.5)(.6)^3}$$

$$y = (3.0986 \times 10^4)\ \frac{(P)}{2}$$

$$\frac{P}{2} = 3227.68y \qquad \text{Equation (1)}$$

Using the perfect string equations (justified by the use of a very flexible cable)

$\theta = \tan^{-1} \alpha/\ell$ and $P/2 = T \sin \theta$

$\theta = \tan^{-1} \frac{(.335)}{(7.05)}$

$\theta = 2.72$

$\frac{P}{2} = T\sin(2.72)$ Equation (2)

Combining equations 1 & 2

$3227.28y = T\sin(2.72)$

$\frac{(3227.28)}{(\sin 2.72)} y = T$

$T = 68007y$

The variable "y" is the distance measured by the deflection meter. The scale reading (SR) indicates deflection in thousandths of an inch. Therefore:

$y = .001\ (SR)$

Combining equations

$T = 68.007\ (SR)$

The scale reading was 42.5 for this sample

$T = 68.007\ (42.5)$

$\underline{T = 2890 \text{ lbs}}$

It should be noted that this analysis is only applicable to flexible cables.

IV VIBRATION METHOD

A commonly experienced phenomenon is the way a string on a musical instrument changes its sound when a change is made in the string's tension. The sound change of course is due to the change in the frequency of vibration of the string. Therefore, it seems reasonable that if one could measure the frequency of vibration of a guy cable, then the tension in the cable could be determined. Two types of vibration of a tensioned guy cable will be considered. The first type is called a transverse mechanical pulse and is shown in Figure 15. The cable is displaced by applying a force at point "P" and releasing the cable. The pulse travels along the cable until it reaches the right end support. The

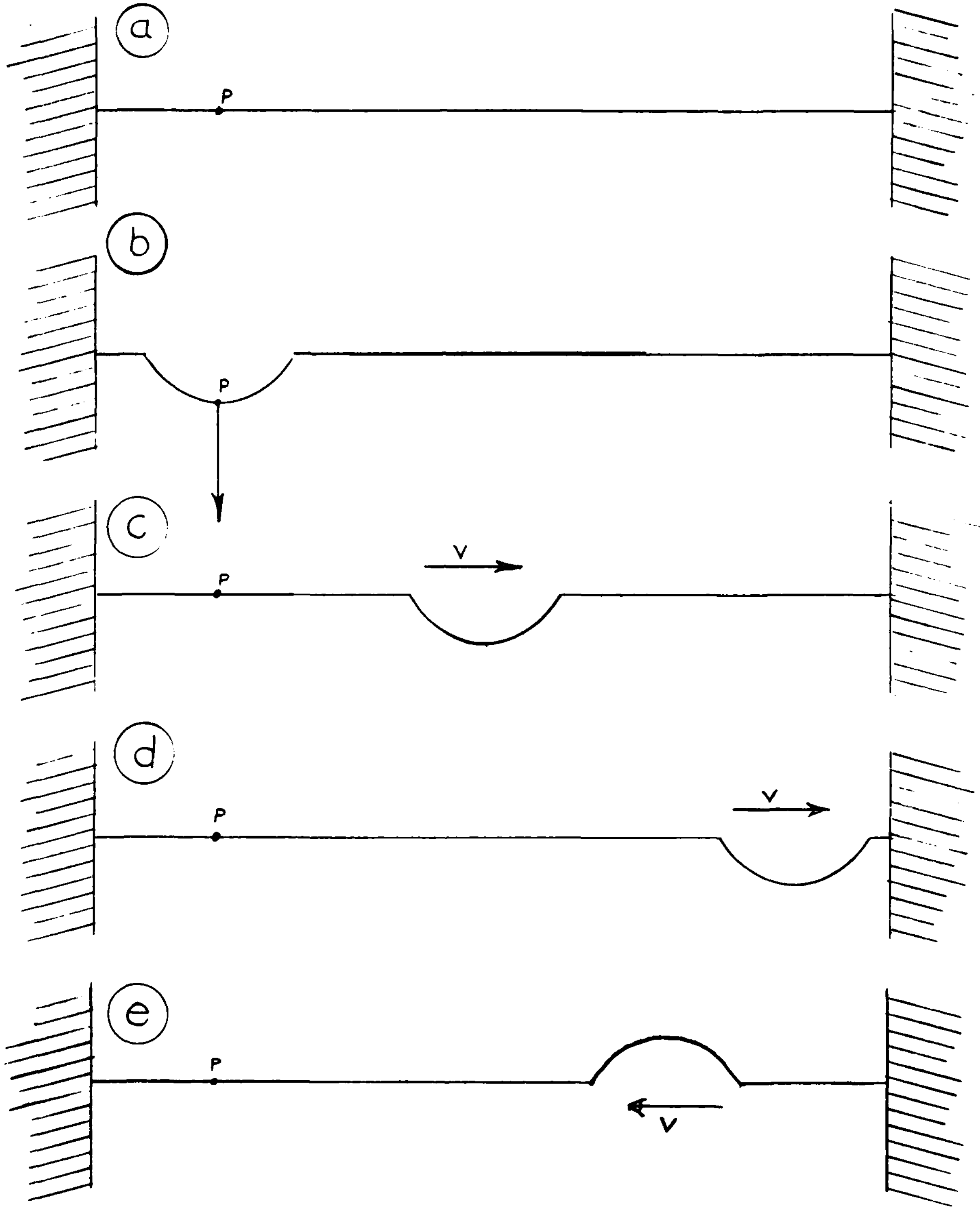


FIGURE 15
TRANSVERSE PULSE

pulse is then reflected back to the left end support. The pulse repeats this motion until it is dampened out. The velocity of the pulse is a function of the tension in the cable, the mass of the cable and the length of the cable. The velocity of the pulse in a tensioned guy cable can be obtained by measuring the time it takes for the pulse to travel up the cable to the tower and to return to the ground. The application of the force at point "P" can be accomplished by striking the cable with a pipe or by pulling on the cable and quickly releasing it.

The second type of vibration of a tensioned guy cable is called a standing-wave motion and is shown in Figure 16. Both modes are easy to establish in a tensioned guy cable by applying a sinusoidal motion to the cable several feet away from the ground anchor. The first mode, however, is the easiest to work with. The frequency of the wave motion is dependent upon the tension of the cable, length of the cable, and mass of the cable. The frequency can easily be measured by counting the number of cycles of motion over a certain time period.

Using the data for wave motion in a tensioned string, from Reference 2 (Pg 375-390), the following relationships for computing the tension force in a guy cable are obtained:

a. Transverse Pulse

(1) $v = \sqrt{\frac{F}{\mu}}$ where

v = velocity of the pulse

μ = mass per unit length of the cable

F = cable tension

It should be noted here that the velocity of the transverse pulse depends only on the inertia of the cable and not on the weight or the angle of inclination of the cable. This is true only when the cable tension is much greater than the cable weight and there are not any lateral forces applied to the cable. Fortunately for this application, the above relationship is adequate.

(2) $f = \frac{v}{\lambda}$ where

f = frequency of vibration

λ = 2 times the cable length = 2L

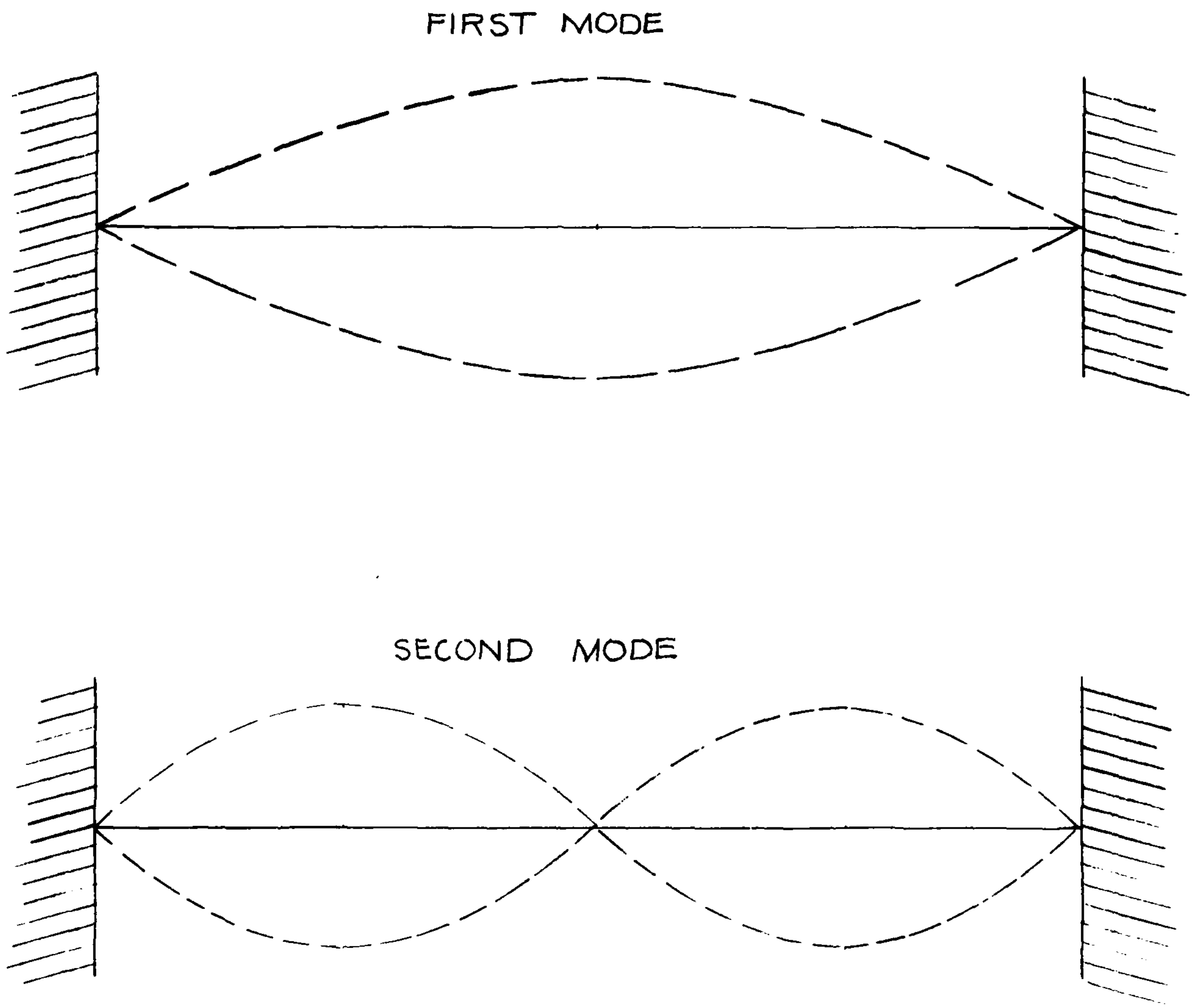


FIGURE 16

STANDING-WAVE MOTION

$$(3)\quad T = \frac{1}{f}$$ where

T = period of vibration

The procedure would be to apply and release a force to the cable and then count the number of cycles of vibration over a time period. Next compute the number of seconds for one cycle, T, by dividing the number of cycles by the total time.

