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Effective Use of Guylines on Logging Spars

J.M. Ewart, P.Eng.

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201 - 2112 WEST BROADWAY, VANCOUVER, B.C., CANADA V6K 2C8
143 PLACE FRONTENAC, POINTE CLAIRE, QUE., CANADA H9R 4Z7

FOREWORD

FERIC asked J. M. Ewart, a professional engineer experienced in cable system design, to examine guyline stresses in differing situations. This FERIC technical note is a reproduction of Mr. Ewart's report and supplements FERIC's continuing studies of cable logging systems.

Mr. Ewart's work was done in Imperial units.

We would like to thank Mr. Brooks Cranston, Workers' Compensation Board; Mr. Hilton Lysons, United States Forest Service; Mr. Les Rush, MacMillan Bloedel; and Mr. Daniel Guimier, FERIC. Each made a valuable contribution to this report.

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SUMMARY

The purpose of this report is to help the logger determine whether or not a logging spar is adequately guyed under any given set of circumstances.

A graph is used to illustrate safe and unsafe combinations of line geometry, line pulls, and guyline sizes. The graph is based on commonly-used yarding configurations.

Recommendations are given for inspection and service, guyline placement, and other factors important to insure stability of the spar.

INTRODUCTION

Historical information on logging spar accidents indicates that the vast majority are inititated by guyline system failures caused by improper use or inspection of equipment. Much of this can be attributed to lack of understanding on the part of operators and supervisors or to the lack of clear guidelines.

This report will clarify basic principles regarding the application of guylines and deal with the most significant parameters affecting safe guyline application--information which all operators and supervisors should know. Variations of these parameters are discussed with regard to the effects on spar stress, line tension and system stability. Both highlead and skyline systems are considered.

CAUSES OF SPAR FAILURE

A recent study of fifteen spar overturns was made by the Workers' Compensation Board of British Columbia and revealed that poor guyline rigging was the cause of all but two of the accidents. Some of these accidents resulted in injuries or fatalities. Undoubtedly there are many more which never come to the attention of the Workers' Compensation Board because no injury resulted. It is reasonable to assume that the percentage of these unreported accidents involving guyline failure would be the same as for the fifteen accidents studied. The failures studied resulted from poor guyline placement and/or tensioning; poor stump selection; failing to tie back stumps and inspect stumps under pull; worn guylines; failure of blocks, shackles and other hardware; and improper securing of the guyline drum. Much of this can be attributed to inadequate attention or inspection. Operators must understand the safe functioning of spar guyline systems.

Of all the errors made with guyline systems, the most common is poor placement of the lines. A poorly-arranged system results in three conditions which may eventually cause collapse or overturn of the spar.

The first condition occurs when an unacceptably high percentage of the guyline reaction (resulting from tension in the operating lines) is placed on one guyline, causing it to fail. If the guylines are spaced properly, failure could be caused by uneven tightening, uneven length of guylines, or by the slackening of a guyline transferring all the load to another line when an anchor or stump loosens.

Unequally-spaced guylines alter the stability of the spar, the second condition resulting from poor guyline placement. As the angle between two adjacent guylines approaches 180 degrees, guyline tension increases rapidly and the spar becomes less stable. Figure 2 shows the ideal situation with six guylines spaced at 60-degree intervals about the spar. Should one of the guylines fail, the maximum angle between two adjacent guylines becomes 120 degrees. If the remaining guylines are properly anchored and pre-tensioned, the spar may remain standing but its stability is drastically impaired. If the yarding operation is not stopped immediately, the increased load placed on these two guylines may cause one of them to fail. Now the included angle becomes 180 degrees and the spar falls. It is conceivable that unequal spacing of guylines could create the situation where failure of one guyline leaves an angle approaching or even exceeding 180 degrees. Obviously it is not sufficient to say that yarding reactions must be countered by two or more guylines. Nor is it sufficient that the operator be satisfied when all guylines are properly secured to good solid stumps. Rather, he should recognize the perilous situation which exists if just one guyline fails. The remaining guylines may not ensure stability of the spar. The reality of this is borne out by accident reports stating how spar collapse was caused by the failure of just one guyline or a rapid succession of guyline failures. Often the reports include a statement that guyline placement was poor.

