DEVELOPMENT OF A CABLE LOGGING SYSTEM ANALYSIS PACKAGE FOR MICRO-COMPUTERS

by

Joosang Chung

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APPROVED:

J. Sessions

Associate Professor of Forest Engineering in charge of major

William A. Atkinson

Head of the Department of Forest Engineering

Date paper is presented May, 1987

Typed by Hyerim Chung for Joosang Chung

AN ABSTRACT OF THE THESIS OF

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Title: Development of a Cable Logging System Analysis Package for Micro-Computers

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A computer program package to estimate cable yarding payload capability was made. The package was intended to expand applicability of existing packages and to be user friendly. It has six system options: live skyline, standing skyline, running skyline, slackline, multispan and highlead. In the standing skyline and multispan analyses, load path analysis, as well as payload analysis, is available as an optional basis.

Each program for the analysis of a system was built to include subroutines to consider its mechanical characteristics, which are usually ignored in existing packages. The running skyline program has an option to consider the maximum torque on the haulback drum. The highlead analysis program has an option to consider the effect of cable drag. The multispan has a subroutine to check

carriage passage over a support jack and an option to consider the effect of jack friction. In addition, the effect of log drag and log shape as well as choking strategy can be considered as an optional basis.

The paper was written to present the mathematical formulations and modeling procedures used in building the package. In addition, outputs of an example run for each system are presented with interpretations.

ACKNOWLEDGEMENT

This paper should be dedicated to my parents; Soonbin Chung, my father, and Young-le Kim, my mother. They have encourged and supported me to study abroad. Thank you, Father and Mother.

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LIST OF SYMBOLS

A : Metallic area of a cable, in

bcl: Butt-rigging clearance over ground, ft

C : Choking point distance from the leading end of a log, in

cwt: Carriage weight, lb

D : Cable rope diameter, in

dL : Horizontal length of a skyline left cable segment, ft

dR : Horizontal length of a skyline right cable segment, ft

ds : Horizontal span length, ft

E : Modulus of elasticity of a cable, psi

hc : Carriage clearance over ground, ft

hh : Elevation difference between tops of adjacent supports in a loaded span of multispan, ft

hL : vertical length of a skyline left cable segment, ft

HL : Horizontal tension component of upper span in multispan, lb

HR : Horizontal tension component of lower span in multispan, lb

L : Average log length, ft

LC : Choker line length, ft

li : Length of cable segment i, ft

LL : Haulback line length left on drum after being stretched, ft

Mh : Maximum haulback drum torque, lb-in

PL : Maximum payload capability, lb

R1 : Leading end diameter of a log, in

R2 : Trailing end diameter of a log, in

Rb : Empty haulback drum radius, in

Ri : weight of cable segment i, lb/ft

S : Stretched cable segment length, ft

So : Unstretched skyline length, ft

Slj: Skyline length of a loaded span, ft

Smin: Shortest stretched skyline length (fixed skyline length), ft

Suj: Skyline length of an unloaded span, ft

Tave: Average tension loaded on a continuous cable line, lb

TL : Lower end tension of a cable segment, lb

Ts : Critical skyline tension for a successful carriage passage of a gross payload, lb

TU : Upper end tension of a cable segment, lb

w : Unit weight of a cable segment, lb/ft

y : Elevation difference between top of supports, ft

α : Angle between a loaded choker line and the horizontal, rad

β : Log-to-ground angle, rad

ε : Log Centroid Distance from leading end of a log, ft

μ : Friction coefficient for log drag

μj : Friction coefficient for jack friction effect of multispan

μm : Friction coefficient for mainline drag of highlead

DEVELOPMENT OF A CABLE LOGGING SYSTEM ANALYSIS PACKAGE FOR MICRO-COMPUTERS

I. INTRODUCTION

Cable logging was introduced into the Pacific Northwest of the United States, in one form or another, in the late 1800s. It has been developed for a variety of systems and has become a major tool to transport timber on steep terrain. Accompanying the development of cable logging, a number of payload analysis methods have been developed to meet the requirement of cable logging planning. Most of the conventional models were based on physical or empirical tools such as nomographs, a model yarder or chain and board. These conventional methods lack speed and accuracy.

Cable logging planning has entered a new phase with the introduction of hand-calculators and desk-top computers. Using programming algorithms, many mathematical formulations developed in related fields have been applied to cable logging mechanics. As a result, a number of sophisticated programming payload analysis models have developed to meet the need of advanced cable logging planning. Payload analysis has become much more accurate and faster.

The programming models were limited in system types and their design criteria. They focused on such system analysis as the live skyline, standing skyline, running skyline and/or multispan. The scope of analysis was usually limited only to payload analysis with a fixed log-to-ground friction coefficient, usually 0.6, or with an assumption of a fully suspended log.

This paper expands the scope of applicability of the existing programming models in logging planning. It increases the number of systems that can be analyzed, the information on system operations and the options.

The package has six system options: live skyline, standing skyline, running skyline, slackline, multispan and highlead. Among them, the standing skyline and multispan analyses have an option to solve a load path problem by specifying a trial payload. The highlead model is designed for a user to enter haulback tensions if desired.

Specifically, this package considers the following systems or options, which are not available in existing programming packages.

1. The information to tension the unloaded skyline of the standing skyline.
2. The payload capability of the running skyline including consideration of the torque capability of the haulback drum.
3. The slackline system analysis for specified skyline and

haulback tensions.

4. The analysis of the multiple span standing skyline (multispan) considering jack friction and carriage passage over the support jack.
5. The highlead system analysis considering mainline drag on the ground.
6. Options to specify the leading and trailing log end diameters, and the distance of choking point from the leading end.
7. Options to specify the log-to-ground friction coefficient.
8. Summation of horizontal and vertical components of the cable tensions at the spars for use in guyline analysis.

From chapter III through VIII, modeling and programming procedures for each system are discussed. The formulas or procedures which can be applied to other system analysis are presented in chapter III. All the specific subroutines in the package other than utility subroutines are presented in the chapter of the corresponding system analysis.

The general application of this package is presented in chapter X with an example problem and the outputs of solutions for each system type. In addition, the effect of the optional parameters on system payload capability, such as log dimensions, running skyline yarder parameters, slackline, and jack friction coefficient and chord slope break of the multispan, are illustrated in chapter XI.

The cable link formulas discussed in this paper will be based on statics. Cable link assumptions will be chosen from either rigid or catenary link assumptions as is appropriate. The skyline systems are assumed to use unclamped carriages and the highlead uses butt-rigging.

II. LITERATURE REVIEW

The literature indicates that the trend of study on cable logging analysis has progressed from simple physical models to hand-calculator models to computer programming models. Most of recent works have focused on the development of sophisticated programming models.

The mathematical formulations for hand-calculator or computer assisted cable segment analysis have been introduced or developed mainly by Carson (4, 5, 6 and 7), Falk (8), and Mann (6 and 7). Miller (1984) made comparisons quantitatively between cable segment analysis models such as weightless link, rigid link and catenary link. He concluded "Which model is appropriate for any particular problem depends upon the lengths and weights of the lines, the tensions involved, the accuracy and the algorithm complexity .... ".

Based on the methods of cable segment analysis, a number of payload prediction models, published or unpublished, have been developed. Carson and Mann (1971) developed a programming model for the load path analysis of the running skyline. Carson (1975) developed a package for an HP 9830 desk-top calculator with catenary link formulations. It includes standing skyline, running skyline and multispan analysis programs for full suspension. Carson (1975) also developed a programming model for the analysis of the running skyline with log dragging. It was the first model considering partial log suspension (log drag). Falk (1981) made a package for hand-calculators. It includes payload analysis programs for a live skyline, standing skyline and running skyline considering the effect of partial suspension. Nickerson (1980) made a package which includes all the system options above for desk-top computers. Later the package was converted to the MS-DOS operating system as LOGGERPC by Balcom (1987).

Binkley and Sessions (1978) suggested procedures to predict the carriage passage over a multispan support jack using chain-and-board methods. The conditions of the carriage passage for uphill yarding and downhill yarding were studied by Brantigan (1978) and Bobbe (1981), respectively. Brantigan determined a critical skyline tension and a critical mainline tension as the conditions to check the carriage passage over a support jack. Bobbe determined a critical condition as the relationship between the upper span skyline deflection, the percent chord slope change and their influence on carriage passage.

III. LIVE SKYLINE ANALYSIS

The concept of the live skyline is to maximize load-carrying capability by varying skyline clearance. However, it is actually impossible to maintain a fixed skyline clearance from pickup point to landing because (1) it is difficult for the operator to visually gauge a skyline length adjustment and (2) skyline length adjustments take time since most yarders lack the ability to adjust the skyline length and continue inhaul simultaneously (Nickerson, 1980). In order to guarantee the minimum skyline clearance specified by a user for some reason such as avoiding obstacles or protecting the logging site, the yarder operator must lift the skyline at various points along the span. This is the major assumption in modeling a live skyline.

Payload capability of a cable system can be determined by calculating the maximum load-carrying capability in two different ways associated with log suspension conditions. (1) The maximum load-carrying capability for a fully suspended log can be determined using maximum tension and deflection of skyline. (2) For a partially suspended log, ground slope and log geometry as well as maximum tension and deflection of the skyline must be considered. The effect of log dragging geometry has been often over-simplified or not considered in some existing models.

Log drag

A typical log dragging geometry is viewed in figure 1. The angle between the chokerline and the horizontal (α) can be formulated as a function of ground slope (θ), log-to-ground angle (β), log length (L), distance of log centroid to leading end (ε) and log-to-ground friction coefficient (μ) as

$$\alpha = \tan^{-1} \frac{\left[1 - \dfrac{(\cos\theta - \sin\theta \tan\beta)(\cos\theta - \mu \sin\theta)}{(L/\varepsilon)(1 + \mu \tan\beta)} \right]}{\left[\dfrac{(\cos\theta - \sin\theta \tan\beta)(\sin\theta + \mu \cos\theta)}{(L/\varepsilon)(1 + \mu \tan\beta)} \right]}$$

(equation 1)

Once α is known, carriage clearance (hc) can be expressed as

$$hc = \frac{LC \sin(\alpha + \theta) + L \sin\beta}{\cos\theta}$$

(equation 2)

where LC: choker line length.