Using equations (1), (2) and (3) we have:

$$v^2 = \frac{F}{\mu}$$ from (1)

$$v = f\lambda = \left(\frac{1}{T}\right)(2L)$$ from (2) and (3)

Solving for F, we have:

$$F = (v^2)\ (\mu) = \frac{4L^2\mu}{T^2}$$ where

μ = mass per unit length (slugs/ft) = w/g

w = weight per foot of cable (lbs/ft)

g = 32.2

$$(4)\quad F = \frac{4L^2w}{gT^2}$$ where

F = cable tension force (lbs)

L = distance between cable supports (Ft)

T = period of pulse (seconds)

w = weight per foot (lbs/ft)

g = 32.2

<u>Sample Calculation</u>:

A 1½ inch steel stranded cable has a length from ground level to tower connection (including the length of the turnbuckle) of 343.18 ft. The cable weight is 4.73 lbs/ft.

$$F = \frac{4L^2w}{gT^2}$$

For the period of the pulse, 10 pulses were counted in 10.06 sec.

$$F = \frac{4(343.18\text{ft})^2(4.73\text{ lb/ft})}{(32.2\text{ ft/sec}^2)\left(\frac{10.06\text{sec}}{10}\right)^2}$$

$\underline{F = 68{,}377 \text{ lbs}}$

b. Standing Wave (HARMONIC)

(5) $\lambda = 2L/n$ where

λ = wave length

L = distance between cable supports

n = any positive integer

n = 1 for the fundamental (first) mode

(6) $v = \sqrt{\frac{F}{\mu}}$ where

v = velocity of a transverse wave

F = cable tension

μ = mass per unit length of the cable

(7) $f = \frac{v}{\lambda}$ where

f = frequency of vibration

(8) $T = \frac{1}{f}$ where

T = period of vibration

The procedure would be to apply a varying force to the cable at a convenient distance from the ground anchor until a standing wave is established. Continue to apply the force and count the number of cycles of vibration over a time period. Next compute the number of seconds for one cycle, T, by dividing the number of cycles by the total time.

Using equations (5), (6), (7) and (8), we have

(9) $F = \frac{4L^2w}{gT^2}$ where

F = cable tension force (lbs)

L = cable length (Ft)

T = period of vibration (seconds)

w = weight per foot (lbs/ft)

g = 32.2

Note that equation (9) is identical to equation (4) for the transverse pulse since a standing wave is a continuous sinusodial transverse wave.

Sample Calculation:

A one inch steel standard cable has a length from ground level to tower connection (including the length of the turnbuckle) of 135.79 ft. The cable has a weight per length of 2.10 lbs/ft.

$$F = \frac{4L^2w}{gT^2}$$

For the period of vibration, 50 waves for 19.21 sec.

$$F = \frac{4(135.79\ \text{ft})^2(2.10\text{lbs/ft})}{(32.2\text{ft/sec}^2)\left(\frac{19.21\text{sec}}{50}\right)^2}$$

$$\underline{F = 32{,}587\ \text{lbs}}$$

Procedure for Transverse Method

1. Obtain a stopwatch.
2. Displace the cable by pulling it down.
3. Let go of the cable being careful not to push or shake.
4. Allow the wave to steady by making a few passes between the end points.
5. Place a hand on the base of the cable and count down three waves to zero and then start the watch. This helps to insure that at time zero, a wave is just leaving the ground on its way to the tower.
6. Count and time as many waves as possible until the pulse dampens out.
7. The value of cable length to be used in the equations must include the distance from the work point (usually a plate where the lower end of the turnbuckle is attached) to the ground.

Procedure for Standing Wave Harmonic Method

1. Obtain a stop watch.
2. Place a hand near the base of the cable and slowly shake.
3. Quicken the rate of the force application until the first harmonic of the cable is reached. This can be observed from a distance if the cable forms half a sine wave with the nodes occurring at the ends.
4. Start the watch and count a large number of waves (50) while continuing to shake at harmonic frequency.

NOTE: It is possible to damage the towers if excessive deflections in the cable or tower were to occur; thus, care should be taken to keep the wave amplitude to a minimum.

5. The value of cable length to be used in the equations must include the distance from the work point (usually a plate where the lower end of the turnbuckle is attached) to the ground.

FIELD OBSERVATIONS

Both frequency methods are quick methods for measuring guy cable tensions. Excessive deformation of the cable could possibly damage the cable or tower. If proper precautions are observed, there is little danger of structural problems.

As with the sag method, the cable tension is a squared function of the cable length. It is important that accurate length measurements be acquired. It is also observed that for both types of waves, transverse and harmonic, the wave is reflecting at the ground and not at the lower work point. Therefore, the length to be used in the equation is measured from the upper work point to the ground.

For short, light cables, the harmonic method is the easiest of the two frequency procedures to use. It is very easy to find the first harmonic and since the wave is not allowed to dampen out, a large number of waves can be counted. For large heavy cables, the transverse method is more easily applied. However, due to large cable tensions, it is necessary to use a ladder in order to displace the cable at a location several feet above the ground.

When using the harmonic method, do not allow the tower to noticeably sway. The cable will remain in reasonance with little effort. Since the cable frequency is not a function of amplitude, the wave amplitude should be kept small.

The transverse method is convenient for large heavy cables since a large force needs to be applied to achieve harmonic resonance. Transverse waves are difficult to count in short cables because the wave dampens too quickly. When displacing the cable, a quick release will result in a short pulse which will distort little and be easy to count. It is important to be sure when timing the wave that the watch is started on a count of zero, not one.

For both procedures, a large number of waves counted will result in greater frequency measurement accuracy. For the harmonic method as many as 50 should be considered.

V FIELD COMPARISON OF THE THREE METHODS

Several cables on guyed structures at the Stockbridge Test Site were used to compare the results from tension measurements using the sag, vibration, and tensiometer methods. One of the objectives of this effort was to verify that the vibration method is valid and practical for measuring guy cable tensions. Table 1 presents the results. The sag method was considered as a standard to compare to. Excellent correlation exists between the sag and the vibration (or frequency) methods. Tensiometer results were not quite as close. Also, the tensiometer readings were not linearly related to cable tension as required by the analytical analysis. This shows that direct calibration is required for the clamp-on tensiometer. The tensiometer was used on only the ½ inch cables it was designed for. Sag and frequency methods were used on a variety of cable sizes, including dielectric and steel materials, and also on different anchoring arrangements. It can be concluded that all three methods of measuring guy cable tensions are acceptable, that the vibration method is valid, and that clamp-on tensiometers should be directly calibrated as discussed in Section III.

VI SUMMARY AND CONCLUSIONS

This report describes in detail three methods of measuring cable tensions on guyed structures. The methods are sag, deflection meter, and vibration. A field comparison using each method was made for the guyed structures at RADC's Stockbridge Test Site. Also, this report documents the guy cable tensioning efforts performed during the installation of the Computer Controlled Antenna Measurement System in Appendix A. The appendix also provides complete documentation of the cables used on all guyed structures at the site and the results of the cable tension measurements performed for this effort. The results of the field comparisons show the vibration method to be a valid and practical way to measure cable tensions. Furthermore, it is recommended that the vibration method be used for all future guy cable tensioning efforts. The sag method was found to be extremely time consuming to apply. The tensiometer method is by far the easiest and fastest method for measuring cable tensions. However, for accurate results, especially for stiff cables, the meter should be directly calibrated on the same size and type of cable with known tensions. Detailed field observations for each method are given in Sections II, III, and IV along with procedures and sample calculations.

			CALCULATED TENSIONS		
CABLE	TOWER	PROPER TENSION (POUNDS)	FREQUENCY (POUNDS)	SAG (POUNDS)	TENSIOMETER (POUNDS)
G-A4	12	3000	2113		2380
G-A5	12	3000	2503		2516
G-A6	12	3000	2706	2845	2618
H-A4	12	3000	3079		2856
H-A5	12	3000	2927	3191	2686
H-A6	12	3000	3621	3659	2856
K-A2	12	8000	8806		5374
K-A3	12	9000	4035		3196
M-A4	A1	3000	2774	2853	
N-A4	A1	3000	2589	2676	
S-A9	6-7-3	4000	2577		2516
S-A10	6-7-3	4000	1728		1768
A1	WP4	3000	1312		1836
A2	WP4	3000	1738		2244
A3	WP4	3000	2113		2346
A1	WP2	3000	1109		1820
A2	WP2	3000	2048		2142
A3	WP2	3000	2277		2312
CA1	11	68000	59100 *	58400	

* DENOTES TRANSVERSE FREQUENCY WAS USED

TABLE 1

FIELD COMPARISONS

REFERENCES

1. Bennett, A., Wysong, J., "Computer Controlled Antenna Measurement System (CCAMS)", RADC-TR-80-406, Jan 81. AD# B055 752L.

2. Shortley, G., Williams, D., "Elements of Physics", Second Edition, Jul 58.

APPENDIX A

STOCKBRIDGE TEST SITE GUY CABLE DATA

The purpose of this section of the report is to document the guy cable tensioning efforts performed during the installation of the Computer Controlled Antenna Measurement System (CCAMS), to provide complete documentation of the guy cables used on all guyed structures at the site, and to provide the results of the cable tension measurements performed for this effort.

Figure A-1 shows the tower arrangement. The jib is tower 11, the stabilizing towers are 1A and 12, the twin towers, which were in place prior to the CCAMS effort, are 5 and 1, the horizontal bridge support poles are 6, 7 and 3, and the individual wood poles for the Interrogation Threat Subsystem are 2, 4, 9, and 10.

Figure A-2 shows the guying arrangement for the jib crane, tower 11. Figures A-3 and A-4 show the guying arrangement for the stabilizing towers 12 and 1A, respectively. Figure A-5 shows the guying arrangement for the horizontal bridge. Figure A-6 shows the guying arrangement for the individual wood poles used in the Interrogation Threat Subsystem, 2, 4, 9, and 10.

The guying arrangement for the twin towers, 1 and 5, which were not part of the CCAMS effort, is shown in Figures A-7, A-8, and A-9. Note on Figures A-8 and A-9, the rather unusual guying arrangement.

The following paragraphs discuss the guy cable tensioning efforts performed during the CCAMS effort. The jib crane guys were tensioned by using the sag method. The results were given on Pg 96 of RADC-TR-80-406, "Computer Controlled Antenna Measurement System (CCAMS)". The tensions for the horizontal cables between the jib and the stabilizing towers 1A and 12 were not measured. These cables should be in proper tension providing the guy cables for Towers 1A and 12 are properly tensioned. It should be noted that the charts in RADC-TR-80-406 that relate deviations from proper cable tensions to distances away from "reference points" are not useful for checking cable tensions. The primary reason for this is that the physical location of the reference point (shown as 0 in the charts) is not known. Temperature correction data is given on Pg 109 in TR-406. Later in this Appendix, all required data for the sag method will be provided such that cable tensions can be easily calculated. Discussion of the sag method is given in Section II of this report.