The third condition created by poor guyline placement is the result of excessive stresses in the spar. This concerns the total vector of guylines, the operating line reactions about the top of the spar and the resulting bending and compressive stresses. Failures of this type are rare. Occasionally an accident report attributes failure to a previously dented or damaged spar. (The relationship between excessive spar stresses and guyline location will be discussed more fully later.)

ESTIMATING SPAR AND GUYLINE STRESSES

The infinite number of variables affecting guyline reactions and spar stresses makes the evaluation of a yarding system a complex procedure which does not lend itself to assessment by operators in the field. However, certain rules of thumb and rough estimating procedures can be established which will assist the operator and guard against the occurrence of hazardous situations.

Guyline reaction is a factor in the relative geometry of all lines coming from the top of the spar and the total spar-top reaction from all yarding and skylines.

Although yarding and skyline tension is related to the size of the load, it is largely limited to the line-pull capabilities of the winch. The design of all winch components and the sizing of all lines is determined either by the brake capacity on the winch drums or the characteristics of the drive train. Virtually all logging winches are driven by an engine through a torque converter. Maximum converter-output torque occurs at or near stall conditions. This, plus the winch drive ratio, governs the maximum line-pull on the driven drum. Information on the winch characteristics should be available from the winch manufacturer. Some engineers may derive the maximum total spar-top reaction from yarding lines and skylines by adding the breaking strength of all the lines, but as no properly designed winch is capable of achieving breaking pull on all operating lines simultaneously, this approach is overly conservative and is not justified.

SHOCK LOADING

It may be argued that maximum tension as described above may be exceeded through shock loading. This occurs most commonly when the turn suddenly hangs up on its way into the landing, or falls over the edge of a bluff and is suddenly suspended from operating cables. In these cases, the line-pull increases rapidly and may momentarily exceed the line-pull capabilities of the winch because of the mass effect of the rotating winch components and the moving lines.

It is difficult to determine maximum shock loading tension levels in the moving lines. The resultant spar-stress level and guyline tension is more significant as a factor of spar stability and safety. Several factors work to dampen out the effects of shock in the spar and guylines. The first is the elasticity of the cables and the flexibility of the spar. In addition, static line-pull tests taken on the drums of logging winches indicate a line-pull 10 to 20 percent less than the theoretical maximum determined by converter stall and winch drive ratio. This discrepancy is due to friction losses within the drive train and increases with the number of gear meshes involved. Finally, a shock loading and its effects can be minimized by selecting a choker which will break first before anything else fails. There is not enough information to evaluate accurately the effects of shock loading. Experience has shown, however, that much of the design work may be done using the maximum performance capabilities of the winch as a safe and realistic criterion. This would then determine the line sizes and the spar design.

Safety Factors

It is not possible to determine precise engineering safety factors for mobile steel spars because neither the load nor the strength of the anchor stumps can be determined accurately. However, it is possible to estimate these factors for normal operation.

Yarding winches are designed for normal operation between two points on the torque converter curves representing 70% efficiency (Figure 1). The converter must not operate between the low speed 70% point and stall point because it will overheat. The stall point is only reached for short periods when there is a hangup of the logs being yarded. The maximum pull of the winch is calculated by the manufacturer at stall condition. During normal yarding operation the maximum pull is only half this value. In addition, the allowable guyline tension is 70% of the breaking strength of the wire rope. These two factors combined produce a factor of safety of 2.3 for a highlead yarder operating under normal conditions.

For gravity and skyline systems, the haulback and skidding line portions of the spar reaction are calculated in a manner similar to that for highlead. The skyline pull is determined by brake capacity. In order to allow for any inaccuracy in estimating the brake capacity, an additional factor of 1.5 is applied to the skyline portion of the total spar reaction. This has the effect of maintaining the overall 2.3 safety factor for the system.