The sign of θ varies associated with yarding conditions (figure 2). If a loaded log drags along a uphill slope, θ is positive. If it drags along a downhill slope, θ is negative. Then, if the downhill slope is steep and/or the friction coefficient is low, the log may be easily turned around by a slight impact and moves ahead of the carriage. In

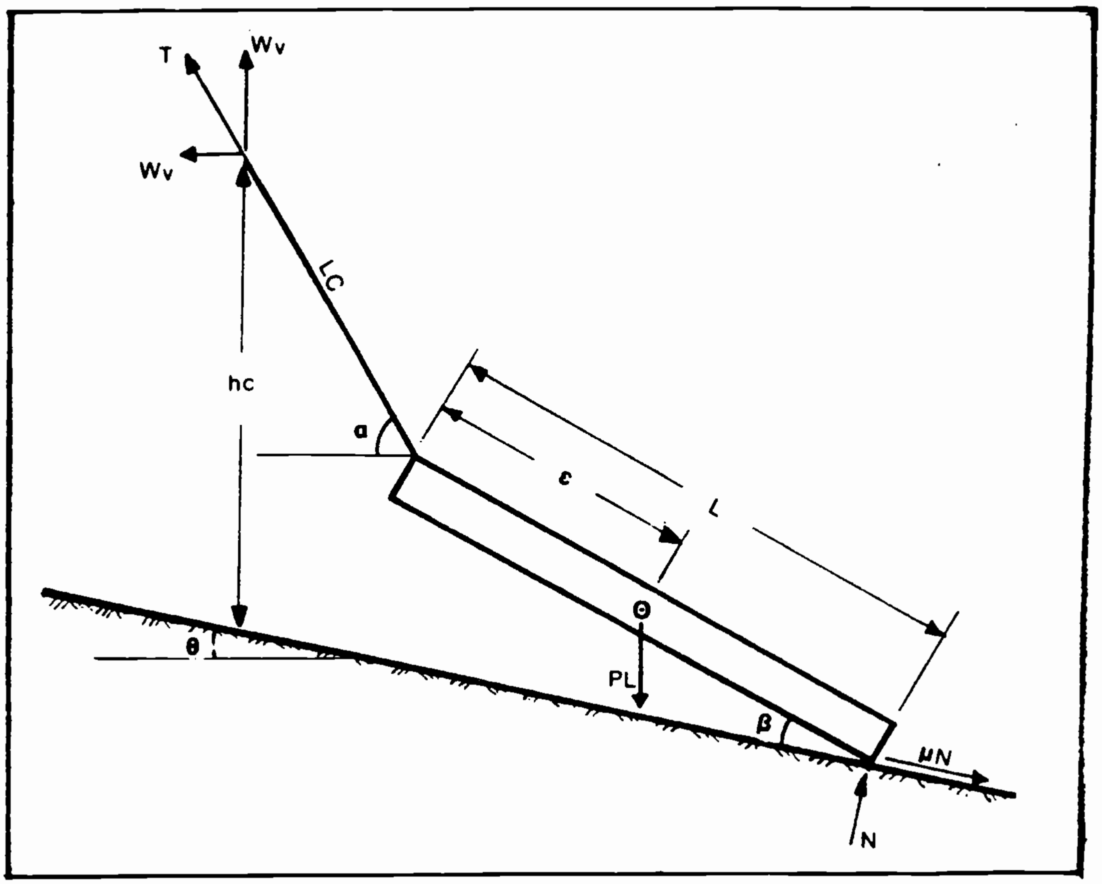

Figure 1. Log drag geometry.

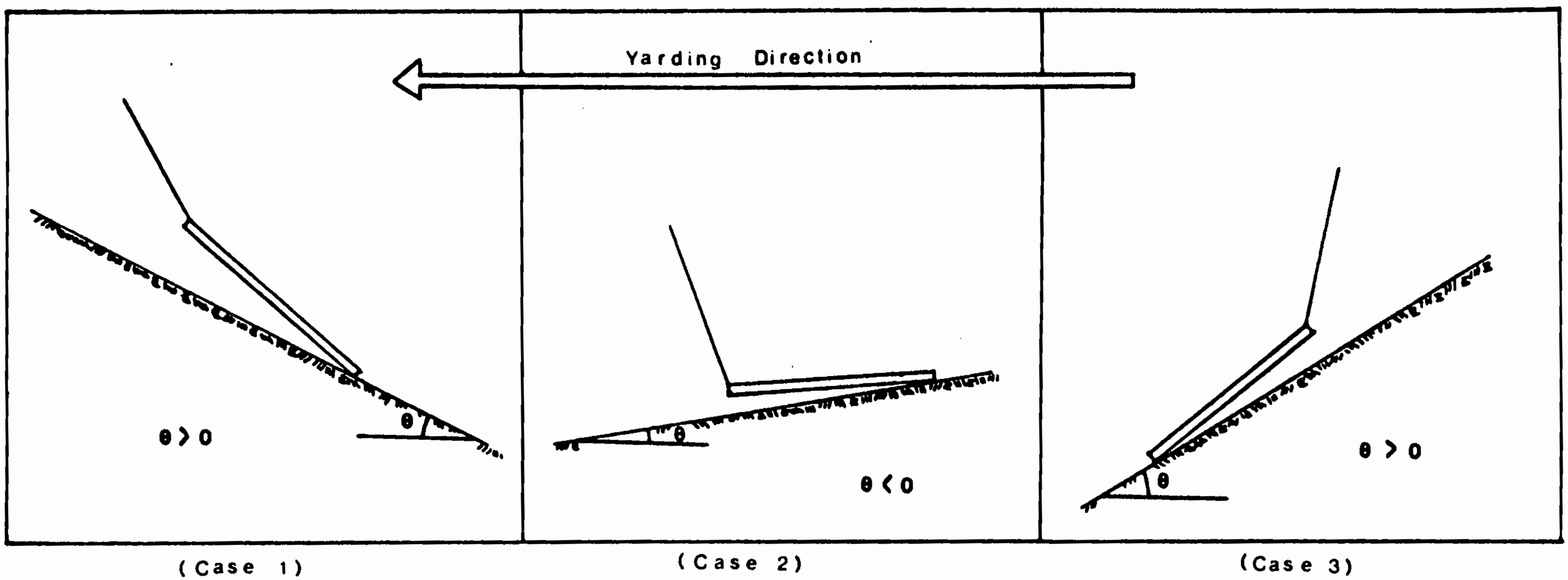

Figure 2. Sign change of θ associated with slope direction and yarding direction

this case, θ is positive, but α becomes negative. As a boundary condition for the log to be turned around, the program uses $\mu = \tan|\theta|$, which is suggested by Wilbanks (1985). If μ is greater than $\tan|\theta|$, the log will still be stable and θ is negative. Otherwise, θ is positive.

Log centroid distance ($\mathcal{E}$) can be expressed as a function of log length (L), leading end diameter (R1), trailing end diameter (R2) and choking point distance from the leading end of a log (C) as

$$\mathcal{E} = \frac{(L + C)(R1^2 + 3\ R2^2 + 2\ R1\ R2)}{4\ (R1^2 + R2^2 + R1\ R2)} - C$$

(equation 3).

Conventionally a log is assumed as a homogeneous, cylindrical column of negligible diameter to length ratio and, as a consequence, C=0, R1=R2 and $\mathcal{E}$=L/2 are used. However, the program has an option to consider log shape and choking point distance.

Cable geometry

The cable geometry can be determined by considering the load path of a carriage along a deflected skyline. When a log is picked up at a point, the skyline will be shortened until the minimum skyline clearance is reached. The deflected skyline length is assumed to be constant during inhaul as long as skyline clearance over the ground is maintained at or over the desired minimum skyline clearance, which must be entered by a user.

As a loaded carriage moves to the landing, it is checked at each terrain point to see if lifting is required. This is done by comparing the skyline length (S) having been used at the previous terrain point with the skyline length (Si) at the current point, which represents the required skyline length at terrain point i for the minimum skyline or log end clearance. If Si is greater than S, no lifting is required and S is still effective for the next inhaul section. Otherwise, the skyline length is shortened to Si at the point or S becomes Si. An example is illustrated in figure 18 of chapter X.

The load path of a loaded carriage which is moving along a fixed-length skyline is assumed to follow a so-called `elliptical load path', which is the trace of an ellipse with the foci at the upper and lower ends of the skyline. The elevation difference between the top of the head spar and the deflected skyline at the carriage or the vertical length of the left cable segment (h1) can be expressed as

$$h1 = \frac{c\, y + [c^2 S^2 - 4\, d1^2 S^2 (S^2 - y^2)]^{0.5}}{2\,(S^2 - y^2)}$$

(equation 4, after Holtorf)

where $c = S^2 + d1^2 - (dd-d1)^2 - y^2$

S : skyline length

y : elevation difference between top of supports

d1: horizontal length of left cable segment

dd: horizontal span length.

When a cable and log geometry is known, force components of all the line segments can be estimated by single- or multi-segment analysis. Force components of single line segments can be expressed as a function of the upper end tension (TUi), unit weight of line (wi), vertical line lingth (hi) and horizontal line length (di) based on rigid link assumption as follows.

$$Hi = \frac{TUi\ di}{li} \left[1 - \left(\frac{wi\ di}{2\ TUi} \right)^2 \right]^{0.5} - \frac{wi\ di\ hi}{2\ li}$$

(equation 5, Miller, 1984)

$$Vi = Hi\ (hi/di) - Ri/2$$

(equation 6, Miller, 1984)

where Hi, Vi : horizontal and vertical tension components at the lower ends of single segment i, respectively

Ri : weight of a cable segment i

li : length of a cable segment i.

The lower end tension of a single segment (TLi) can be expressed as $TLi=(HLi^2 + VLi^2)^{0.5}$ or as a function of Tui, wi and hi as TLi=TUi-(wi hi) based on catenary formulations.

Equation 5 can be used only when TUi is known. TU1 is given by a user as a skyline safe working load or calculated through the line tension adjustment procedure which will be discussed later. TU2 can be determined directly by using the static boundary condition of a continuous line that is TU2=TL1 when y>h1 or TU2=TL1+(w1 h2) when y<h1. Then, TU3 can not be determined directly and equation 5 is not applicable to the line tension analysis of segment 3. To determine H3 and V3, a static equilibrium at the carriage must be considered in two differnet manners associated with

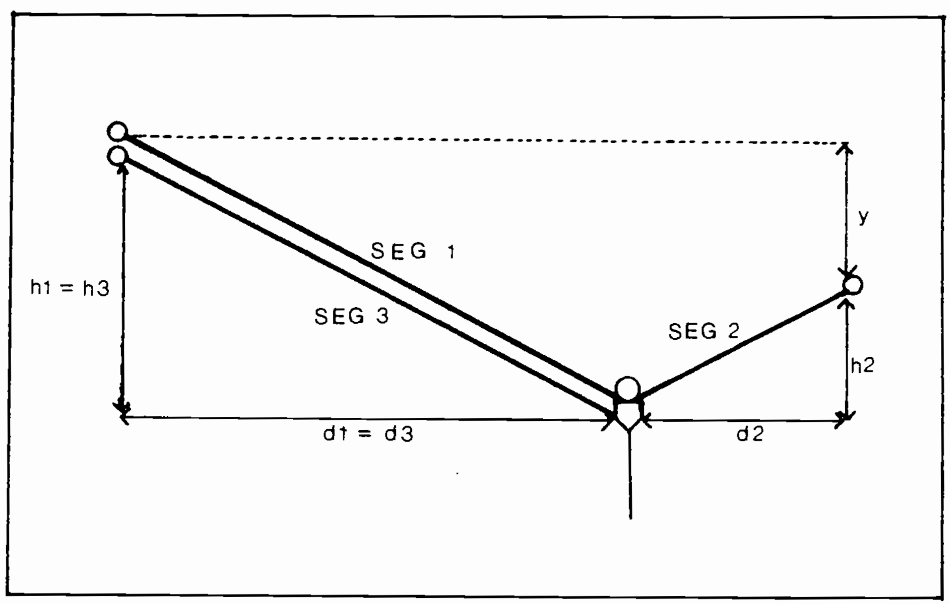

Figure 3. Configuration of the three-segment cable system.