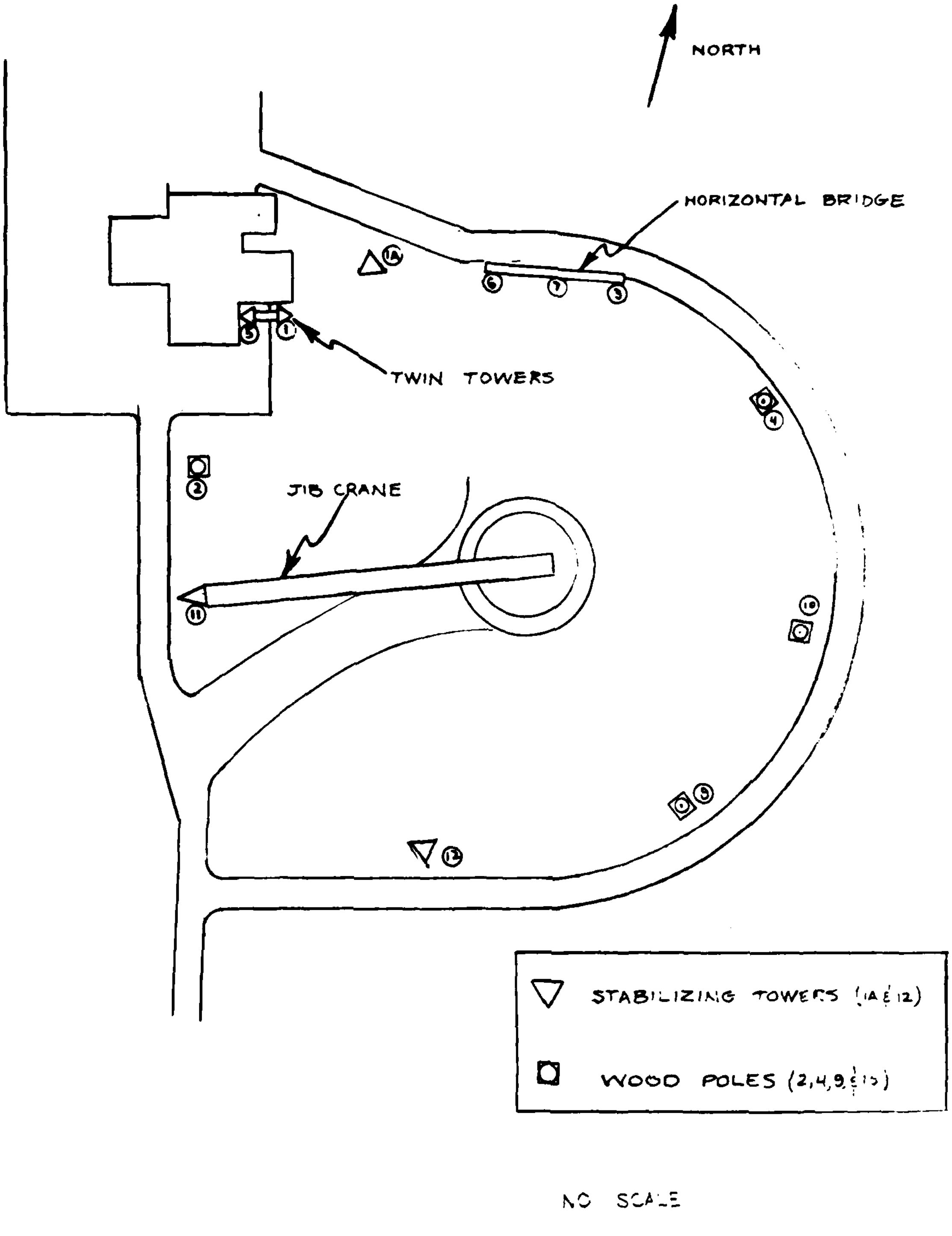


FIGURE A-1
SITE PLAN FOR TOWER LOCATION

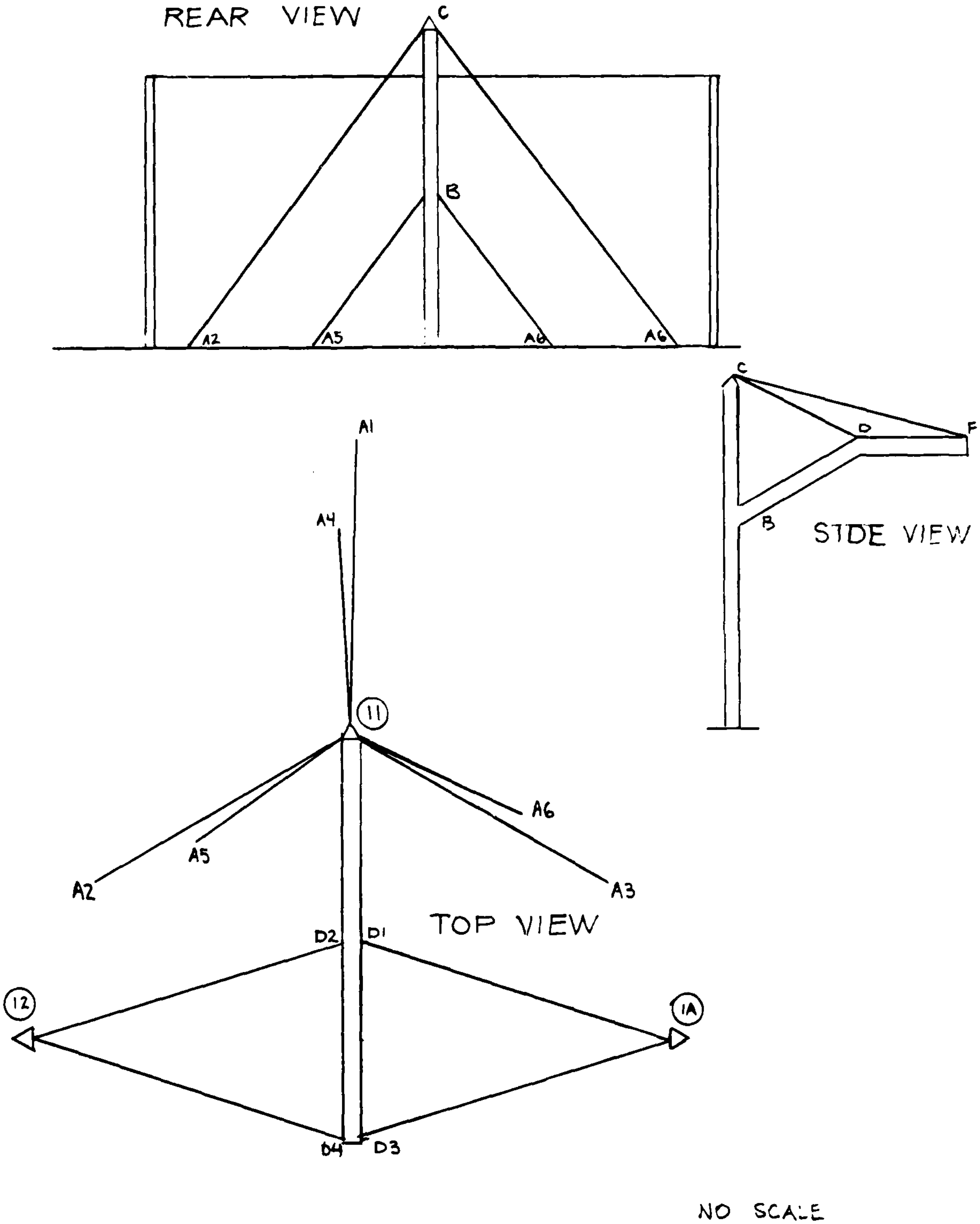


FIGURE A-2
JIB CRANE

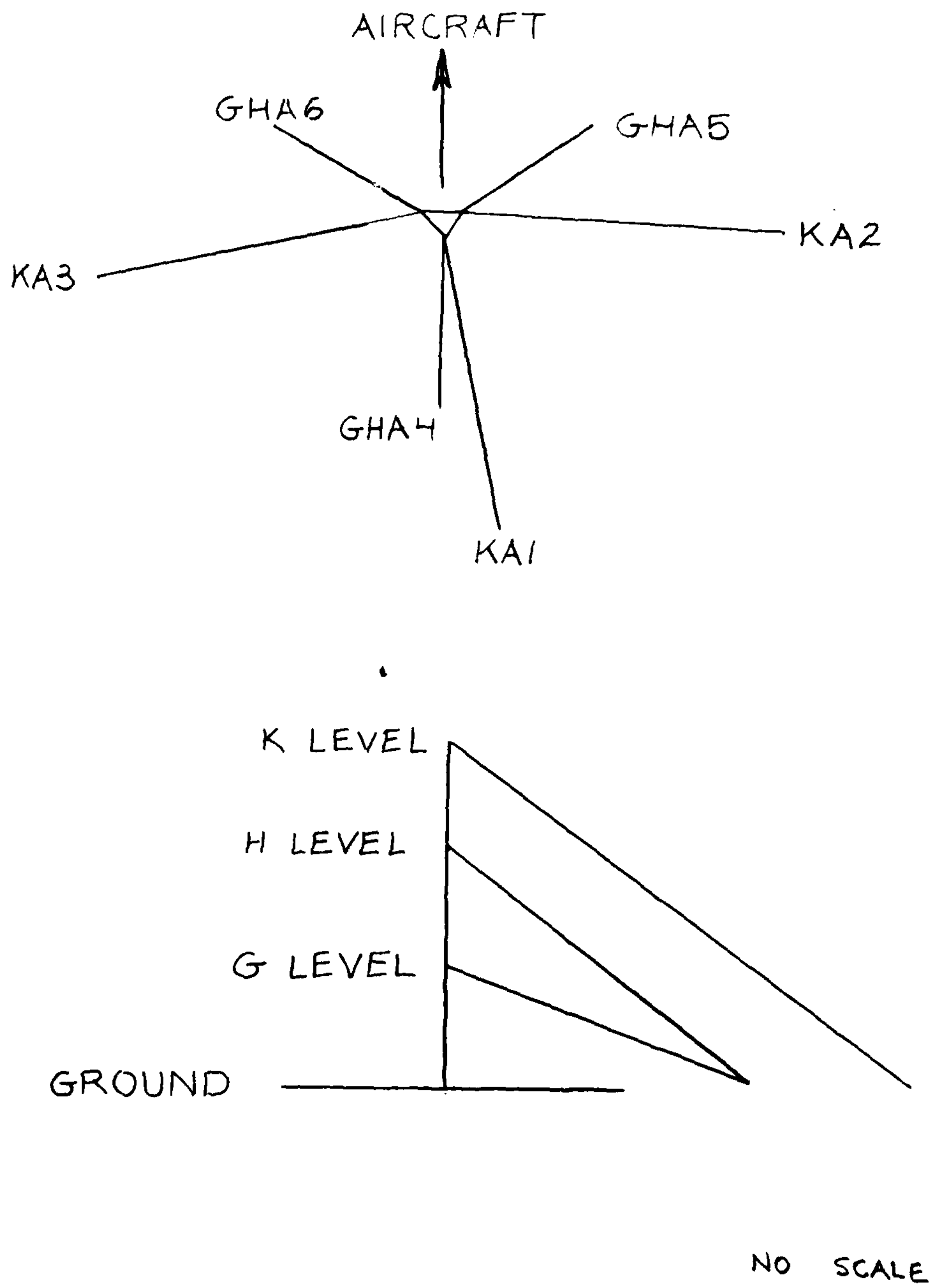
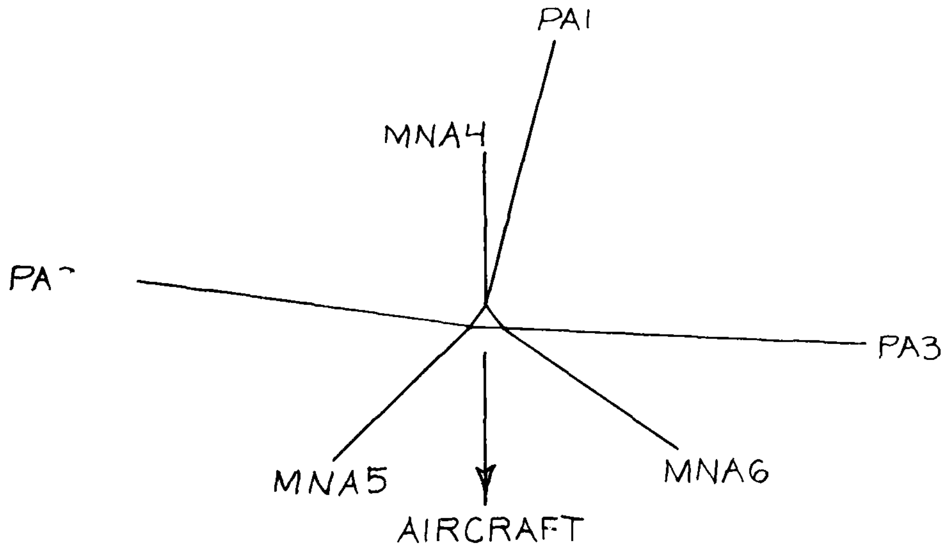