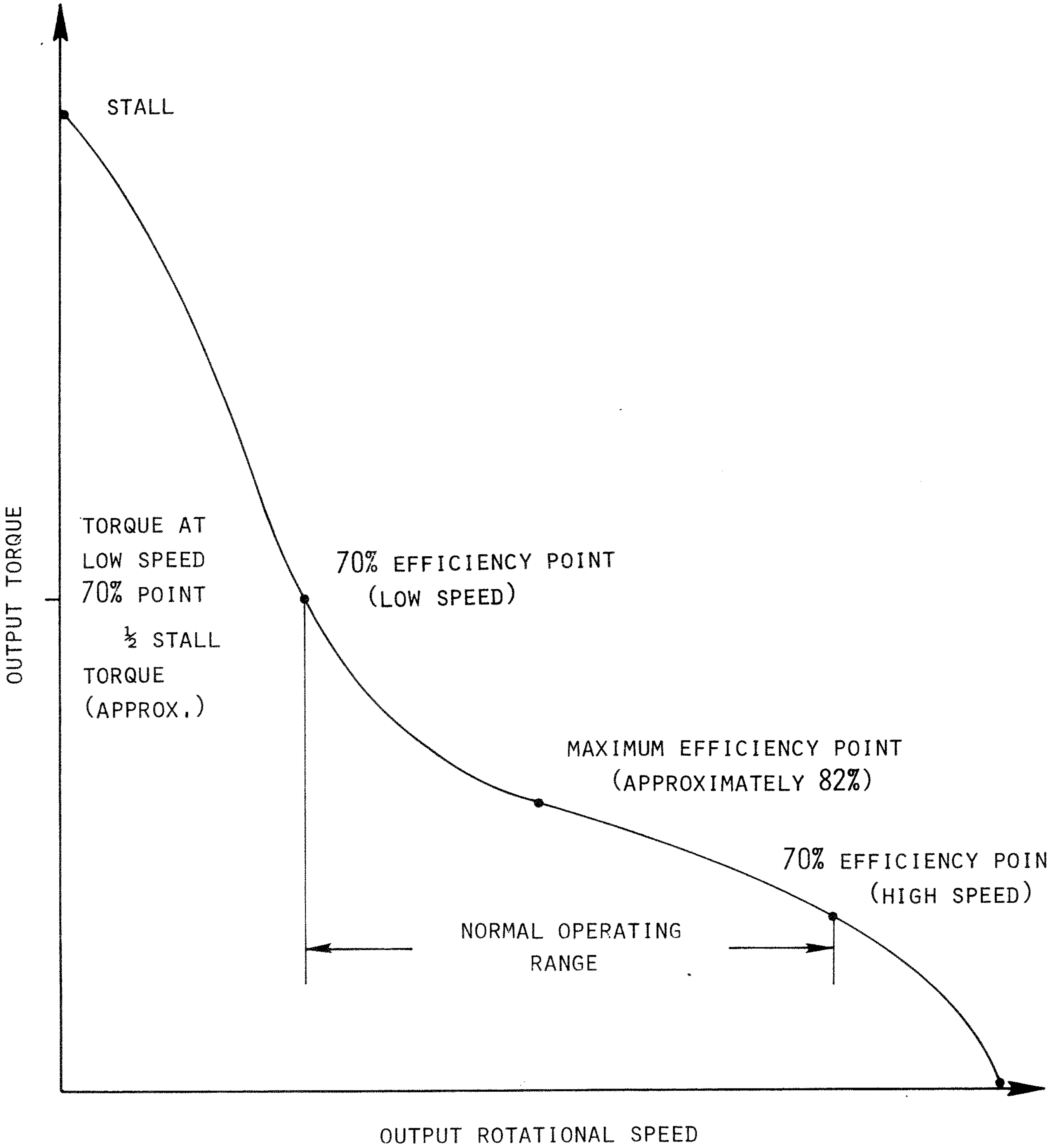


FIGURE 1. TYPICAL CONVERTER PERFORMANCE CHARACTERISTICS

Elasticity in the lines, flexing of the spar, and breaking strength limitation of the chokers all limit the effect of shock loading. Friction within the winch drive train and in the lines and sheaves has the effect of limiting the actual yarding tensions to a value below that theoretically calculated. All this further enhances the safety factor. The purpose of this safety factor, as of any safety factor, is to compensate for the intangibles, the indeterminates and the unexpected which are inevitable in any logging operation.