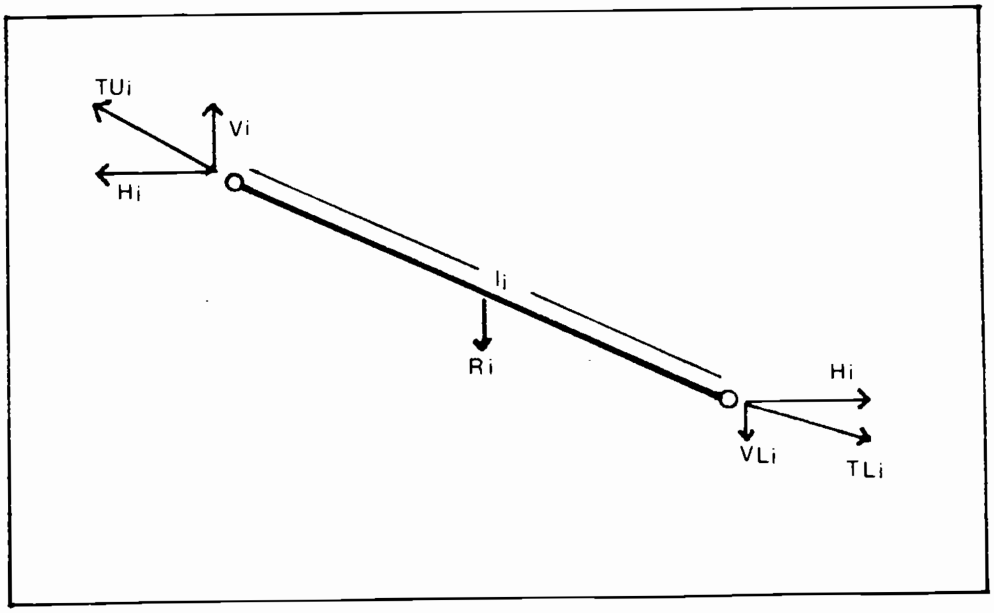

Figure 4. Rigid body diagram of the force equilibrium of cable segment i

log suspension conditions.

First, if log is fully suspended, H3 and V3 can be determined directly from $\Sigma Fh=0$ and $\Sigma Fv=0$, which represents, respectively, the horizontal force equilibrium and vertical force equilibrium at the carriage. The payload capability can be expressed as $\Sigma Vi - cwt$, where cwt represent the carriage weight.

Second, if log is partially suspended, H3 and V3 can be determined as

$$H3 = \frac{\tan\alpha\,(H1 - H2) - (V1 + V2 - cwt) + R3/2}{h3/d3 - \tan\alpha} \qquad \text{(equation 7)}$$

where α is negative in case a log is turned around (case 3 in figure 2). The derivation procedure of the equation is presented in appendix.

Once H3 is found, V3 can be determined by equation 6 and the payload capability can be calculated as follows.

$$PL = \frac{V1 + V2 + V3 - cwt}{\left[\dfrac{(\cos\theta - \sin\theta\tan\beta)(\cos\theta - \mu\sin\theta)}{(L/\varepsilon)(1 + \mu\tan\beta)}\right]}$$

(equation 8, after Miller, 1984)

where cwt: carriage weight.

When TU3 is determined in cable segment analysis, the program checks if TU3 exceeds the mainline safe working load. If the safe working load is exceeded, the program adjusts TU1, which is initially assigned to the skyline safe working load, and repeats the whole procedure for cable tension analysis until TU3 reaches the condition that TU3 equals the mainline safe working load. In order to find the TU1 which satisfies the condition, the program uses a modified secant search, which is formulated as

$$TU1new = TU1 - \frac{TU3 - TA3}{(TU3 - TU3old)/(TU1 - TU1old)}$$

(equation 9)

where TU1new: new upper end tension of segment 1

TU1 : old upper end tension of segment 1

TU1old: old upper end tension of segment 1 of the former iteration

TU3 : old upper end tension of segment 3

TA3 : safe working load of segment 3

TU3old: old upper end tension of segment 3 of the former iteration.

Programming Procedures

a) Determine the log and cable geometry, and the skyline length required to maintain the desired skyline clearance at each terrain point.

b) Determine the payload capability with the log and cable geometry at the pickup point. In this step, if the mainline tension exceeds the mainline safe working load before calculating the payload capability, adjust the skyline tension and repeat step b until mainline tension equals its safe working load (equation 9).

c) Check if skyline lifting is required at the next inhaul section. If the skylin length at the current point is shorter than that at the previous point, the skyline must be lifted and a new skyline length assigned. Otherwise, no lift is required and the skyline length used at the previous terrain point is maintained.

d) Determine the new system geometry. Cable line geometry can be determined through the elliptical load path analysis (equation 4). A log geometry can be determined by equation 1, 2 and 3 in case of partial suspension.

e) Determine the payload capability with the new system geometry and repeat the whole procedure from step c until the log arrives at landing. Mainline tension is also checked in this step as it was in step b.

f) Determine the load-carrying capability for the pickup point by selecting the smallest payload among the payloads calculated in step b and e.

g) If a terrain point for log pickup is left, repeat the whole procedure from step b with the new skyline length for the new pickup point. Otherwise, stop the analysis.

IV. STANDING SKYLINE ANALYSIS

The standing skyline configuration is very similar to that of the live skyline. The difference is that both ends of the skyline are fixed. The fixed skyline length can be determined by finding the shortest possible skyline length, with which loaded skyline clearance can be maintained or exceeded at any terrain point.

The procedures of the standing skyline payload analysis are less complicated than those of the previously discussed live skyline analysis, which are a series of the standing skyline analyses. The system geometry, elliptical load path, multi-segment line tension analysis and line tension adjustment discussed in the live skyline analysis can be used in the standing skyline payload analysis.

The unloaded skyline tension analysis is provided in addition to the standing skyline payload analysis. The information is useful in preparing field operations or checking skyline tension during operations.

Estimating the Unloaded Skyline Tension

The unloaded skyline tension can be determined using the elastic property of a cable segment. Using Hooke's law, the unstretched skyline length (So) can be estimated approximately as

So = S/[1+Tave/(AE)]

(equation 10)

where Tave: average tension loaded on skyline, lb

S: length of stretched cable segment, ft

A: metallic area of the cable, in

E: modulus of elasticity of the cable, psi

The modulus of elasticity for logging cables varies between 10 to 14 million psi depending on cable construction and the type of material. The metallic area is approximately .465 times the diameter squared. Sometimes the product of A

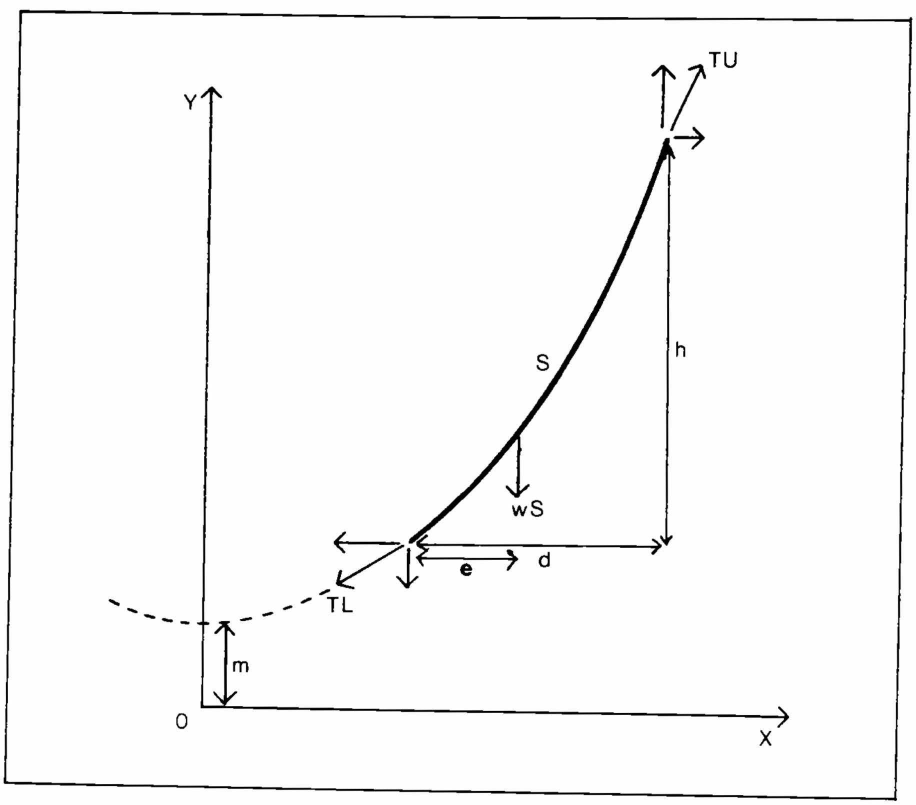

Figure 5. Rigid body diagram of a catenary segment.

and E is expressed as 3,500,000 times the unit weight of a cable (after Carson, unpublished).

The fixed skyline length (Smin) of the standing skyline is the elongated skyline length under the maximum allowable skyline tension. Thus, So can be found by substituting Smin for S in equation 10. Smin was found based on rigid link assumption, which provides quite accurate solution for a taut cable segment. The unloaded skyline is not as taut as the loaded skyline and the catenary link assumption may be appropriate. With the catenary link assumption, S can be expressed as

$$S = \{h^2 + [2m \sinh(d/2m)]^2\}^{0.5}$$

(equation 11, Carson, 1970)

$$\text{where } m = \frac{-wShe/d^2 + \{(wShe/d^2)^2 - [1+(h/d)^2][(wSe/d)^2 - TU^2]\}}{w\,[1+(h/d)^2]}$$

$$e = d/2-(h/S)[m-d \coth(d/2m)/2]$$

By solving equations 10 and 11 numerically, the unloaded skyline length and tension can be determined. The program uses the secant method in which TU, S and e are initially guessed. The initial guess for TU is determined through binary search and the initial guesses for S and e are determined using such physical geometry as $S=(h^2+d^2)^{0.5}$ from Pythagorean theorem and e=d/2 from the weightless link formulation, respectively.

Programming Procedures for Payload Analysis

a) Determine the log geometry and/or chokerline angle to find the skyline length required for the minimum skyline clearance at each point. The choker line angle can be determined by solving equation 1. Once skyline lengths for all the terrain points are known, find the shortest one, which is the fixed stretched skyline length of the system.

b) Determine the cable geometry through the elliptical load path analysis (equation 4).

c) Determine log geometry numerically by solving eqution 1, 2 and 3 in case of partial suspension.

d) Determine payload capability with the log and cable geometry at the pickup point. In this step, if the mainline tension exceeds the mainline safe working load before calculating the payload capability, adjust the the skyline tension and repeat step b until mainline tension equals its safe working load (equation 9).

e) If any terrain point is left for the payload analysis, repeat from step c.

f) Determine the unloaded skyline length using equation 10 and 11. Then stop the analysis.

Load Path Analysis

The load path analysis is another option of the standing skyline program. A user must select one of two options to start a standing skyline analysis. Load path analysis provides the information on the line tension, skyline deflection and log geometry when a given payload is moving from the farthest terrain point to landing. A sequence of iterative procedures using a modified secant method, which are similar to the skyline tension adjustment procedure, is used. This involves finding the corresponding skyline tension and deflection at each terrain point based on the payload specified by a user.