FIGURE A-3
TOWER 12



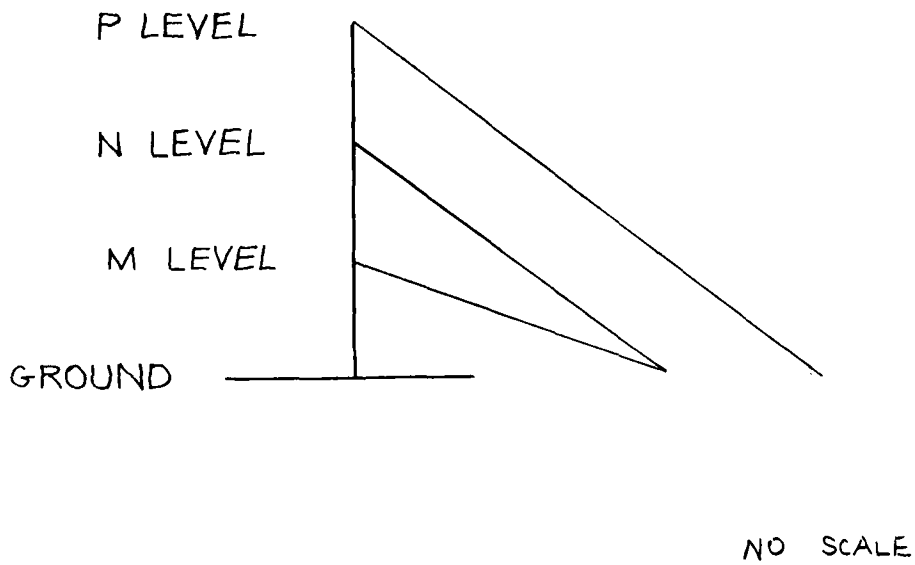


FIGURE A-4

TOWER 1A

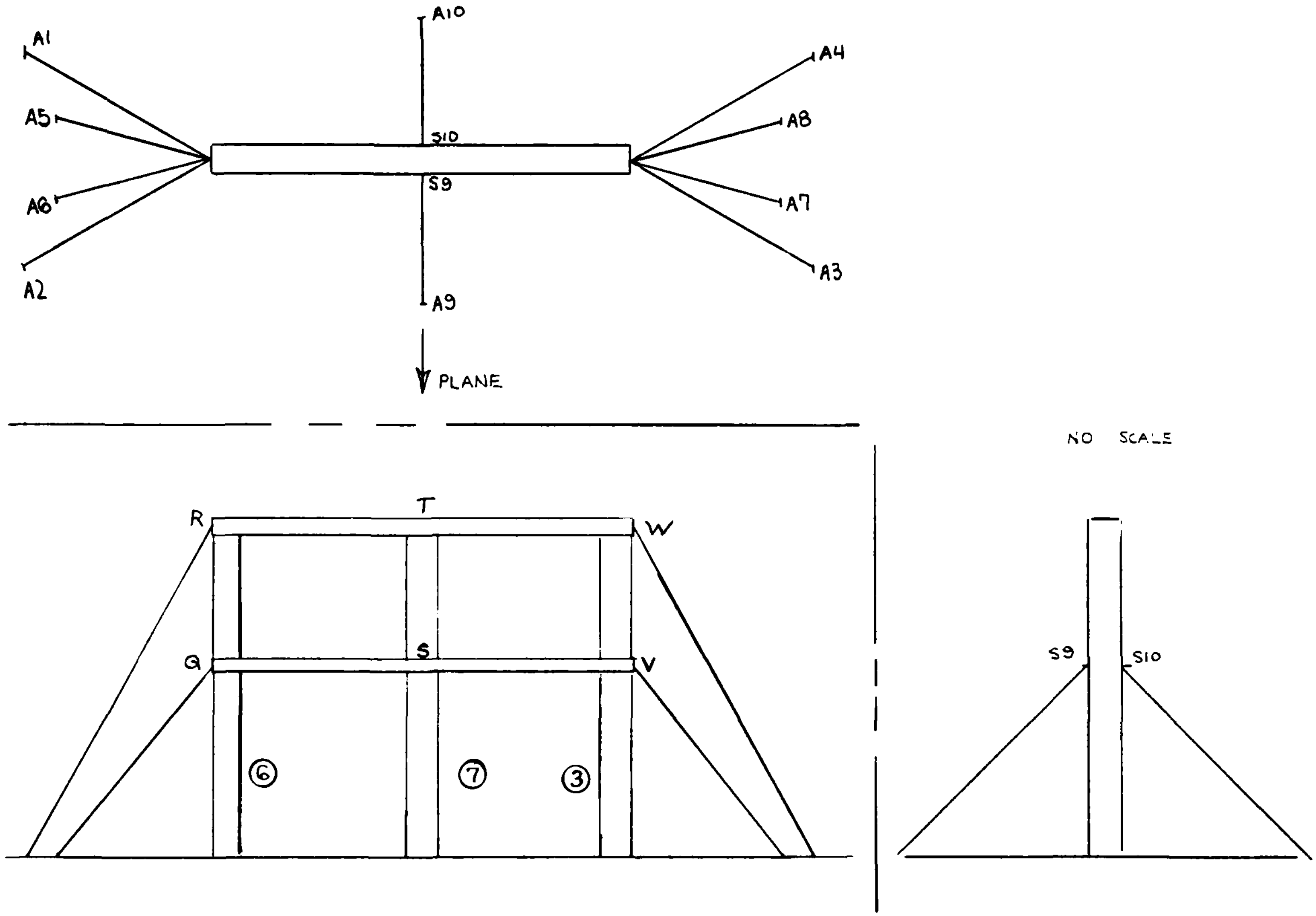


FIGURE A-5 HORIZONTAL BRIDGE

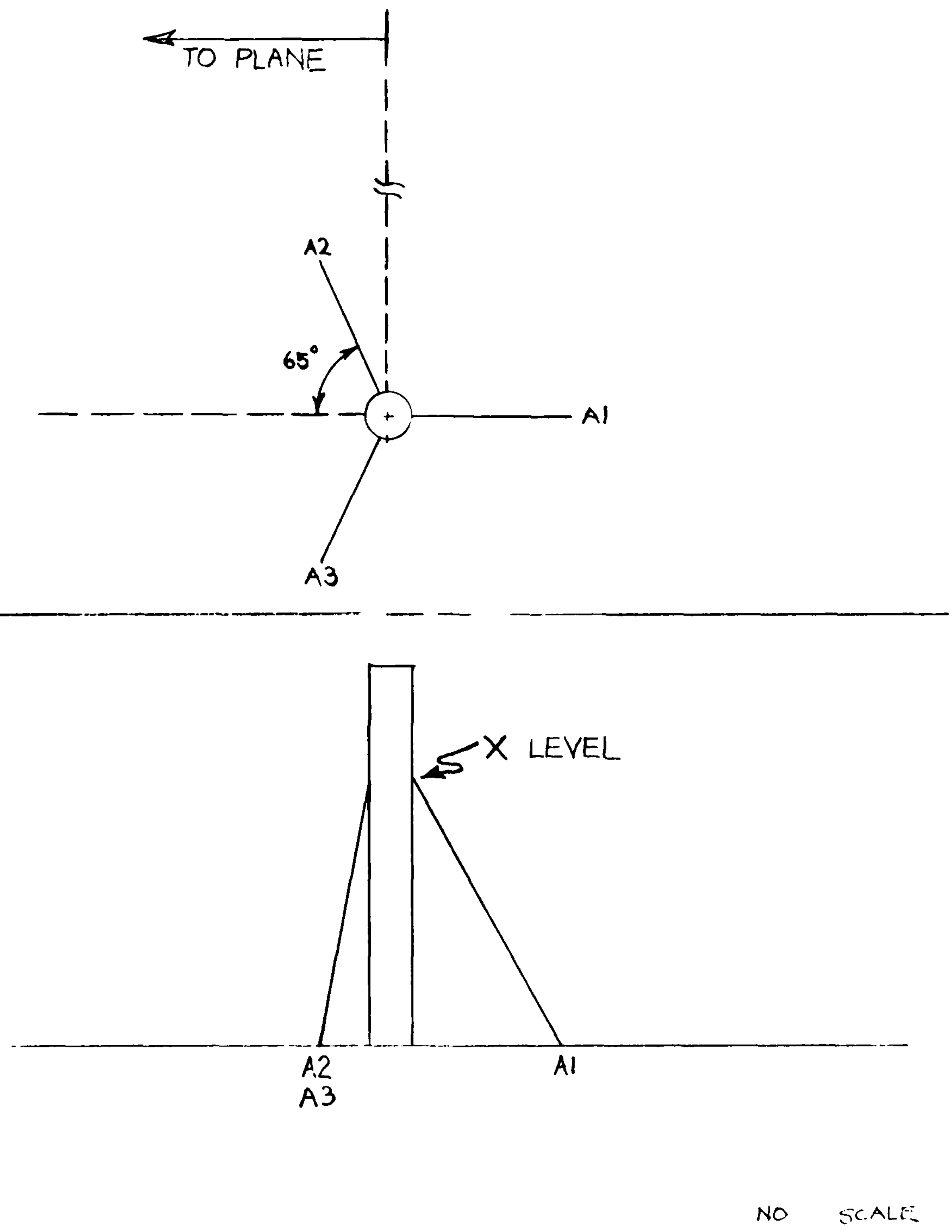


FIGURE A-6

WOOD POLE GEOMETRY 2, 4, 9, 10

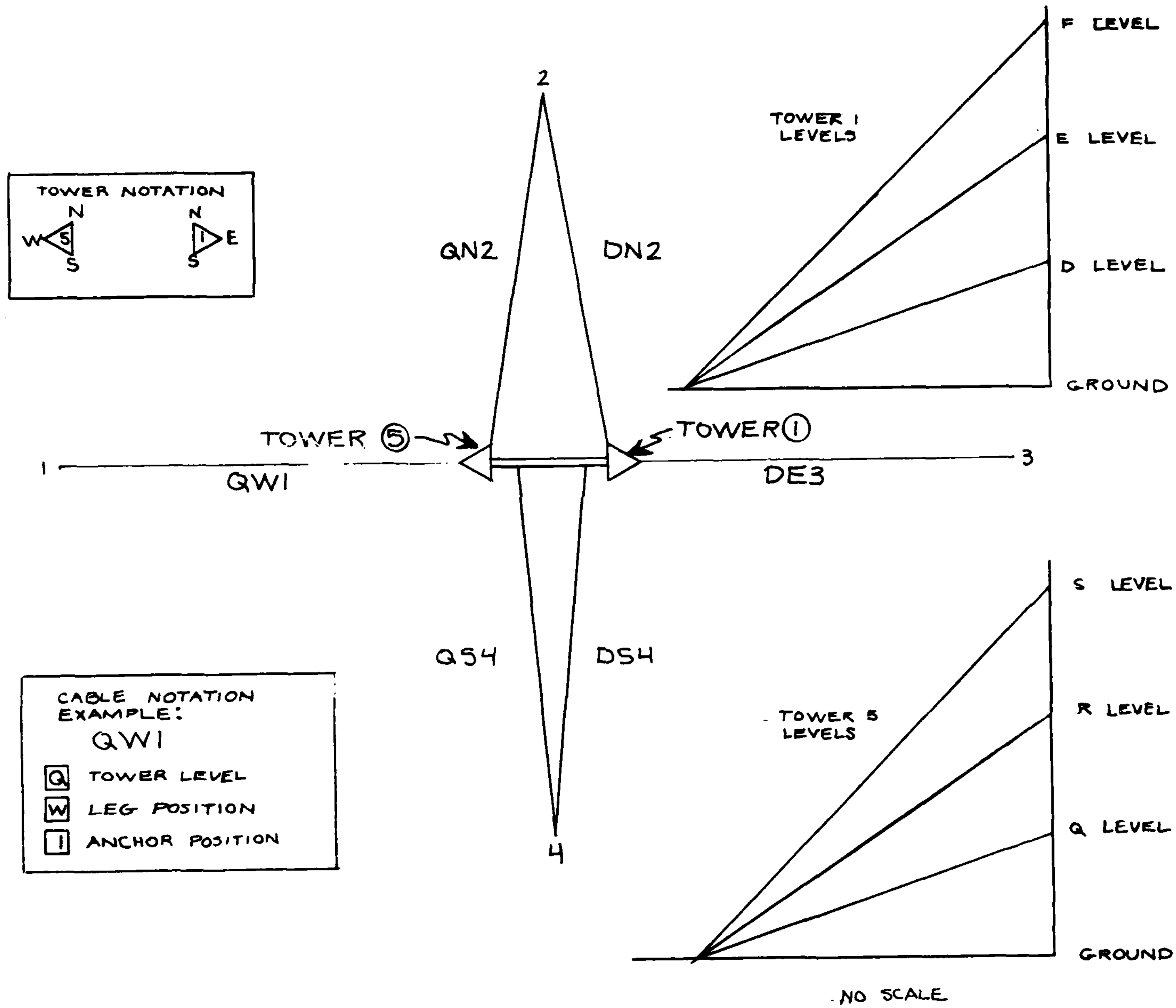


FIGURE A-7 TOWERS 1&5 LOWER LEVEL

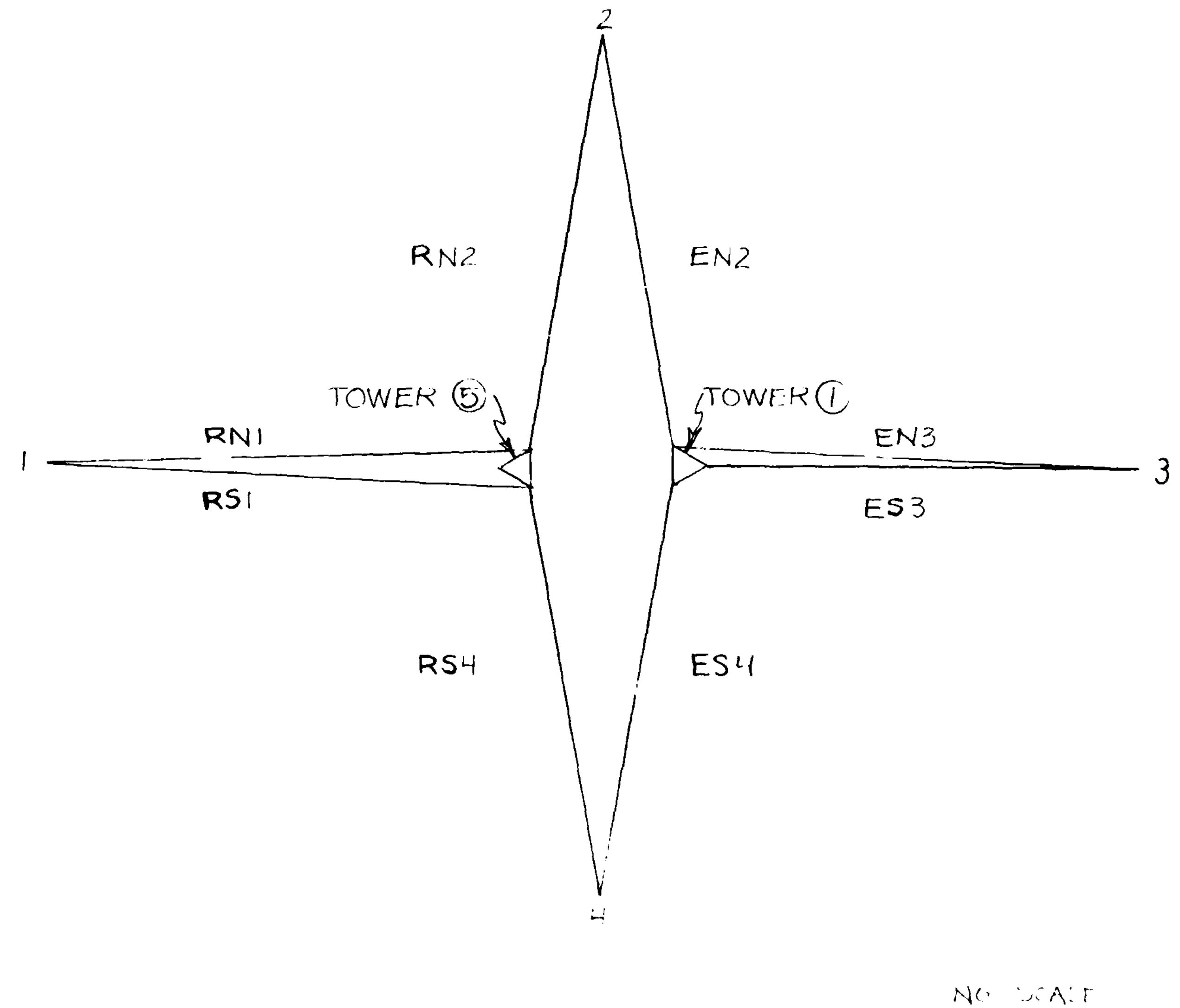


FIGURE A-8 TWIN TOWERS 1&5 LEVEL R&E (MIDDLE)

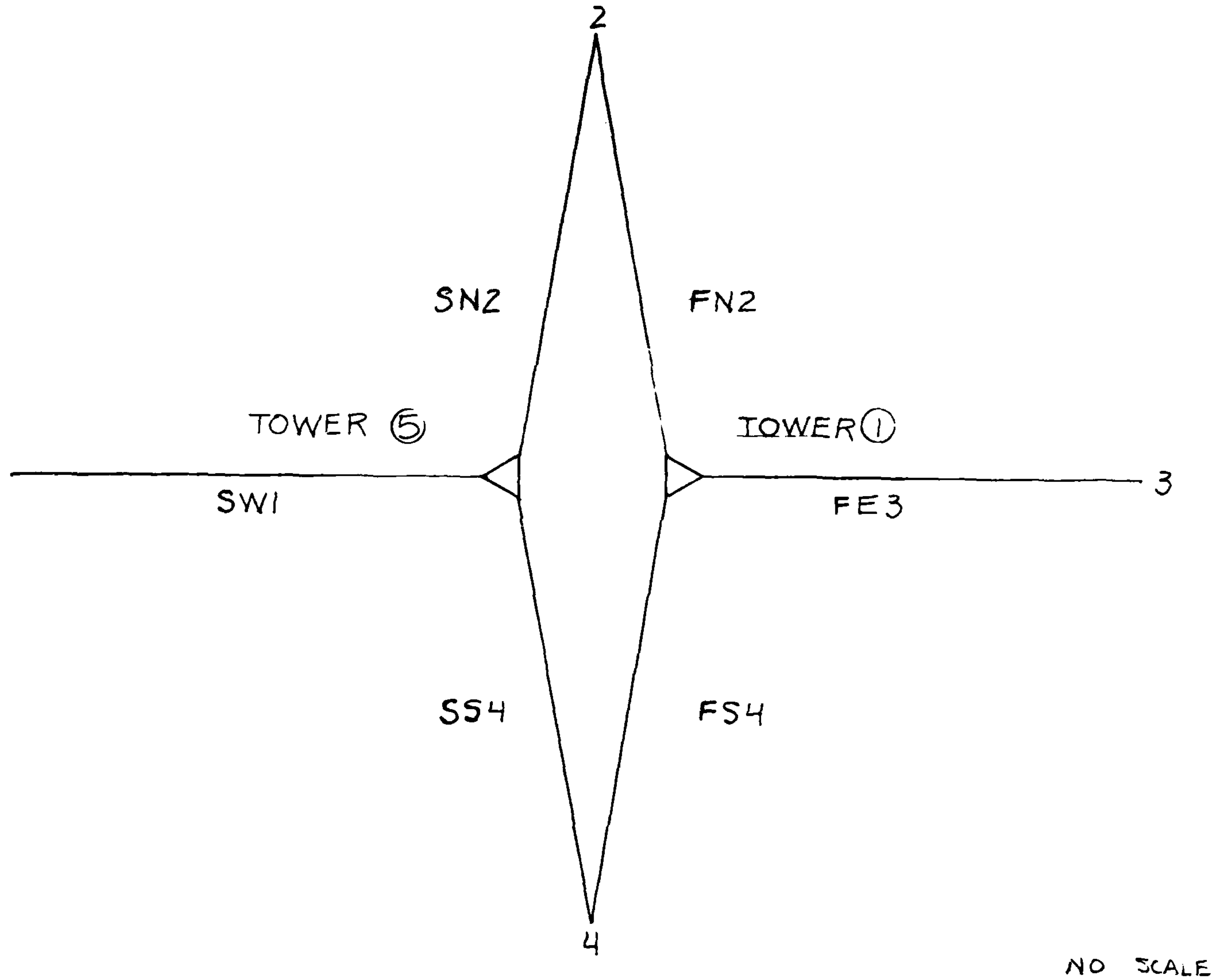


FIGURE A-9 TWIN TOWERS 1&5 LEVEL S&F (TOP)

For the stabilizing towers, 1A and 12, only the single large cable at the top of each tower (KA-1 and PA-1) was originally tensioned using the sag method. All other cables were tensioned using a clamp on tensiometer. The sag method data reported in RADC-TR-80-406 is no longer valid, however, due to a reguying effort that subsequently took place. Extensive changes in the top plate assembly where the cables attach to the tower were made. The cable tensioning efforts for the new guying system were not documented. Proper values for cable tensions are known from data given in Drawing 2500-0405 (Drawing is part of data archieves at the Stockbridge Antenna Test Site). Care must be taken when using the drawing in that three copies of this drawing exist. Each copy has revisions that do not appear on the other copies. Therefore, when using the drawings, each copy should be checked in order to be sure the data is not obsolete. This Appendix will provide guy cable data that is current as of Fall, 1981.

For the horizontal bridge support poles 3, 6, and 7, four cables were tensioned using the sag method and a clamp on tensiometer used on six cables for the CCAMS effort.

For the Interrogation Threat System Poles 2, 4, 9, and 10, all cables were tensioned using a clamp on tensiometer. Certain of the guy cables used on these poles are Nuplaglas dielectric rods and are very stiff. The use of a clamp on tensiometer on a cable that can exhibit beam properties is questionable unless the device has been calibrated using known cable tensions with an in-line force gage. Section III of this report discusses the use of a clamp on tensiometer on stiff cables.