Total Spar-Top Reaction for Highlead and Skyline

For the purposes of stress and line-reaction analysis, the yarding system may be classified as a two-line highlead system or a skyline system. Variations on the two-line highlead system include the scabline and grapple yarding arrangements. The pull on the third line, used to open the tong on a grapple system, simply augments the main line tension and may be considered as a component of it. Reactions in the two-line highlead system result from tension in the mainline (as determined by the winch drive system), and restraining tension in the haulback line (as determined by the brake).

Example: Madill 009 Highlead Yarder (maximum conditions from manufacturer)

Mainline stall winch condition	110 kips
Haulback braking reaction	30 kips
Total spar-top reaction	140 kips

The same conditions are not true for skyline systems. These systems, including the gravity system, rely on a sustained high skyline tension for their effectiveness in maintaining lift on the turn. This tension level is determined by a skyline drum brake which may have three to four times the torque capacity of any brake on a highlead winch of comparable size, and it is fully applied most of the time. To reflect this more severe service in the determination of the total spar-top reactions from yarding lines and skyline, a factor of 1.5 is applied to the maximum skyline tension as determined by the maximum skyline brake capacity before adding on the main or skidding stall tension and the maximum haulback tension if applicable.

Example: Madill 046 Slackline Skidder (maximum conditions from manufacturer)

Skyline brake capacity x 1.5 = 110 x 1.5 =	165 kips
Skidding line-pull	80 kips
Haulback pull	30 kips
Total spar-top reaction	275 kips

In this case the spar-top reaction is much greater than for highlead.

GEOMETRY AND FORCE RELATIONSHIPS

The relationships between total spar-top reaction from all yarding and skylines, guyline tension and spar stress can be determined by calculation. Three angular measurements are critical in determining the forces acting on guylines.

1. The Angle Between Guylines: this is the horizontal angle between two load-sharing guylines (Figure 2). A load-sharing guyline is defined as one which is located in a 120-degree arc opposite to the direction of yarding about the spar. As further guylines are placed beyond this range their load-sharing effectiveness will be severely diminished. When more than two guylines are considered, the largest of the Angles Between Guylines should be used.

2. The Yarding Angle: this is measured between the spar axis and the resultant of all lines other than the guylines (Figure 3). This includes the main and haulback lines for the highlead arrangement. Since the mainline vector is the predominant factor of this resultant, the yarding angle may be closely approximated by considering the mainline angle to the spar. For the skyline operation, the yarding angle may be considered the same as the angle between the spar and the skyline.

3. The Guyline Angle: this is the smallest of the angles taken between the spar and the load-sharing guylines (Figure 3).

NOMOGRAM TO DETERMINE GUYLINE TENSION

The determination of guyline tension from all the parameters introduced previously has been simplified and is presented in the form of a nomogram in Figure 4.