Load path analysis must proceed as follows.

a) Specify a trial payload which will pass through each terrain point.

b) Determine the unstretched skyline length using the shortest skyline length and the allowable skyline tension (equation 10).

c) Guess a skyline tension and determine the stretched skyline length by solving equation 10, in which skyline tension and unstretch skyline length are involved.

d) Determine the log and cable geometry. Calculate the payload capability of the system through the multi-segment analysis procedure.

e) Check if the calculated payload capability is equal to the trial payload. If they are different, adjust the skyline tension by the secant method and recalculate the stretched skyline length. Then repeat the whole procedure from step d until both payloads are the same.

f) If any terrain point is left for the analysis, repeat whole procedure from step c. Otherwise, stop the analysis.

V. RUNNING SKYLINE ANALYSIS

The running skyline is a system with two or more suspended moving lines, referred to as the haulback and the mainline. The haulback is separated into three segments for the multi-segment analysis purpose. The system is applicable to downhill yarding as well as uphill yarding.

The program assumes that the higher elevation spar-tree is always located at the left most terrain point (T.P. 0). The nomenclature of cable segments is illustrated in figure 6. If the headspar is located at T.P. 0, the operation is called `uphill yarding' and a haulback consists of single segment 1, 2 and 4. Segment 3 is the mainline. Otherwise, it is called `downhill yarding' and segment 4 is a mainline, while segment 1, 2 and 3 are the haulback.

During the inhaul operation, the log end clearance or carriage clearance over the ground is assumed constant from a pickup point to the landing. Once carriage clearance or haulback clearance is known, log geometry can be determined the same way as was discussed in the live skyline analysis.

For the running skyline, the load-carrying capability of the yarder can be considered as an option. If data on the maximum torque generated at the haulback drum, drum size and cable line length before rigging are available, a user may enter them. If the data are entered, the program determines

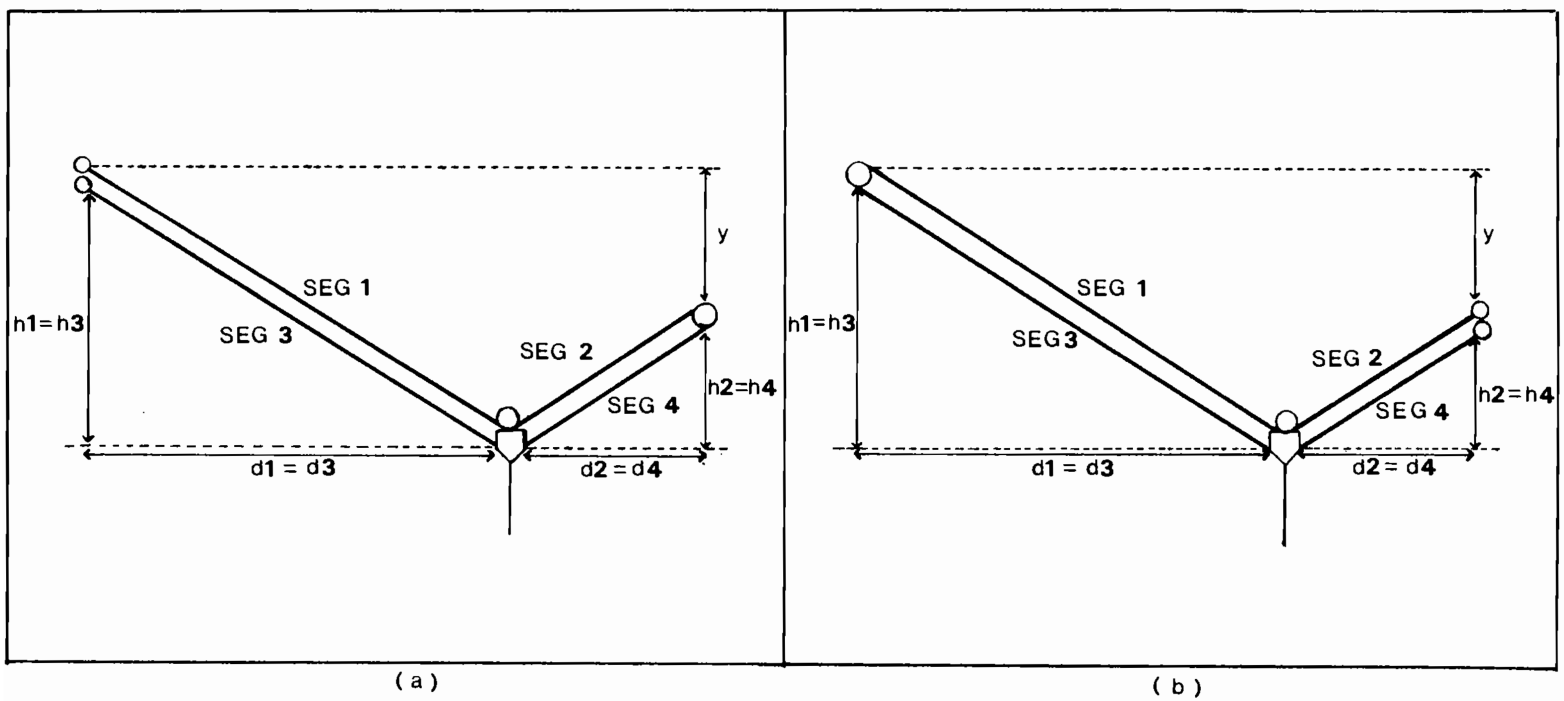

Figure 6. Configuration of the running skyline system

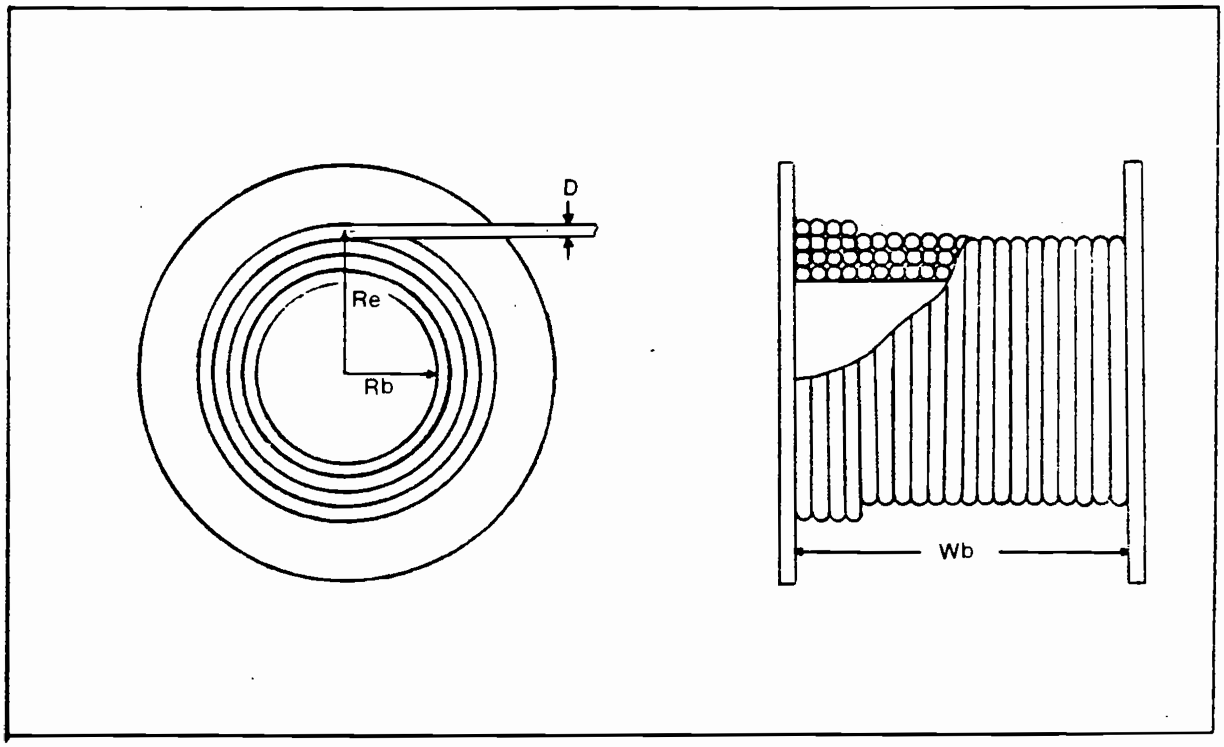

Figure 7. Configuration of the haulback drum.

if the payload capability of the system is limited by the yarder capability, the haulback safe working load or the mainline safe working load.

Payload Capability of Yarder

At the beginning of the system analysis, the program checks if all the parameters, which are necessary to calculate the upper end tension of cable segment 1, are entered. If so, the initial haulback tension must be determined by comparing the tension capability of the yarder with the haulback safe working load. The smaller of the two be the initial maximum haulback tension.

Wilbanks (1985) derived the following formula to estimate the yarder tension capability (Th) as

$$Th = Mh/Re \qquad \text{(equation 12)}$$

where $Re = Rb + (n - .5)D$

$$n = \frac{-Rb + [Rb^2 + (D^2 Lh)/(k\ Wb)]^{0.5}}{D}$$

n : number of wrap on haulback drum, integer number

Re: effective haulback drum radius, in

Mh: maximum haulback drum torque, lb-in

Rb: radius of empty barrel, in

Wb: barrel width, in

D : rope diameter, in

Lh: haulback line length left on drum, ft

k : .2618

Cable Segment Analysis

Once the log and cable geometry, and the initial upper end tension of cable segment 1 are known, each segment of the haulback can be analyzed with the single-segment formulation and the boundary conditions of the multi-segment analysis. With the vertical and horizontal force components of the haulback segments at the carriage and the mainline geometry, the force components of the mainline segment at the carriage can be found using static equilibrium conditions.

If the log is partially suspended, the mainline tension can be analyzed in two ways according to the yarding direction. In case of uphill yarding, the mainline horizontal tension component can be expressed as

$$H3 = \frac{\tan\alpha(H1-H2-H4) - (V1+V2+V4-cwt) + R3/2}{h3/d3 - \tan\alpha}$$

(equation 13).

In case of downhill yarding,

$$H4 = \frac{\tan\alpha(H2-H1-H3) - (V1+V2+V3-cwt) + R4/2}{h4/d4 - \tan\alpha}$$

(equation 14).