Concerning the twin towers 1 and 5, a tower face was added to tower 5 and certain guy cables were relocated. These towers were present prior to the CCAMS effort, and documentation of guy cable data was not provided. Prior in-house efforts concerning these towers will be used to provide length and pretension data.

The following paragraphs will provide all data necessary to measure guy cable tensions for the CCAMS structures. Details on how to use the sag method are given in Section II of this report. Sections III and IV provide datails on how to measure guy cable tensions using the clamp on tensiometer method and the vibration method, respectively. Each structure will be presented separately and appropriate notes and comments will be included.

JIB CRANE (Tower 11)

See Figure A-2 for the guying arrangement. Table A-1 provides the basic guy cable data. The breaking strength and the proper pretension values are from Drawing 2500-0405. The length (work point to work point) values were not taken from the drawing, however. Length data are based on field measurements used for the sag method during the CCAMS installation and reported in RADC-TR-80-406. Figures A-10, A-11, and A-12 provide the necessary geometry information to solve the sag method equations given in Section II of this report. It should be noted that targets are not attached to the tower legs for all cables. At the time of this report, targets for the "B" level were not present. Targets for the "C" level were attached to the tower for use during this effort. For cable C-A3, the top of the target tape is 7 ft, 0 inches below the cable to tower work point. For cables C-A1 and C-A2 the target tapes are 8 ft, 0 inches below the tower work point. These vertical dimensions must be considered when collecting sag data. Also, it should be noted that the target tapes are marked in tenths of feet, not in inches.

STABILIZING TOWER 12

See Figure A-3 for the guying arrangement. Table A-2 provides the basic guy cable data. The lengths for all cables were measured in the field by using an inclinometer on the cable to measure the cable slope, and a tape measure to measure horizontal distance from the tower leg to the cable anchor, and then computing the chord length. If it is desired to use the sag method for measuring cable tensions, the information in Figure A-13 is provided. Only those cables that were measured by the sag method for this effort are listed. Because of the modifications to the top level guying attachment, the sag method data for cable K-A1 in RADC-TR-80-406 is no longer valid.

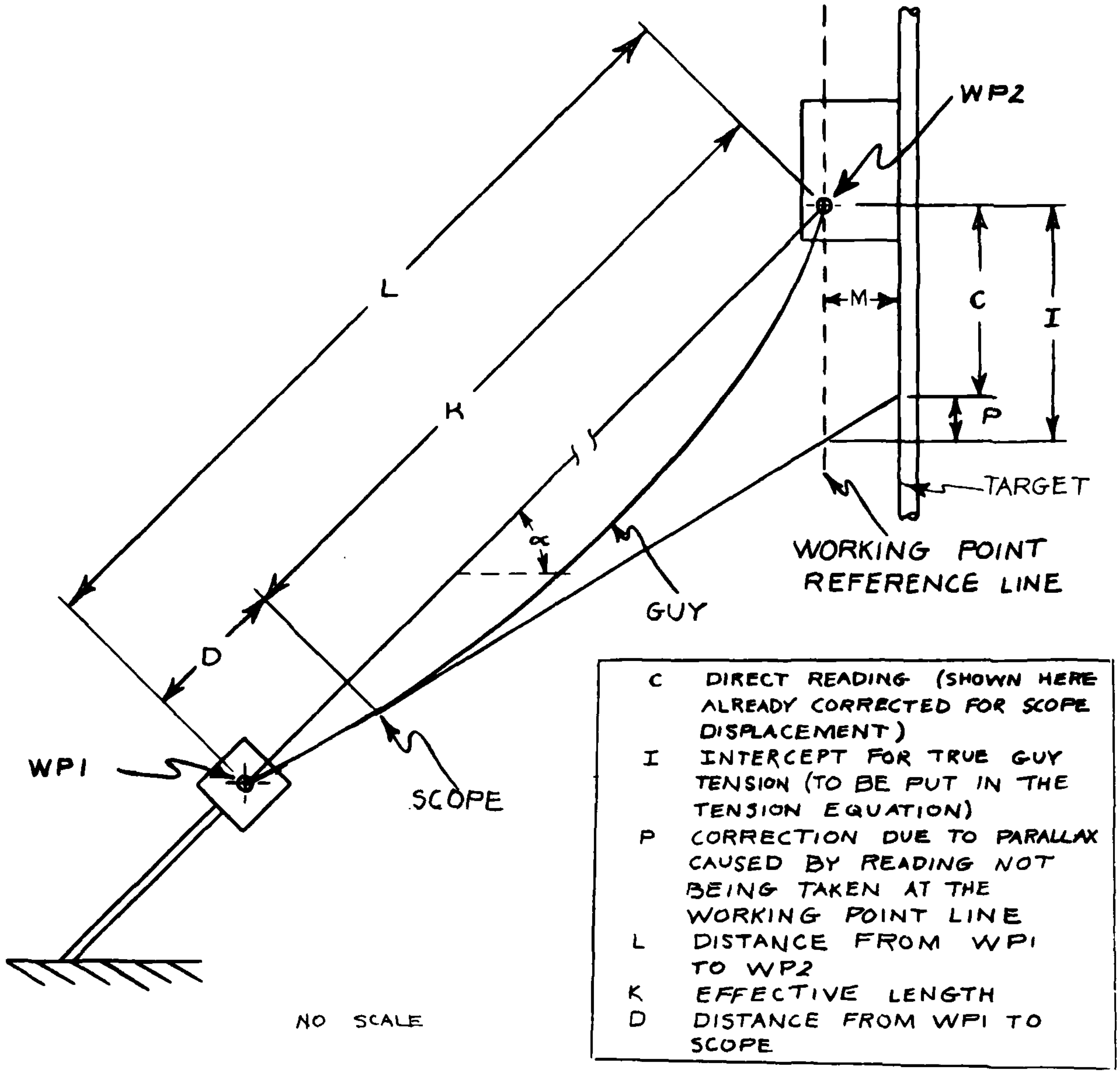
STABILIZER TOWER 1A

See Figure A-4 for the guying arrangement. Table A-3 provides the basic guy cable data. The same comments concerning cable material, length measurements, modifications to the top level guying attachment, and sag data in RADC-TR-80-406 for tower 12 apply to tower 1A.

CABLE NUMBER	DIAMETER (INCHES)	MATERIAL	WEIGHT PER LENGTH (lbs./ft.)	BREAKING STRENGTH (POUNDS)	CORD LENGTH WP TO WP (FEET)	PROPER TENSION (POUNDS)
B-A4	1	STEEL	2.10	122000	128.79	28000
B-A5	1 1/2	STEEL	4.73	276000	133.79	44000
B-A6	1 1/2	STEEL	4.73	276000	138.67	44000
C-A1	1 1/2	STEEL	4.73	276000	336.18	68000
C-A2	1	STEEL	2.10	122000	295.29	20 000
C-A3	1	STEEL	2.10	122000	298.72	20000
D1-P	1	STEEL	2.10	122000	44.72	20000
D2-K	1	STEEL	2.10	122 000	44.72	20000
D3-P	1	STEEL	2.10	122000	45.28	20000
D4-K	1	STEEL	2.10	122000	45.28	20000
C-D	1	STEEL	2.10	122000	110.71	16000
C-F	1	STEEL	2.10	122000	204.30	29000

TABLE A-1

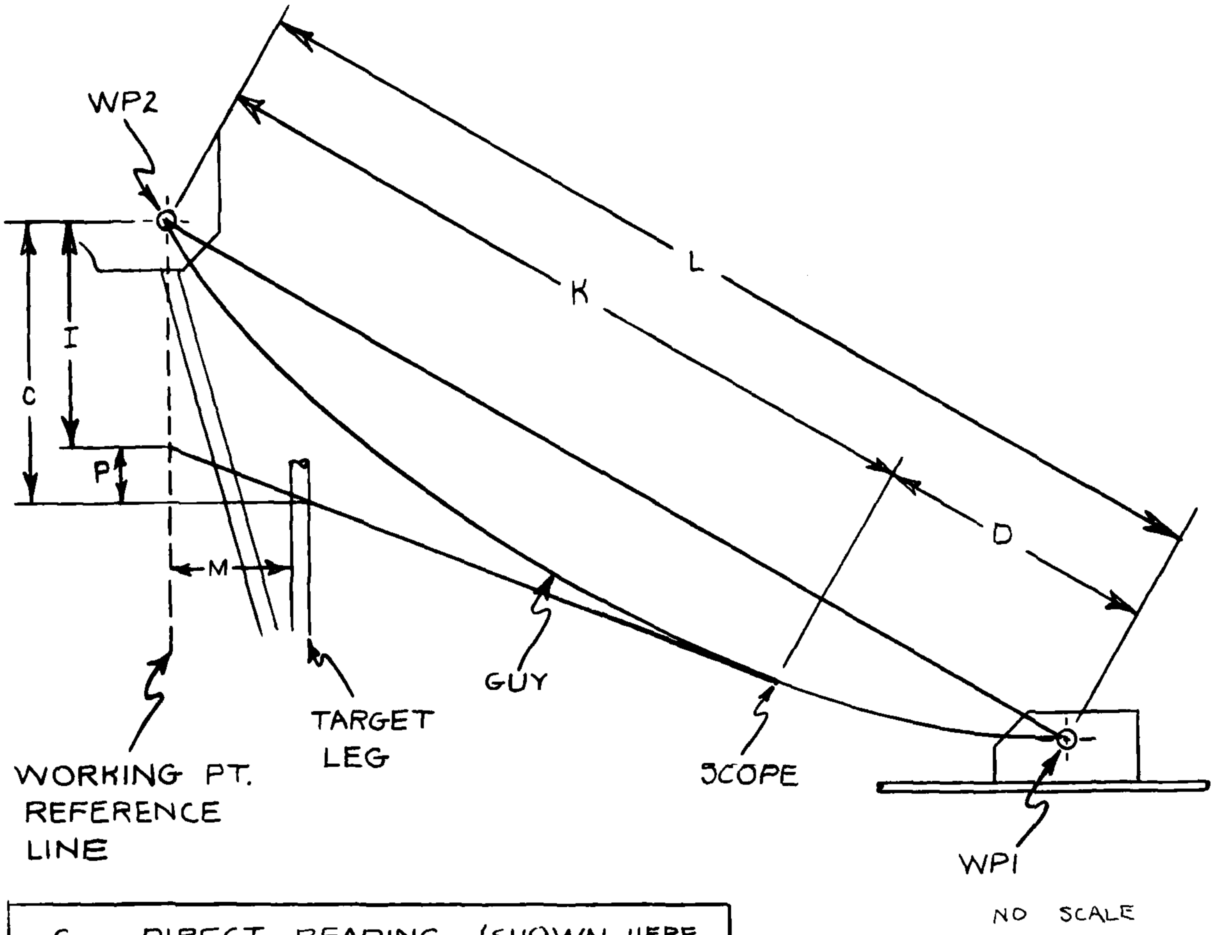
JIB CRANE GUY CABLE DATA



GUY	DIA. (INCHES)	W (#/FT.)	L (FEET)	M (FEET)	α (DEGREES)	P (FEET)	PROPER TENSION (lbs.)
B-A4	1	2.10	128.79	.46	44.9843	.46	28000
B-A5	1.5	4.73	133.79	.42	44.8516	.42	44000
B-A6	1.5	4.73	138.67	.42	44.9737	.42	44000