FIGURE 2. PLAN VIEW OF SPAR AND GUYLINES

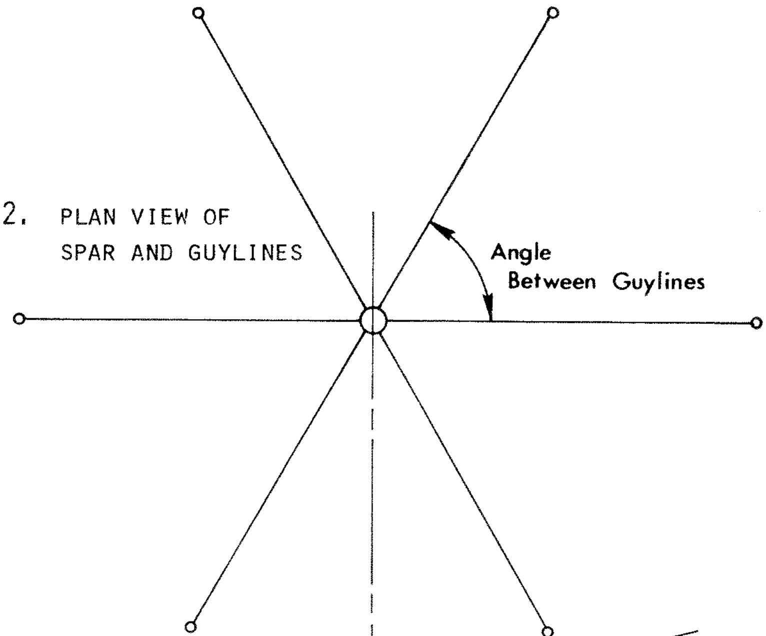
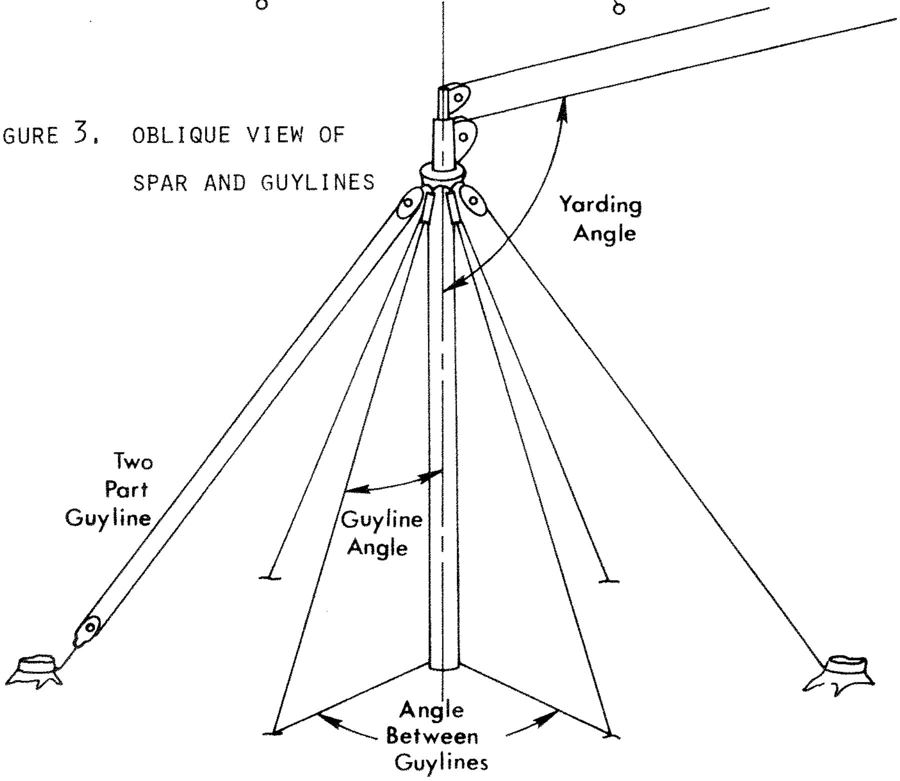