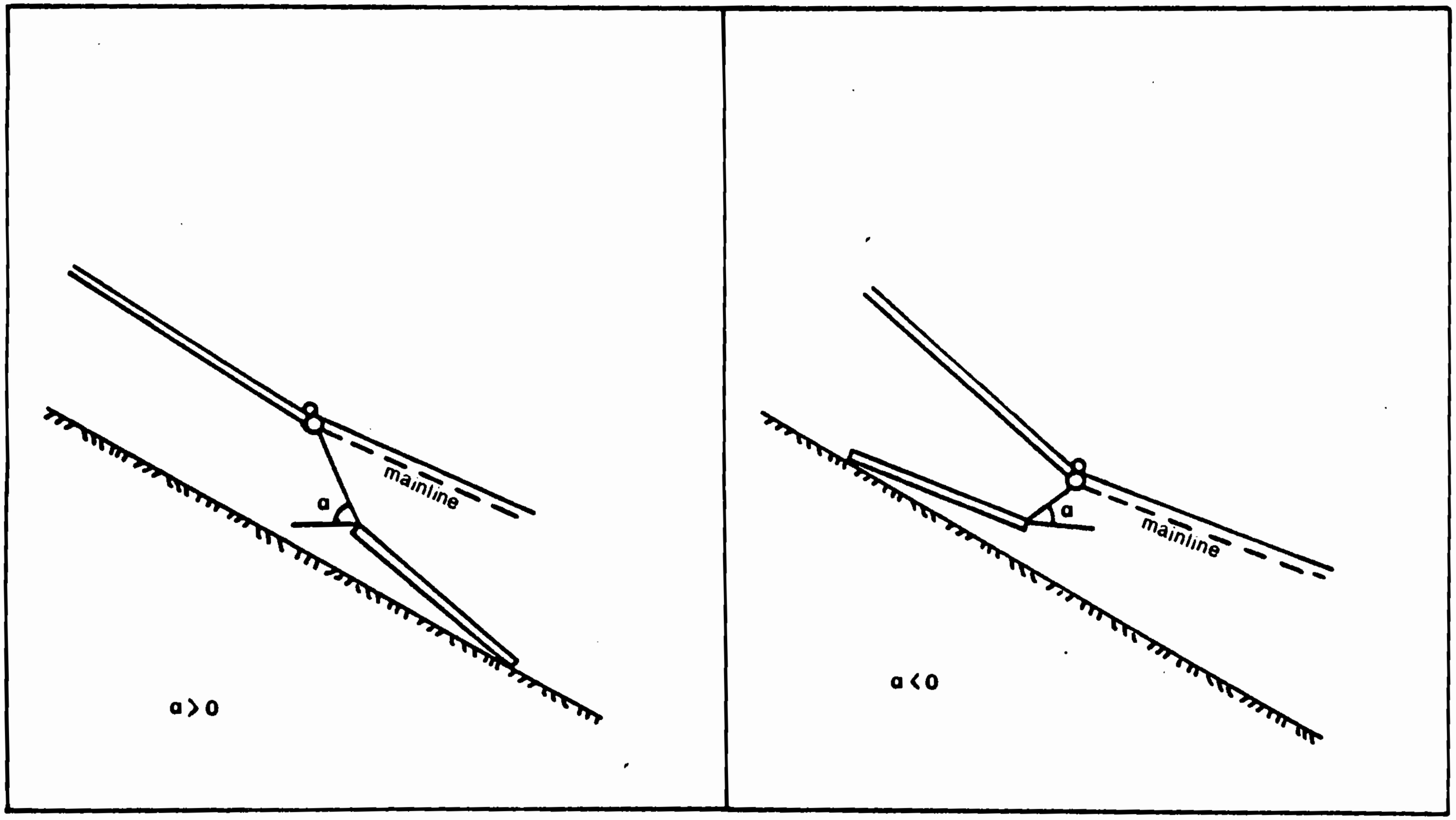

Figure 8. Sign change of according to log drag situations of downhill yarding

Figure 8 shows log drag situations for downhill yarding and the sign change of α. The vertical force component and payload can be determined by equation 6 and 8, respectively.

Programming Procedures

a) Determine the log and cable geometry.

b) Determine the limiting upper end haulback tension. If Mh, br, w,d and line length have been entered, determine Th by equation 12. Then select the smaller one as the upper end haulback tension between the haulback safe working load and Th. Otherwise, the safe working load is the upper end haulback tension.

c) Determine the load-carrying capability through line tension analysis. If the calculated mainline tension is greater than the mainline safe working load, repeat the line tension analysis of step c with an upper end tension adjusted by a modified secant method until the calculated mainline tension equals the mainline safe working load.

d) If more terrain points are left for the payload analysis, repeat the procedures from step a. Otherwise, stop the analysis.

VI. SLACKLINE ANALYSIS

The slackline is an effective system, which is, especially, adaptable to downhill yarding as well as uphill yarding. The carriage clearance or log end clearance over the ground is assumed to be constant from a pickup point to landing. The slackline is assumed to run parallel to the skyline. With the definition that the support at higher elevation is located at the left-most terrain point, assigned to segment 3 and 4 the line names slackline and mainline depending on the yarding direction.

The log and cable geometry, and the line tension components of segment 1 and 2 are determined the same way as

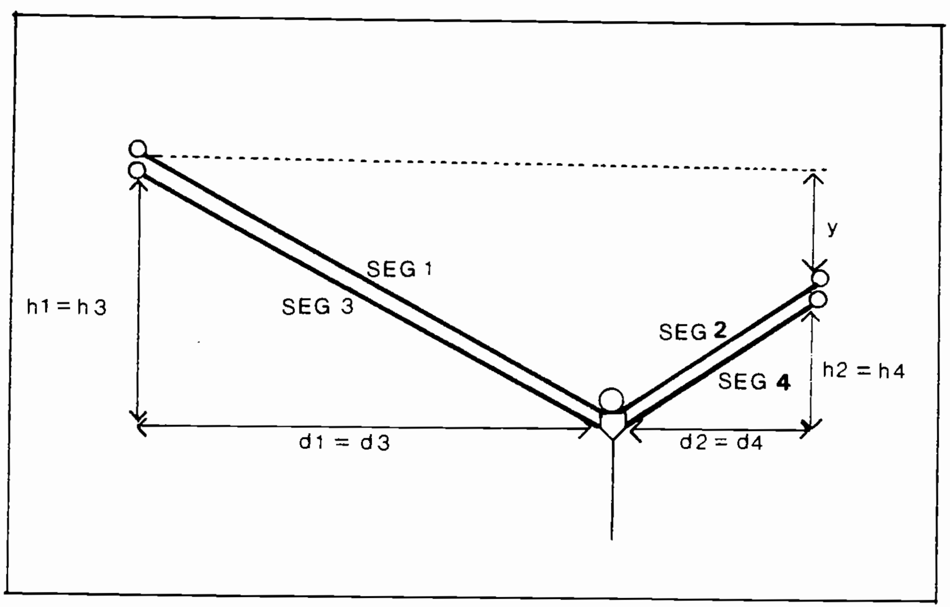

Figure 9. Cable geometry of the slackline.

was discussed previously. The programming procedure for the slackline analysis is more complex than that of the running skyline analysis because neither the line tension of segment 3 nor 4 can be found through multi-segment analysis boundary conditions.

To simplify the problem, the upper end tension of segment 4 is assumed to be as large as its safe working load as long as the tension of segment 3 does not exceed its safe working load. If the tension exceeds its safe working load, the tension of segment 1 or segment 4 must be adjusted to make the tension of segment 3 equal to its safe working load.

Programming Procedures

a) Determine log and cable geometry.

b) Determine the line tension components of segment 1 and 2 at the carriage.

c) Assuming that the upper end tension of segment 4 is at its safe working load and segment 3 and 4 are parallel to each other, determine the line tension components of segment 4 at the carriage.

d) By using equation 6 and 13, determine the line tension components of segment 3 at the carriage. If the upper end tension of segment 3 does not exceed its safe working load, skip step e. Otherwise, set the tension of segment 4 to zero and resolve the line tension components of segment 3.

e) If the resolved upper end tension of segment 3 exceeds its safe working load, set the tension of segment 4 to zero and adjust the upper end tension of segment 1 and, then, resolve the line tension components of segment 3 until the upper end tension of segment 3 equals its safe working load. Otherwise, set the upper end tension of segment 1 to its safe working load and adjust the line tension of segment 4 until the upper end tension of segment 3 equals its safe working load.

f) Determine the payload capability of the system at the current point. If any terrain point is left, move to the next terrain point. Otherwise, stop the analysis.

VII. MULTISPAN ANALYSIS

The multispan is a standing skyline system with two or more spans supported by some form of intermediate spar(s), a headspar, and a tailspar. The skyline length is fixed and, if the skyline length is assumed constant, the loaded carriage moves along an elliptical load path. Once the skyline length of a loaded span is determined, both payload analysis and load path analysis follow the corresponding procedures of the standing skyline analysis.

The upper end skyline tension for each span is estimated, as an option, by considering the effect of friction force between a support jack and a skyline. The user can enter an appropriate friction coefficient. Otherwise, the friction force is assumed to be zero.

When a gross payload for a terrain point is determined, the program tests if the loaded carriage can pass over the support jack(s) successfully on the way to the landing. If the carriage passage is not feasible, the payload capability would have to be limited to the maximum payload being able to pass over the jack.

Cable Geometry

The cable geometry of the multispan can be found by determining the load path of the carriage through the elliptical load path analysis which is previously discussed in chapter III. To solve equation 4 for the elliptical load path, the skyline length for the loaded span must be defined by using the catenary or rigid link formulations as follows.

a) Determine the upper end tension and the unloaded skyline length for each span based on catenary formulation (equation 11) and find the shortest skyline length of each span for the minimum skyline clearance. Then find the shortest stretched skyline length of the multispan among the combinations of the loaded and unloaded skyline lengths.

b) Determine the skyline length of the loaded span j. It can be expressed as the fixed skyline length minus the sum of the unloaded span skyline lengths as

$$Slj = Smin - (\Sigma Sui - Suj)$$

(equation 15)

where Slj : skyline length of the loaded span j

Smin: fixed stretched skyline length of multispan

Sui : unloaded skyline length of span i.

The program has the option to consider the friction between a support jack and a skyline in finding the upper end skyline tension of each span. The jack friction may have a significant effect on the load-carrying capability of the multispan associated with the friction coefficient (μj) and

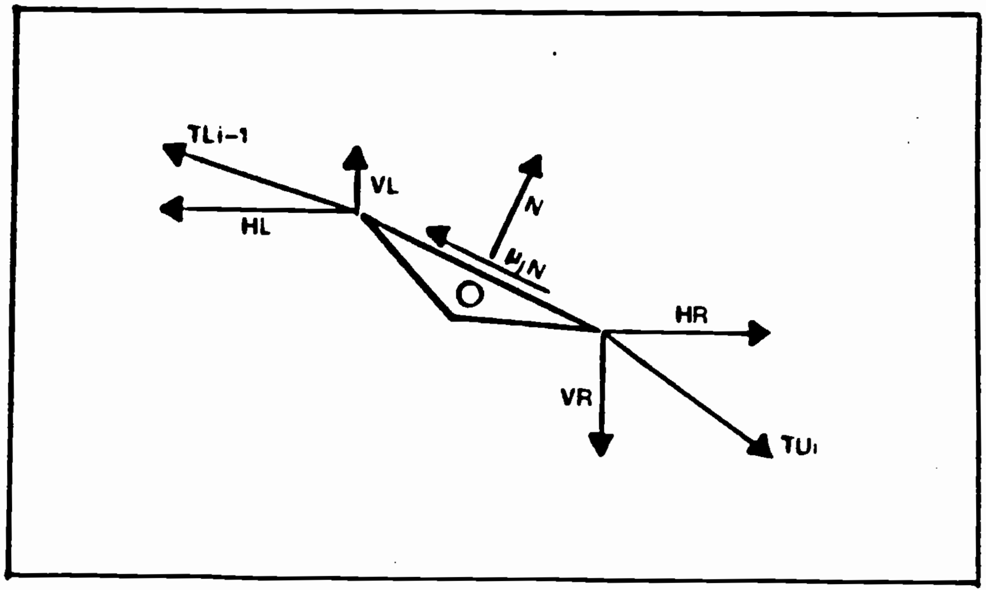

Figure 10. Free body diagram of a intermediate support jack

the chord slope change. As the friction coefficient and/or the chord slope break increase, the friction effect will increase.