FIGURE A-11

GEOMETRY OF GUY SAG FOR JIB CRANE CABLES C-D & C-F

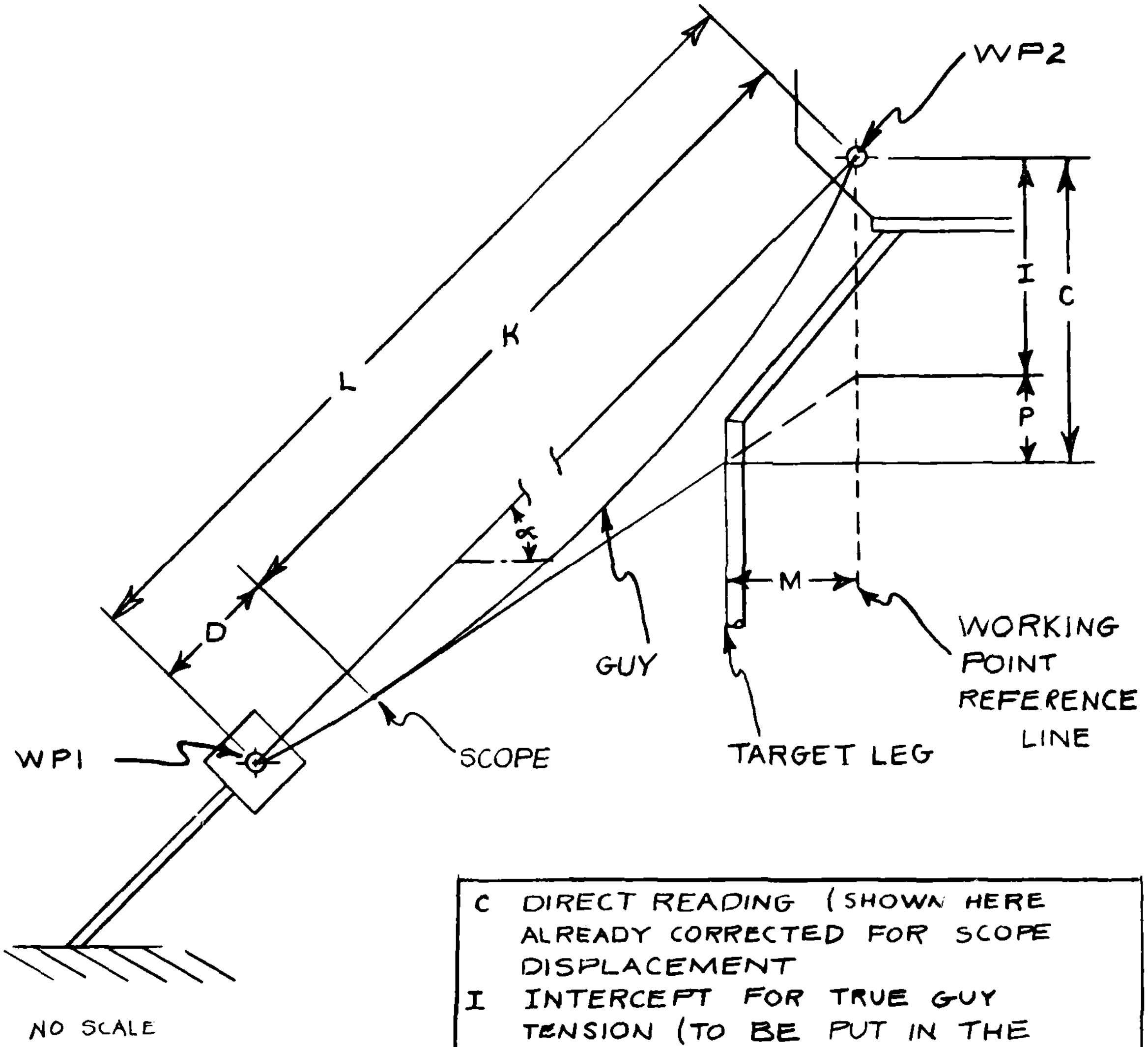


C	DIRECT READING (SHOWN HERE ALREADY CORRECTED FOR SCOPE DISPLACEMENT)
I	INTERCEPT FOR TRUE GUY TENSION (TO BE PUT IN THE TENSION EQUATION)
P	CORRECTION DUE TO PARALLAX CAUSED BY READING NOT BEING TAKEN AT THE WORKING POINT LINE.
L	DISTANCE FROM WP1 TO WP2
K	EFFECTIVE LENGTH
D	DISTANCE FROM WP1 TO SCOPE

GUY	DIA. (INCHES)	W (#/FT.)	L (FEET)	M (FEET)	α (DEGREES)	P (FEET)	PROPER TENSION (lbs.)
C-D	1	2.10	110.71	1.927	27.704	1.01	16000
C-F	1	2.10	204.30	1.927	14.256	0.49	29000

FIGURE A-10

GEOMETRY OF GUY SAG LEVEL "B"



C DIRECT READING (SHOWN HERE ALREADY CORRECTED FOR SCOPE DISPLACEMENT
I INTERCEPT FOR TRUE GUY TENSION (TO BE PUT IN THE TENSION EQUATION)
P CORRECTION DUE TO PARALLAX CAUSED BY READING NOT BEING TAKEN AT THE WORKING POINT LINE
L DISTANCE FROM WP1 TO WP2
K EFFECTIVE LENGTH
D DISTANCE FROM WP1 TO SCOPE

GUY	DIA (INCHES)	W (#/FT)	L (FEET)	M (FEET)	α (DEGREES)	P (FEET)	PROPER TENSION (lbs.)
C-A1	1.5	4.73	336.18	3.69	44.9506	3.68	68000
C-A2	1	2.10	295.29	3.63	54.6678	5.12	20000
C-A3	1	2.10	298.72	3.67	54.4567	5.13	20000

FIGURE A-12

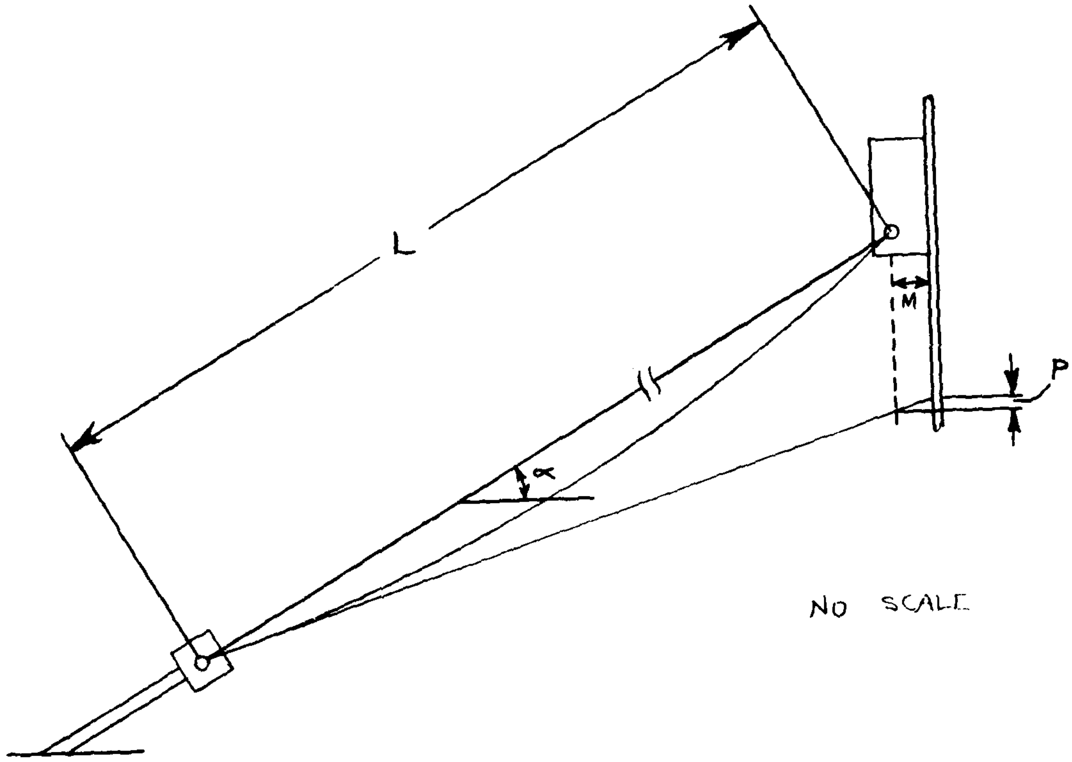
GEOMETRY OF GUY SAG LEVEL "C"

CABLE NUMBER	DIAMETER (INCHES)	MATERIAL	WEIGHT PER LENGTH (lbs./ft.)	BREAKING STRENGTH (POUNDS)	CORD LENGTH WP TO WP (FEET)	PROPER TENSION (POUNDS)
G-A4	1/2	STEEL	.517	26900	141.5	3000
G-A5	1/2	STEEL	.517	26900	144.0	3000
G-A6	1/2	STEEL	.517	26900	144.1	3000
H-A4	1/2	STEEL	.517	26900	172.2	3000
H-A5	1/2	STEEL	.517	26900	176.1	3000
H-A6	1/2	STEEL	.517	26900	175.6	3000
K-A1	1 1/2	STEEL	4.73	276000	260.8	56000
K-A2	1/2	STEEL	.517	26900	260.2	8000
K-A3	1/2	STEEL	.517	26900	229.4	9000

CABLE NUMBER	DIAMETER (INCHES)	MATERIAL	WEIGHT PER LENGTH (lbs./ft.)	BREAKING STRENGTH (POUNDS)	CORD LENGTH WP TO WP (FEET)	PROPER TENSION (POUNDS)
M-A4	5/8	DIELEC.	.27	30000	146.5	3000
M-A5	5/8	DIELEC.	.27	30000	147.0	3000
M-A6	5/8	DIELEC.	.27	30000	146.0	3000
N-A4	5/8	DIELEC.	.27	30000	179.9	3000
N-A5	5/8	DIELEC.	.27	30000	179.6	3000
N-A6	5/8	DIELEC.	.27	30000	177.6	3000
P-A1	1 1/2	STEEL	4.73	276000	263.5	56000
P-A2	5/8	STEEL	.813	42400	263.0	8000
P-A3	5/8	STEEL	.813	42400	263.0	8000

TABLE A-3

TOWER 1A GUY CABLE DATA



GUY	DIAMETER (INCHES)	WEIGHT PER LENGTH (#/FEET)	L (FEET)	M (INCHES)	α (DEGREES)	P (INCHES)	PROPER TENSION (POUNDS)
G-A6	1/2	.517	142.8	2.5	21.35	.377	3000
H-A5	1/2	.517	176.1	2.5	41.45	2.21	3000
H-A6	1/2	.517	175.6	2.5	40.76	2.15	3000

GUY	DIAMETER (INCHES)	WEIGHT PER LENGTH (#/FEET)	L (FEET)	M (INCHES)	α (DEGREES)	P (INCHES)	PROPER TENSION (POUNDS)
M-A4	5/8	.27	146.5	2.5	24.79	1.15	3000
N-A4	5/8	.27	179.9	2.5	42.31	2.28	3000

FIGURE A-13

SAG GEOMETRY FOR STABILIZING TOWERS 1A & 12

HORIZONTAL BRIDGE POLES 3, 6, 7

See Figure A-5 for the guying arrangement. Table A-4 provides the basic guy cable data. The cable length values were field measured as described for tower 12. Material and breaking strength data are from SRL drawing 2500-0405.