FIGURE 3. OBLIQUE VIEW OF SPAR AND GUYLINES



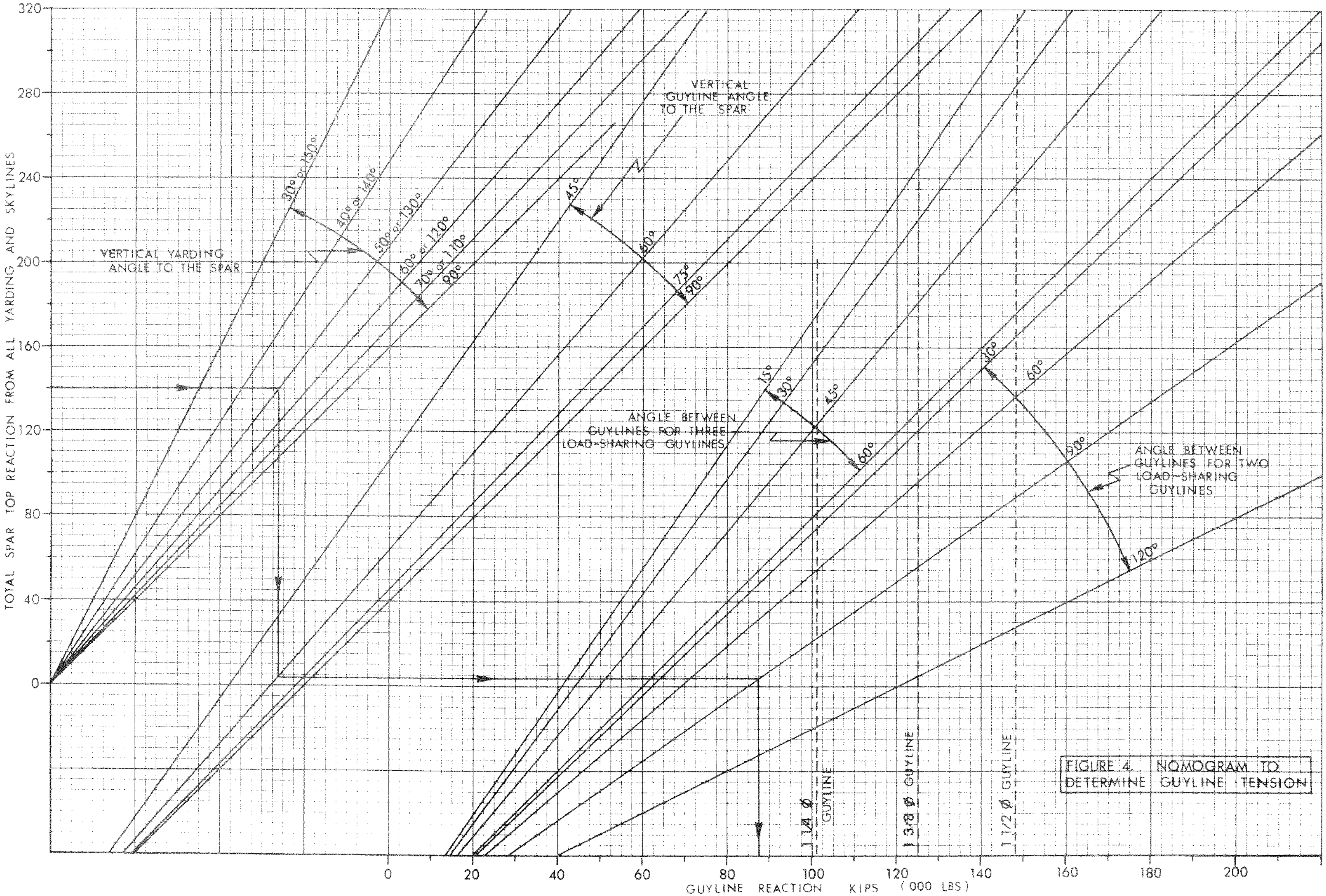


FIGURE 4. NOMOGRAM TO DETERMINE GUYLINE TENSION

The "Y" axis represents the maximum total reaction possible from simultaneous main, haulback and skyline forces acting from the top of the spar. A series of diagonal lines represents the parameters of vertical yarding angle to the spar, vertical guyline angle to the spar,and the horizontal angle between guylines for systems having either two or three load-sharing guylines. The "X" axis represents the resulting guyline pull after establishment of the above parameters.

Dotted lines have been superimposed showing a maximum line pull of 102,000 lb for a 1 1/4-inch diameter guyline and 125,000 lb for a 1 3/8-inch diameter guyline. These values represent 70% of the breaking strength for these lines.

The primary use of the nomogram is for checking the safety of existing guyline systems. For instance, the highlead yarder cited in the previous example as having a maximum total spar-top reaction of 140,000 lb is guyed with 1 1/4-inch diameter guylines (Figure 5). The yarding angle is 50 degrees, the guyline angle is 60 degrees, and there are two load-sharing guylines 90 degrees apart.