Friction can be expressed as the difference between the lower end skyline tension of the upper span and the upper end skyline tension of the lower span (figure 10). Assuming the vertical and horizontal tension components at both ends of a jack are known, the upper end skyline tension of the lower span (TUi) can be expressed considering the friction effect as

$$TUi = TLi-1 + \mu j \, [(HL-HR)^2 + (VL-VR)^2]^{0.5}$$

(equation 16)

where TLi-1 : lower end skyline tension of upper span

HL, VL: horizontal and vertical force component of upper span, respectively

HR, VR: horizontal and vertical force component of lower span, respectively.

Through the single segment analysis procedure, HL and VL can be determined once TLi-1 and the cable geometry are known. HR and VR can not be determined directly. Thus, TUi is assumed to be equal to TLi-1 then HR and VR can be estimated approximately.

Carriage Passage over Jack

The feasibility of the carriage passage over a support jack can be tested statically by analyzing the skyline deflection condition when the loaded carriage approaches close to the support jack. The deflected cable configuration near the jack is illustrated in figures 11, 12 and 13. If the angle ∂ of each configuration is less than 90 degrees, the loaded carriage will pass the jack successfully. If the initial skyline is long enough and the gravity and/or mainline tension is large enough to establish the geometry, which is equal to or more than 90 degrees, the carriage would fail to pass the support jack.

The boundary condition for the carriage passage is

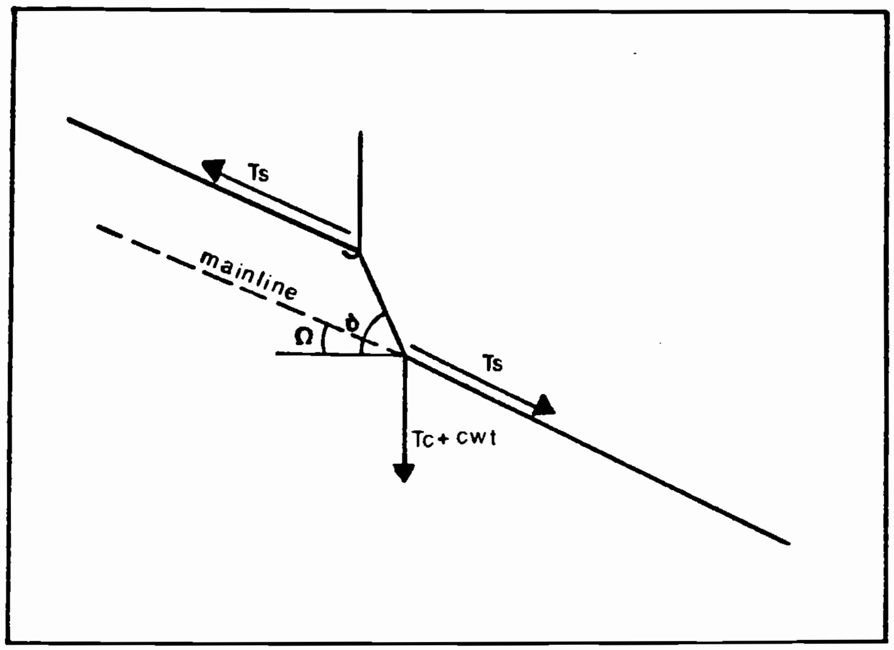

Figure 11. Cable geometry when a loaded carriage approaches to a support jack (uphill yarding and full suspension case).

*Tc: Tension on the loaded choker line

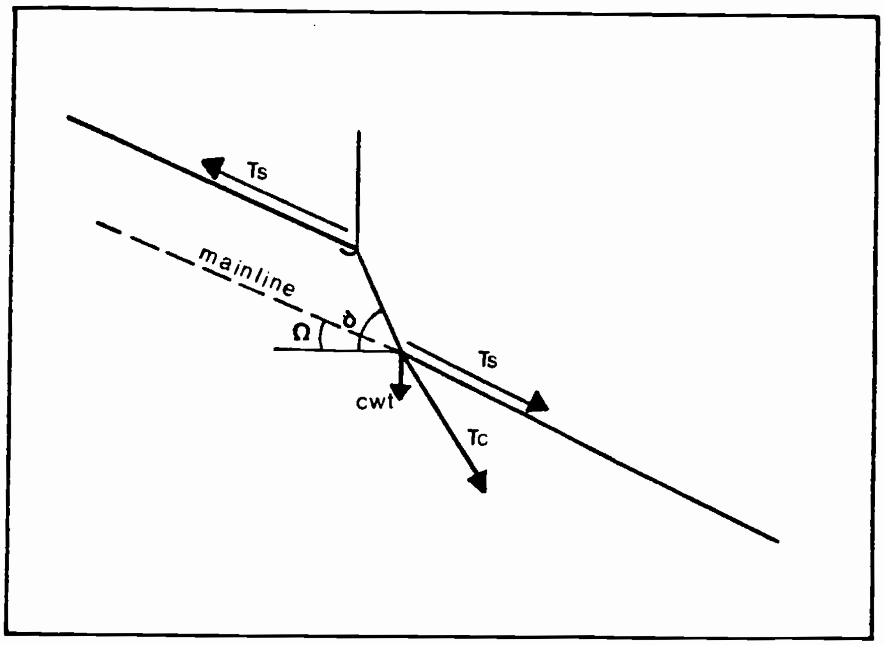

Figure 12. Cable geometry when a loaded carriage approaches to a support jack (uphill yarding and partial suspension case).

* Tc: tension on the loaded choker line.

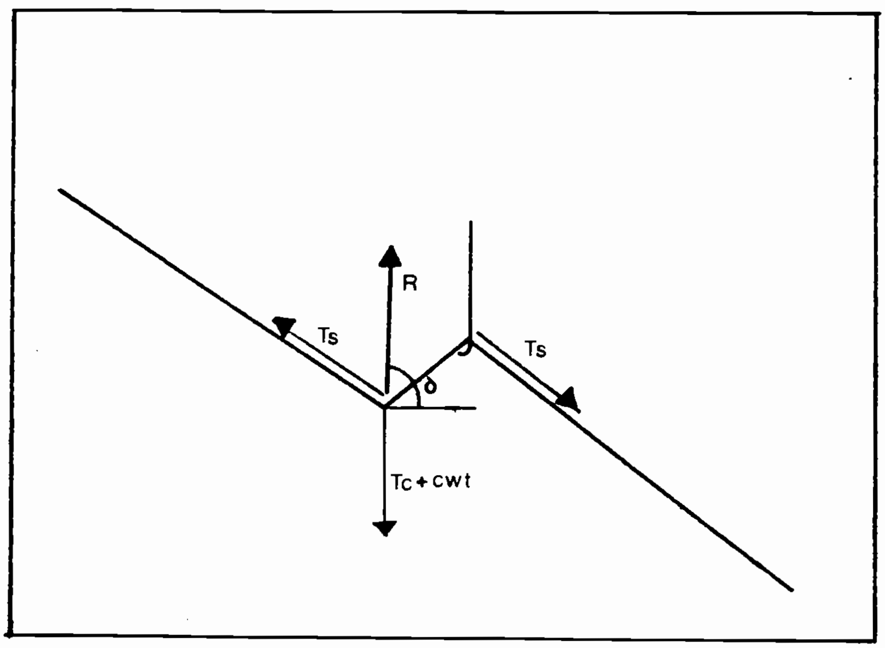

Figure 13. Cable geometry when a loaded carriage approaches to a support jack (downhill yarding).

*R: Resultant force of skyline tensions on both sides of the carriage.

checked at a point which is one foot ahead of the support jack. If a critical skyline tension for the boundary condition is known, the feasibility of the carriage passage can be tested by comparing the critical skyline tension with the skyline tension which is required to support a gross payload passing through the point to be checked (Brantigan, 1978). His method could not be applied due to difficulty in converging on a correct skyline tension and length when the carriage was very close to a support.

The skyline tension when the carriage is very close to the jack can be found numerically with the elliptical load path assumption discussed in chapter III. But, as the loaded carriage approaches to the jack, the error using the elliptical load path assumption increases. As a consequence, the iterative procedures rarely converge to a reasonable tolerance, i.e. 10^{-3} or 10^{-4}.

The program used an alternative method, in which the elliptical load path is not involved. The procedure has two phases as follows.

First, determine the unloaded skyline tension and compare that with the critical skyline tension. The unloaded skyline tension can be determined by solving equation 10 and 11. The procedure is similar to that in the standing skyline unloaded skyline tension analysis but more complicated because more than one span is involved. If the unloaded skyline tension is larger than the critical skyline tension, the loaded carriage will pass over the jack successfully because a loaded skyline tension is larger than the unloaded skyline tension.

Second, if the unloaded skyline tension is smaller than the critical skyline tension, the load-carrying capability with the critical skyline tension must be determined because it is not then obvious that the loaded skyline will be higher than the critical skyline tension. If the payload capability for the critical skyline tension is larger than the passing payload, the loaded carriage will pass over the jack. Otherwise, the payload passing the support jack must be reduced to the critical payload. The cable geometry can be found by solving equation 11 numerically for h with known variables Tu, So, and d.

There are three different approaches to find the critical skyline tension (Ts) associated with yarding direction or log suspension condition as follows.

For the full suspension of the uphill yarding, Brantigan (1978) derived an equation to estimate Ts approximately based on rigid link formulation as follows.

$$Ts = \frac{PL + cwt + .5\, w1\, dL \cos\lambda (1 + \tan\lambda \tan\Omega)}{[\, 1 - \cos\lambda (\tan\lambda - \tan\Omega) \,]}$$

(equation 17)

where $\tan\lambda = hL/dL$ and $\cos\lambda = hL/(hL^2 + dL^2)^{0.5}$

dL : horizontal length of loaded span

hL : vertical length of loaded span

w1 : unit weight of skyline

cwt: carriage weight

The equation is derived using static equilibrium between skyline tension, mainline tension and choker line tension when ∂ equals 90 degrees. According to him, the parameter $(\tan\lambda - \tan\Omega)$ is approximately equal to the chord slope break and the greater the chord slope break, the greater the skyline tension required for a given payload.

For the partial suspension of the uphill yarding, Ts can be estimated based on weightless link formulations as follows. The derivation procedures are illustrated in appendix.

$$Ts = \frac{Wv + cwt - Wh \tan\Omega}{1 - \cos\lambda(\tan\lambda - \tan\Omega)}$$

(equation 18)

where Wv: vertical force component of choker line tension

Wh: horizontal force component of choker line tension

In the equation, λ and Ω can be determined from the cable geometry when the carriage approaches the intermediate support jack. Then, Wv and Wh must be determined prior to finding the cable geometry. This step to find Wv, Wh and cable geometry is not implemented in this paper. However, an algorithm to estimate Wh and Wv approximately is suggested in chapter VII.

Instead of the equation above, for calculating purposes, equation 17 was used in the program to determine Ts for the partial suspension case. If the log is partially suspended, Ts from equation 17 is used to calculate the equivalent dragging log to produce this log weight.