INTERROGATION THREAT SYSTEM POLES 2, 4, 9, 10

See Figure A-6 for the guying arrangement. Table A-5 provides the basic guy cable data. The cable length values were field measured as described for tower 12. The material data are from SRL drawing 2500-0405.

TOWERS 5 AND 1

See Figures A-7, A-8, and A-9 for the guying arrangement. Table A-6 provides the basic guy cable data. These towers were in place prior to the CCAMS effort; however, certain guy cables were relocated. Limited structural data for these towers is available. The proper pretension values are based on engineering judgment. A reasonable design practice is to pretension the cables to one half the maximum cable stress under extreme environmental loads. For a cable that has a breaking stength four times the maximum stress, the pretension load would be one eighth of the breaking strength. It is assumed that the cables are high strength steel with a breaking strength of 29,600 lbs.

Prior to the CCAMS effort, field measurements of the guy cable lengths were made for a proposed effort to replace allthe steel cables with Nuplaglas rods. Although the reguying effort did not take place, the field measurements are used for this Appendix. For those cables that were relocated, analytical corrections were made to the field measurements.

FINAL CALCULATED TENSIONS

Table A-7 gives the results of the vibration method applied to each guyed structure at the Stockbridge Test Site. The values for cables C-A2 and C-A3 on Tower 11 are from sag data as vibration data for these cables was not collected. A calculated tension, based on field measurements, that differs from the prescribed pretension by 25% would be acceptable considering the many factors that affect field measurements. Wind forces and temperature variations were observed to produce noticeable changes in cable sag and tension. The prescribed pretensions are for a temperature of 55°F. The field measurements

CABLE NUMBER	DIAMETER (INCHES)	MATERIAL	WEIGHT PER LENGTH (lbs./ft.)	BREAKING STRENGTH (POUNDS)	CORD LENGTH WP TO WP (FEET)	PROPER TENSION (POUNDS)
R-A1	3/4	STEEL	1.155	68000	144.6	14000
R-A2	3/4	STEEL	1.155	68000	142.8	14000
W-A3	3/4	STEEL	1.155	68000	142.0	14000
W-A4	3/4	STEEL	1.155	68000	149.9	14000
Q-A5	5/8	STEEL	.813	42400	108.3	7000
Q-A6	5/8	STEEL	.813	42400	88.3	8000
V-A7	5/8	STEEL	.813	42400	93.1	8000
V-A8	5/8	STEEL	.813	42400	91.1	8000
S9-A9	1/2	STEEL	.517	26900	89.6	4000
S10-A10	1/2	STEEL	.517	26900	91.4	4000
Q-S	1/2	STEEL	.517	26900	52.3	4000
S-V	1/2	STEEL	.517	26900	52.3	4000

TABLE A-4

HORIZONTAL BRIDGE GUY CABLE DATA

WOOD POLE 4

CABLE NUMBER	DIAMETER (INCHES)	MATERIAL	WEIGHT PER LENGTH (lbs./ft.)	BREAKING STRENGTH (POUNDS)	CORD LENGTH WP TO WP (FEET)	PROPER TENSION (POUNDS)
A1	1/2	STEEL	.517	26900	101.83	3000
A2	1/2	STEEL	.517	26900	100.98	3000
A3	1/2	STEEL	.517	26900	101.12	3000

WOOD POLE 10

CABLE NUMBER	DIAMETER (INCHES)	MATERIAL	WEIGHT PER LENGTH (lbs./ft.)	BREAKING STRENGTH (POUNDS)	CORD LENGTH WP TO WP (FEET)	PROPER TENSION (POUNDS)
A1	5/8	DIELEC.	.27	30 000	100.08	3000
A2	5/8	DIELEC.	.27	30 000	101.12	3000
A3	5/8	DIELEC	.27	30000	101.55	3000

WOOD POLE 9

CABLE NUMBER	DIAMETER (INCHES)	MATERIAL	WEIGHT PER LENGTH (lbs./ft.)	BREAKING STRENGTH (POUNDS)	CORD LENGTH WP TO WP (FEET)	PROPER TENSION (POUNDS)
A1	5/8	DIELEC.	.27	30000	101.97	3000
A2	5/8	DIELEC.	.27	30000	102.37	3000
A3	5/8	DIELEC.	.27.	30000	98.52	3000

WOOD POLE 2

CABLE NUMBER	DIAMETER (INCHES)	MATERIAL	WEIGHT PER LENGTH (lbs./ft.)	BREAKING STRENGTH (POUNDS)	CORD LENGTH WP TO WP (FEET)	PROPER TENSION (POUNDS)
A1	1/2	STEEL	.517	26900	100.40	3000
A2	1/2	STEEL	.517	26900	99.16	3000
A3	1/2	STEEL	.517	26900	100.00	3000

TABLE A-5

WOOD POLE GUY CABLE DATA

CABLE NUMBER	DIAMETER (INCHES)	MATERIAL	WEIGHT PER LENGTH (lbs./ft.)	BREAKING STRENGTH (POUNDS)	CORD LENGTH WP TO WP (FEET)	PROPER TENSION (POUNDS)
QW1	5/8	STEEL	.813	29600	166.38	3700
QS4	5/8	STEEL	.813	29600	147.02	3700
QN2	5/8	STEEL	.813	29600	149.17	3700
DN2	5/8	STEEL	.813	29600	149.06	3700
DE3	5/8	STEEL	.813	29600	148.08	3700
DS4	5/8	STEEL	.813	29600	147.44	3700
RN1	5/8	STEEL	.813	29600	203.35	3700
RS1	5/8	STEEL	.813	29600	203.33	3700
RN2	5/8	STEEL	.813	29600	188.78	3700
RS4	5/8	STEEL	.813	29600	184.93	3700
EN2	5/8	STEEL	.813	29600	188.80	3700
EN3	5/8	STEEL	.813	29600	188.89	3700
EE3	5/8	STEEL	.813	29600	188.89	3700
ES4	5/8	STEEL	.813	29600	185.39	3700
SW1	5/8	STEEL	.813	29600	223.15	3700
SN2	5/8	STEEL	.813	29600	212.51	3700
SS4	5/8	STEEL	.813	29600	208.21	3700
FN2	5/8	STEEL	.813	29600	212.05	3700
FE3	5/8	STEEL	.813	29600	210.57	3700
FS4	5/8	STEEL	.813	29600	208.72	3700

TABLE A-6

TOWERS 1 & 5 GUY CABLE DATA

CABLE	TOWER	PROPER PRETENSION (pounds)	CALCULATED TENSION (pounds)
B-A4	11	28,000	31,400
B-A5	11	44,000	52,400
B-A6	11	44,000	55,000
C-A1	11	68,000	58,400
C-A2	11	20,000	26,200
C-A3	11	20,000	20,200
D1-P	11	20,000	---
D2-K	11	20,000	---
D3-P	11	20,000	---
D4-K	11	20,000	---
C-D	11	16,000	---
C-F	11	29,000	---
G-A4	12	3,000	2,100
G-A5	12	3,000	2,500
G-A6	12	3,000	2,700
H-A4	12	3,000	3,100
H-A5	12	3,000	2,900
H-A6	12	3,000	3,600
K-A1	12	56,000	29,100
K-A2	12	8,000	8,800
K-A3	12	9,000	4,000
M-A4	1A	3,000	2,800
M-A5	1A	3,000	2,400
M-A6	1A	3,000	2,500
N-A4	1A	3,000	2,600
N-A5	1A	3,000	2,300
N-A6	1A	3,000	2,800
P-A1	1A	56,000	29,500
P-A2	1A	8,000	4,800
P-A3	1A	8,000	9,300

NOTE:
1. All calculated tensions were rounded off to the nearest hundred lbs.
2. A dashed line signifies the cable was not measured.
3. C-A1, C-A2, & C-A3 from sag data

Key to Tower Labels
11 - Jib Crane
12 - Stabilizing Tower
1A - Stabilizing Tower
6-7-3 - Horizontal Bridge
WP2 - Wood Pole
WP10 - Wood Pole
WP9 - Wood Pole
WP4 - Wood Pole
1-5 - Twin Towers

CABLE	TOWER	PROPER PRETENSION (pounds)	CALCULATED TENSION (pounds)
R-A1	6-7-3	14,000	12,000
R-A2	6-7-3	14,000	12,600
W-A3	6-7-3	14,000	12,000
W-A4	6-7-3	14,000	13,600
Q-A5	6-7-3	7,000	5,200
Q-A6	6-7-3	8,000	6,200
V-A7	6-7-3	8,000	6,700
V-A8	6-7-3	8,000	6,800
S-A9	6-7-3	4,000	2,600
S-A10	6-7-3	4,000	1,700
Q-S	6-7-3	4,000	---
S-V	6-7-3	4,000	---
A1	WP4	3,000	1,300
A2	WP4	3,000	1,700
A3	WP4	3,000	2,100
A1	WP10	3,000	1,400
A2	WP10	3,000	1,400
A3	WP10	3,000	1,600
A1	WP9	3,000	1,300
A2	WP9	3,000	1,700
A3	WP9	3,000	1,300
A1	WP2	3,000	1,100
A2	WP2	3,000	2,000
A3	WP2	3,000	2,300
QW1	1-5	3,700	2,600
QS4	1-5	3,700	2,600
QN2	1-5	3,700	2,300
DN2	1-5	3,700	3,000
DE3	1-5	3,700	2,900
DS4	1-5	3,700	2,200
RN1	1-5	3,700	2,300
RS1	1-5	2,700	2,100
RN2	1-5	3,700	1,900
RS4	1-5	3,700	2,000
EN2	1-5	3,700	2,500
EN3	1-5	3,700	1,600
EE3	1-5	3,700	1,600
ES4	1-5	3,700	1,700
SW1	1-5	3,700	1,700
SN2	1-5	3,700	2,200
SS4	1-5	3,700	2,200
FN2	1-5	3,700	2,500
FE3	1-5	3,700	2,000
FS4	1-5	3,700	2,600

TABLE A-7

FINAL CALCULATED TENSIONS

for this effort were made in temperatures between 75^{o}F and 85^{o}F. A 20 degree increase in temperature would result in a decrease in cable tension of approximately 3 to 5 percent, for example, on the steel cables used on the jib.

For each structure, the following comments are made:

Tower 11

All cables that were measured are properly tensioned. Cables D1-P, D2-K, D3-P, and D4-K were not measured since proper tensioning of Towers 12 and 1A will result in proper tensioning of these cables. Cables C-D and C-F that support the weight of the horizontal boom of the jib were not measured because of their locations. However, these cables, as well as all of the cables attached to the jib, could be checked by using a transit and comparing tower deflections with the field measurements reported in Pg 97-101 of RADC-TR-80-406. Time did not permit field measurement of tower deflections for this effort.

Tower 12

Two cables on this tower, K-A1 and K-A3, were found to be tensioned considerably less than prescribed.

Tower 1A

Two cables on this tower, P-A1 and P-A2, were found to be tensioned considerably less than prescribed.

Horizontal Bridge (Poles 6, 7, 3)

Cables S-A9 and S-A10 were found to be tensioned considerably less than prescribed. Cables Q-S and S-V were not checked because of their locations; however, these cables are not critical for structural stabilty and survival.

Wood Poles 2, 4, 9, 10

All cables on these structures are tensioned considerably less than prescribed. However, structural deflections during high winds for these poles are not critical. Present cable tensions are adequate.

Towers 1 and 5

All cables on these towers are tensioned somewhat below prescribed values. Note, however, that the prescribed values are based on engineering judgment and not on a detailed force analysis of the tower system. At this time, the cable tensions are considered adequate.

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