The guyline pull may be determined in the following way. A horizontal line is projected from the 140,000-lb total spar-top reaction located on the "Y" axis to a point of intersection with the line marked 50 degrees (or 130 degrees) vertical yarding angle. From this point a line is projected down to a point of intersection with the line marked 60 degrees vertical guyline angle. A horizontal projection is made from this point to the line of 90 degrees angle between guylines located within the range indicated for two load-sharing guylines. From here a final projection is made down to the "X" axis where the guyline tension in each line is determined. In the example, guyline tension is 87,000 pounds. This is less than the 70% (102,000-lb) limit for the 1 1/4-inch diameter guyline. This system is safe.

If conditions were such that the limit of guyline tension would be exceeded, the following remedial action would have to be considered to reduce guyline pull.

1. Relocate the spar to a more favourable location. In most cases this solution will be rejected outright as being the least practical.

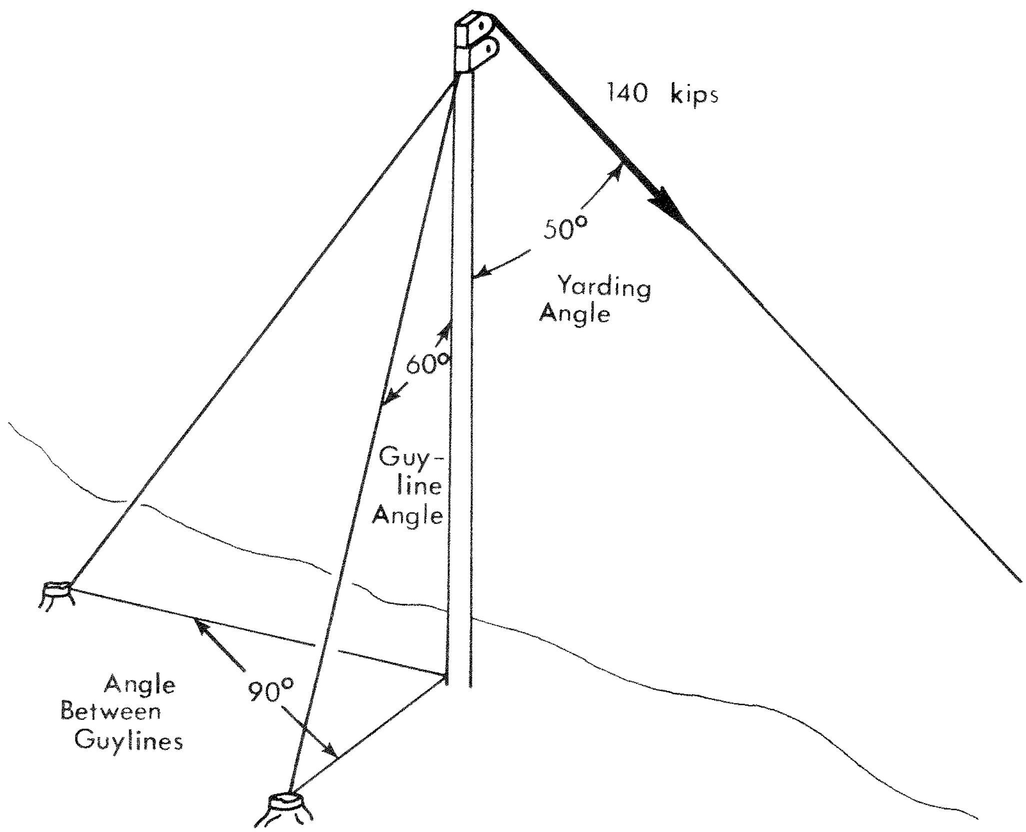


FIGURE 5. DIAGRAM OF ANGLES AND SPAR REACTION USED IN HIGHLEAD EXAMPLE

2. Reposition the load-sharing guylines to achieve either a greater angle to the spar or a smaller angle of spread. Examination of the graph will reveal how either of these measures will reduce guyline pull.

3. Change the load-sharing guylines to two-part lines, thereby cutting the line tension in half, provided the straps and stumps are adequate (Figure 3).