For the carriage passage of a downhill yarding case, the problem is simplified by assumming the haulback tension and mainline tension to be zero. The boundary condition is reached when the resultant force of skyline tension at the carriage forms a 90 degree angle to the horizontal. The critical tension is derived in appendix based on weightless link assumptions as

$$Ts = \frac{PL + CWT}{2 \sin [\tan^{-1} \frac{hh}{dL}]}$$

(equation 19)

where hh: elevation difference between the tops of supports in loaded span

Programming Procedures for Payload Analysis

a) Determine the log geometry and/or choker line angle to determine the shortest skyline length of each span required for the minimum skyline clearance.

b) Determine the unloaded skyline length of each span and find the shortest skyline length (fixed multispan skyline length) among the combinations of the unloaded skyline length(s) and the shortest skyline length of each span found in step a.

c) Determine the cable geometry through the elliptical load path analysis and, then, calculate payload capability through multi-segment analysis. If any terrain point is left for the payload analysis, repeat step c.

d) Determine the unloaded skyline tension with So by solving equation 10 and 11 numerically. The initial guess for the unloaded skyline tension was obtained through binary search and, then, applied to the secant method.

e) Determine the critical skyline tension by solving equation 17 or 19 according to yarding direction. If the unloaded skyline tension is greater than the critical skyline tension, skip to step h.

f) Using the critical skyline tension as the upper end skyline tension, determine the cable geometry, when the gross payload is located at the checking point, by solving equation 10, of which So is known.

g) Determine the payload capability with the cable geometry and the critical skyline tension.

h) If the unloaded skyline tension is greater than the critical skyline tension or the passing load is smaller than the critical payload, the carriage will pass over the jack successfully. If any terrain point is left for the analysis, go back to step e. Otherwise, stop the analysis.

Programming Procedures for the Load Path Analysis

The procedures are the same as those of the standing skyline load path analysis. But, the loaded skyline length of the loaded span must be found by solving equation 15 before step c in the standing skyline load path analysis procedure.

VIII. HIGHLEAD SYSTEM ANALYSIS

The highlead system is a cable yarding system consisting of a butt-rigging and two separated cable segments, which are referred to as the haulback and the mainline. The lifting force for the system is provided by braking the haulback drum. Usually the haulback tension is provided to avoid cable line dragging rather than to lift a log because the lifting force is not sufficient to suspend a log.

At the beginning of the analysis, a user can enter the desired haulback tension for each terrain point as an option. Also the mainline friction on the ground can be considered as

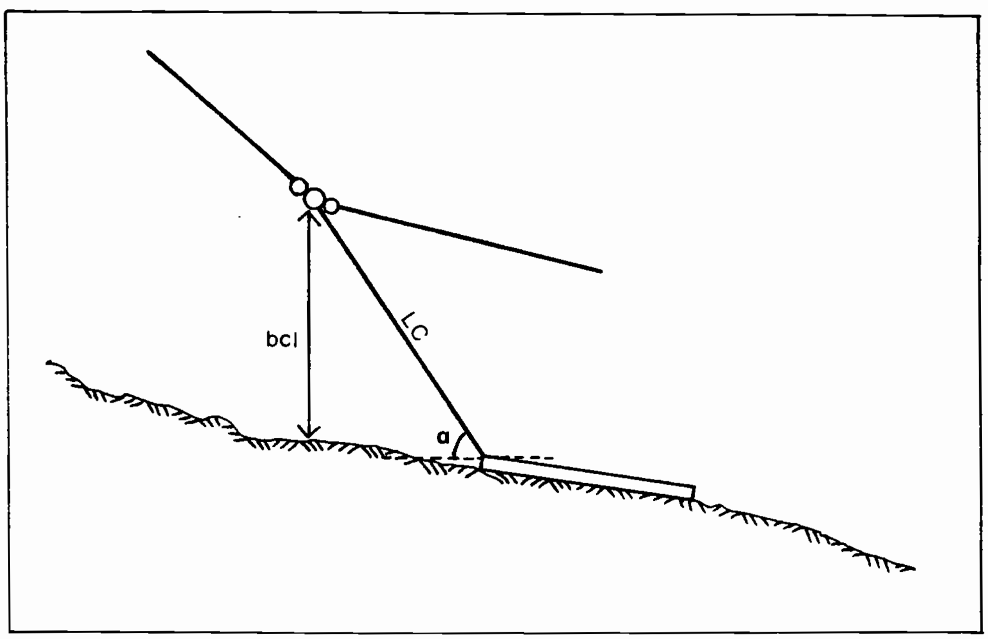

Figure 14. Log drag geometry of highlead

an option if a friction coefficient is entered by a user. The program considers only uphill yarding.

System Analysis

Because the mainline and haulback tensions are known, the static equilibrium at the butt-rigging can be found when the butt -rigging clearance is known. The butt-rigging clearance can be determined by finding a value which satisfies a boundary condition that tan α = Wv/Wh, where Wv and Wh are the vertical and the horizontal tension components of the choker line, respectively (figure 15).

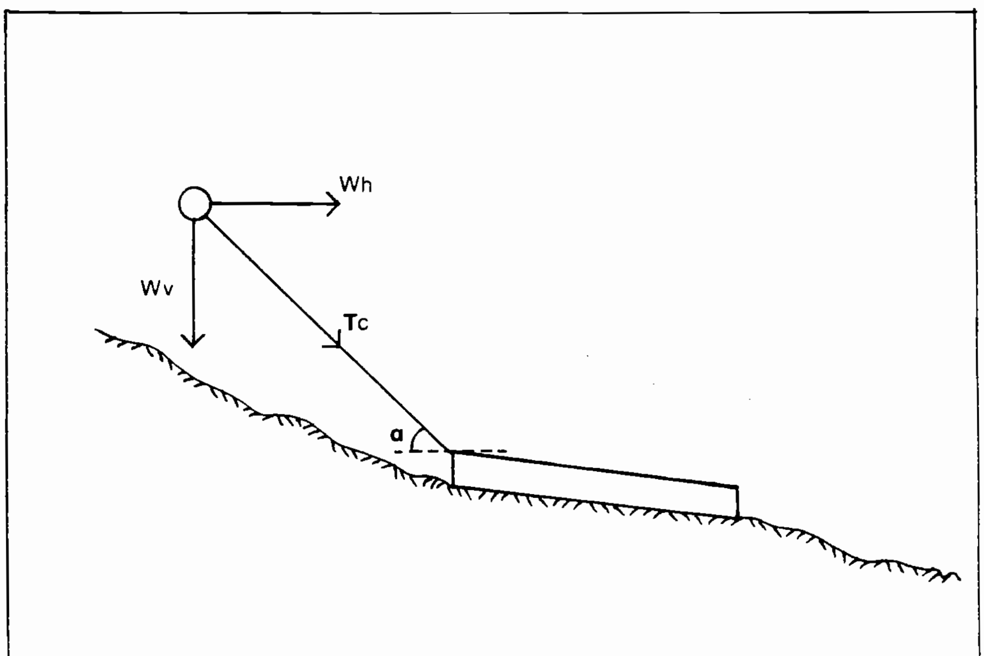

Figure 15. Force equilibrium condition at the butt-rigging.

If the butt-rigging clearance is assumed to be known, each cable segment can be analyzed by the single segment analysis equations (equation 5 and 6). With the mainline and haulback tension components, Wv and Wh can be found through such equlibrium conditions that $\Sigma Fv=0$ and $\Sigma Fh=0$.

α can be estimated two ways associated with log suspension conditions, which is related with haulback tension. First, when the haulback is tightlined enough to suspend a log partially, and are unknown variables. They can be found numerically in the same manner as was discussed in live skyline analysis (equation 1, 2 and 3). Second, when haulback tension is not so large as to provide the lifting force for the loaded log to be suspended (figure 15), α can be expressed as

$$\alpha = \theta + \sin(bcl * \cos\theta)/LC$$

(equation 20)

where bcl : butt-rigging clearance over the ground.

When the butt-rigging clearance is found, the program checks if the mainline contacts the ground at some terrain point(s). If the mainline drags on the ground, the upper end tension of the right hand side mainline segment can be determined by subtracting friction force from the lower end tension of the left hand side segment as was the case in estimating the jack friction in the multispan.

Assuming T2=T1, the normal force can be expressed as

$$N = T1\ [\sin(\psi 3 - \psi 1) + \sin(\psi 2 - \psi 3)]$$

If friction coefficient is μm,

$$T2 = T1 - \mu m\ N$$

(equation 21)

where T1: lower end tension of LHS mainline segment

T2: upper end tension of RHS mainline segment

μm: friction coefficient for cable drag.

The nomenclature is shown in figure 16. If the mainline contacts the ground at one point, $\psi 3$ equals zero.

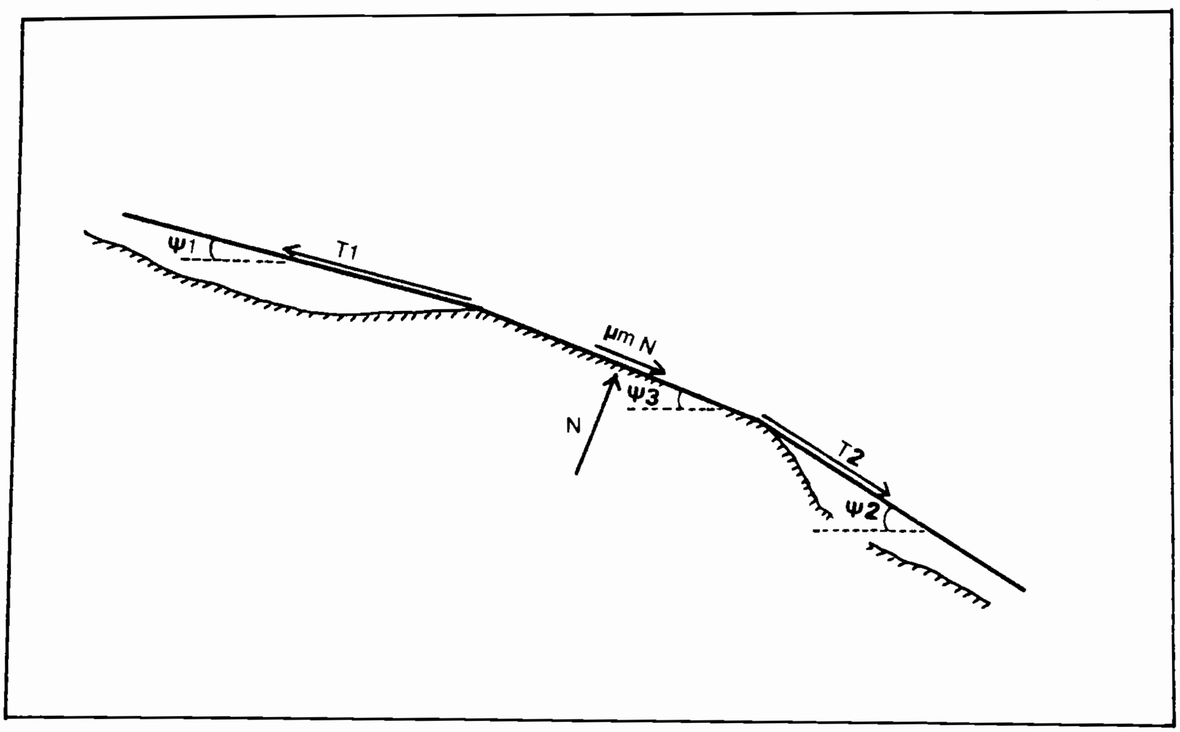

Figure 16. Cable geometry of mainline drag on the ground.