4. Place another guyline between two load-sharing guylines. In the case of the example cited, the new guyline pattern would then consist of three load-sharing lines spaced at 45 degrees. This would have the effect of reducing the guyline tension from 87,000 lb to 51,000 pounds. In relocating this guyline, care must be taken to avoid an unfavourable placement of guylines elsewhere around the spar.

SPAR BENDING, SPAR LEAN, BRAKES AND DEFLECTION BLOCKS

Spar bending and critical column loading are rarely significant for the more common makes of logging spars, except when the angle between guylines becomes too great or the guyline angle to the spar becomes less than 45 degrees. Under these circumstances the guyline becomes overstressed. Stresses in the spar may be critical if the spar is set up with an excessive lean from the vertical or if the spar is damaged.

As mentioned, skyline pull is a function of skyline brake capacity. To decrease deflection and permit a greater degree of "tight-lining," operators will sometimes increase skyline braking, usually by introducing more air pressure to the brake actuator. This is a dangerous practice because the manufacturer's specifications may be exceeded and the assembly overstressed. Care must be taken to ensure that the skyline brake will slip before rated skyline-tension is exceeded. This has a special importance for machines designed for highlead yarding but converted to gravity yarding. Unless the skyline braking system is carefully designed and controlled, overtensioning is a real and dangerous possibility.

Occasionally, back guylines are used to anchor deflection blocks for the haulback line in a gravity or skyline situation. Under certain circumstances, this can impose an intolerably high tension in the guyline. As a general rule for safety, the line chosen should not be considered as one of the load-sharing guylines.

Consider two load-sharing guylines placed 60 degrees apart in a six-guyline arrangement. If a third guyline is located between these guylines for the purpose of mounting a deflection block, the remaining three guylines must be placed within the remaining 300 degrees about the spar. The included angles become very large and the spar may be unstable. This is an extreme example, but does illustrate a dangerous tendency and the need for extra care when mounting haulback line deflection blocks on guylines. This danger could be avoided by adding a seventh guyline, specifically for the deflection block.

RECOMMENDATIONS AND CONCLUSIONS

1. Inspection and Service

It is very seldom that maximum conditions of tension in all operating lines occur simultaneously with the worst allowable placement of the lines. Failures usually occur when equipment is in poor condition. Regular inspections and service should be conducted as follows:

(a) replace guylines when damaged;

(b) inspect and lubricate guyline blocks each time the spar is lowered;

(c) replace guyline shackles at regular intervals or whenever there is a sign of wear, bending, or distortion;

(d) examine guyline rings periodically or replace them when distorted or cracked;

(e) examine spars for dents and cracks.

Repairs must be carried out immediately, according to manufacturer's specifications.

Although not included in the scope of this report, stump-anchor selection is very important.

2. Guyline Placement

(a) Angle between guylines (Figure 2)--Avoid large angle spacing between load-sharing guylines. This angle must not exceed 90 degrees on six-guyline machines or 60 degrees on eight-guyline machines. At the same time, little is achieved by placing guylines closer than 30 degrees to one another. Doing so will jeopardize proper spacing of guylines elsewhere around the spar.

(b) Guyline angle (Figure 3)--Avoid steep guyline angles. Load-carrying guylines must never be less than 45 degrees from the spar.

(c) Guyline length--Avoid excessive differences in guyline lengths. The greater stretch of a long guyline will prevent it from taking its fair share of the load, causing a greater tensioning of the shorter guylines.

(d) Dutchman block--A guyline on which a deflection (dutchman) block is suspended cannot be considered as a load-sharing guyline.

(e) Pre-tensioning--Pre-tension all guylines equally--or if lengths differ widely, pre-tension the long ones more, in proportion to their length.

3. Yarding Angle (Figure 3)

Since guyline reactions increase as the yarding angle approaches the horizontal, the yarding angle should be as far away from the horizontal as possible.

4. Braking

On skyline machines including gravity slackline, never increase braking capacity without the permission of the manufacturer. Never dog the skyline drum. The brakes must allow the drum to slip under a heavy pull.

5. Line Size

Always conform to the manufacturer's specifications for line size.

6. Regulations

Be familiar with and observe local safety codes.