Programming Procedures

a) Guess the butt-rigging clearance above the ground.

b) Check if the mainline contacts ground. If so, determine the new upper end mainline tension (equation 21) and new cable geometry of the RHS segment of the contacting terrain point.

c) Determine the mainline and haulback tension components at the butt-rigging (equation 5 and 6).

d) Determine Wh and Wv.

e) Determine α (equation 1, 2 and 3 or 20).

f) If Wv/Wh is not equal to tan α, determine the new butt-rigging clearance and repeat the whole sequence of steps from step b.

g) Calculate the payload capability by equation 8. If any terrain point is left, repeat from step a. Otherwise, stop the analysis.

IX. VALIDATION

The programs were tested by comparing solutions with those of LOGGERPC and programs from Sessions (class notes). The subroutines unique in this package were tested by hand-calculations along the procedures as were discussed in this paper.

The solutions of the example problems in chapter X are compared with the available solutions of LOGGERPC. As shown in figure 17, the comparisons were made based on the average payload capability of each system. The difference of two solutions for each system varies 0.1 to 3.3 percent. The slight difference may result from different assumptions, on which each program is based.

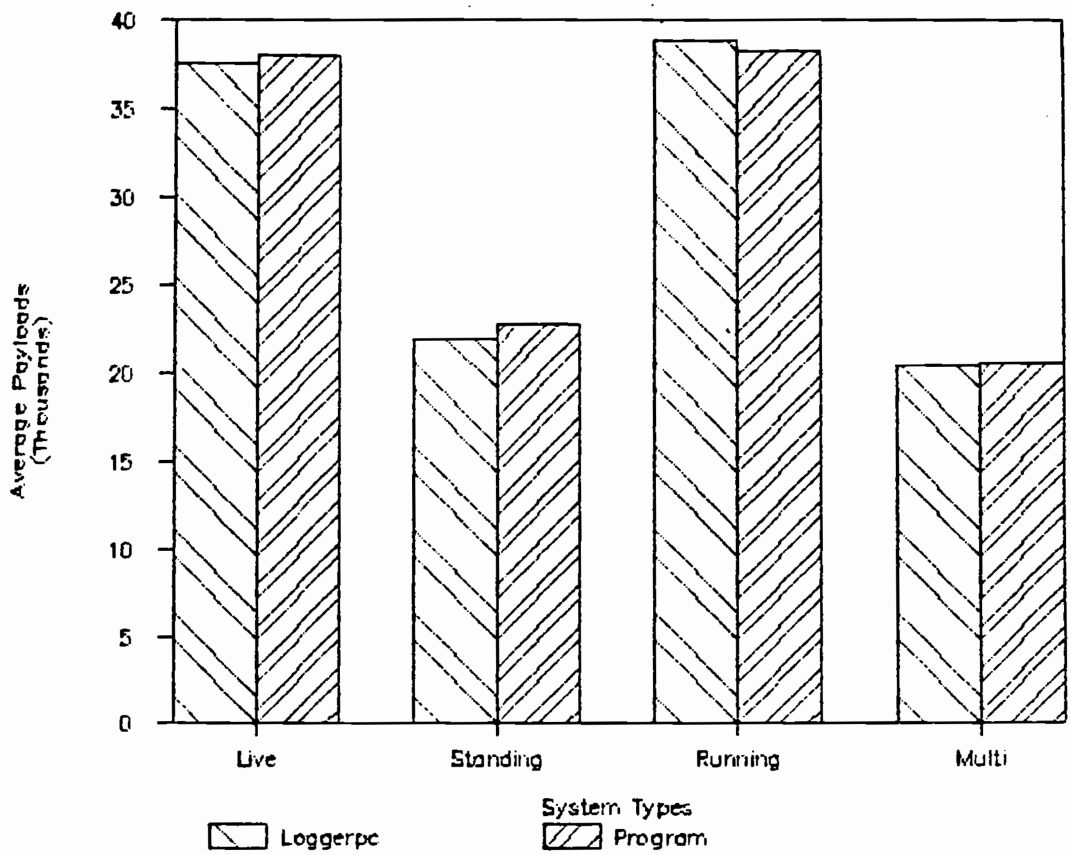

Figure 17. Comparison between the results of example analysis of the package and those of Loggerpc.

X. APPLICATIONS OF THE PACKAGE

Example 1: Live Skyline

Given the ground profile in table 1 and the data set below, the solutions shown in figure 18 can be obtained. The data set represents the minimum data to run the live skyline analysis program.

- system options -

live skyline (uphill direction, partial suspension)

- yarder data -

carriage weight : 2000 lbs depth : .01 ft

choker line length : 12 ft

1 1/4 in. skyline SWL : 53300 lbs

unit weight : 2.89 lbs/ft

1 1/8 in. mainline SWL : 43300 lbs

unit weight : 2.34 lbs/ft

- spar height and location -

head spar location : T.P. 0 height : 40 ft

tail spar location : T.P. 11 height : 40 ft

- operating parameters -

min. log end clearance : 6.8 ft

average log length : 32 ft

friction coefficient : .6

Lifting information: The `LINE LENGTH' column is the minimum skyline length required to provide the log end

T.P.	slope dist. (ft)	% slope
1	120	-64
2	116	-57
3	96	-43
4	124	-56
5	146	-47
6	78	-74
7	84	-46
8	79	-25
9	113	-14
10	73	24
11	127	54

Table 1. Ground profile data set 1

clearance of 6.8 feet at each corresponding terrain point. The `Number of lifts' column represents the number of lifts required for a moving log to be suspended at least 6.8 feet during inhaul. As an example, the skyline must be lifted six times to inhaul a log picked up at terrain point 7 to landing.

Payload analysis: All the information is based on the analysis at a critical terrain point of which the maximum payload limits that of a pickup point. As an example, the payloads picked up at T.P. 6 through 10 must be less than or equal to 34284 pounds, even though the actual payload capabilities are greater than the critical one at T.P. 3. The `CLR' column represents the skyline clearance over ground required to suspend a log at a corresponding log end clearance over ground. In this example, the maximum payload capability at each terrain point is limited by the skyline safe working load.

```
               \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
=LIFT=         ]       LIVE SKYLINE ANALYSIS        *
               -----------------------------------------
################################################################################
            PICK-UP T.P.   LINE LENGTH    NUMBER OF LIFTS
    ----------------------------------------------------------------------
```

PICK-UP T.P.	LINE LENGTH	NUMBER OF LIFTS
1	1102.9	0
2	1106.4	1
3	1107.0	2
4	1114.7	3
5	1123.8	4
6	1139.3	5
7	1150.9	6
8	1156.3	7
9	1162.7	8
10	1150.7	6

```
################################################################################
               \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
==PAYLOAD ==   ]       LIVE SKYLINE ANALYSIS        *
               -----------------------------------------
################################################################################
```

T.P.	PAYLOAD	CLR	SKY. T.	MAIN.T.	HAUL.T.	SLACK.T	L.E.CLR	CARRIAGE
1	59258	15.0	53016	43300			6.8	
2	46891	15.4	53300	31333			6.8	
3	34284	15.0	53300	22943			6.8	
4	34284	15.0	53300	22943			6.8	
5	34284	15.0	53300	22943			6.8	
6	34284	15.0	53300	22943			6.8	
7	34284	15.0	53300	22943			6.8	
8	34284	15.0	53300	22943			6.8	
9	34284	15.0	53300	22943			6.8	
10	34284	15.0	53300	22943			6.8	

```
################################################################################
```

Figure 18. Outputs of example 1

Example 2: Standing Skyline

Assumming the same ground profile and the same data set as the live skyline but a different system option, the standing skyline can be run. In this case, the data set still represents the data required. Figure 19 and 20 show the outputs of analysis when the optional data below are added to the data set above.

Information on skyline: The information is useful in preparing field operations or checking skyline tension during operations. When the unloaded skyline tension is 7487 pounds, the system has an adequate skyline length to carry the maximum payload with the clearance as shown in the output of payload analysis.

Load path analysis: The maximum payload at T.P.3 is chosen as a trial payload, which will pass each T.P.'s from T.P. 10 through T.P. 1. The analysis results provide cable line tensions, skyline clearance and log end clearance as the trial payload passes each terrain point. At T.P. 3 (figure 20), all the information is same as those of T.P. 3 in the payload analysis (figure 19).

```
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
]        STANDING SKYLINE ANALYSIS        ^
-------------------------------------------
```

UNLOADED SKYLINE TENSION REQUIRED	:	7486.5 lbs
UNLOADED SKYLINE LENGTH REQUIRED	:	1102.9 ft
UNSTRETCHED SKYLINE LENGTH	:	1097.2 ft

```
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
==PAYLOAD ==     ]        STANDING SKYLINE ANALYSIS        ^
-------------------------------------------
```

T.P.	PAYLOAD	CLR	SKY. T.	MAIN.T.	HAUL.T.	SLACK.T	L.E.CLR	CARRIAGE
1	59258	15.0	53016	43300			6.8	
2	31558	24.9	53300	19400			15.1	
3	22841	27.0	53300	13465			17.2	
4	14646	48.5	53300	5945			FULL	
5	13815	68.4	53300	5102			FULL	
6	13855	96.8	53300	4838			FULL	
7	14296	111.7	53300	4577			FULL	
8	15294	112.9	53300	4335			FULL	
9	18515	107.1	53300	3804			FULL	
10	23114	81.0	53300	2858			FULL	

Figure 19. Outputs for the payload analysis of example 2

```
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
 ]       STANDING SKYLINE ANALYSIS        ^
 ----------------------------------------
################################################################################

Do you want Payload analysis or Load path ?    L
TRIAL PAYLOAD  (lbs)                     ?    22841
```

```
################################################################################

                 \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
  == LOAD PATH ==  ]       STANDING SKYLINE ANALYSIS        ^
                 ----------------------------------------
################################################################################
```

T.P.	PAYLOAD	CLR	SKY. T.	MAIN.T.	HAUL.T.	SLACK.T	L.E.CLR	CARRIAGE
1	22842	20.8	31345	16369			11.8	
2	22836	27.6	44764	13920			17.5	
3	22841	27.0	53300	13465			17.2	
4	22841	42.8	69471	9187			31.0	
5	22841	61.3	73698	7682			FULL	
6	22841	89.9	73517	7196			FULL	
7	22842	105.6	72087	6558			FULL	
8	22841	108.0	69143	5819			FULL	
9	22842	105.1	61286	4349			FULL	
10	22843	81.1	52871	2844			FULL	

```
################################################################################
```

Figure 20. Outputs for the load path analysis of example 2

Example 3: Running Skyline

The same ground profile and system data set as those of the live skyline analysis can be used to run the running skyline analysis program. But, the skyline in the live skyline is called as a haulback in the running skyline. The output of results is shown in figure 21. All the payloads are limited by the mainline safe working load.

The example problem above does not include the option to consider the yarder payload capability. Assuming the empty

==PAYLOAD == 3 RUNNING SKYLINE

T.P.	PAYLOAD	CLR	SKY. T.	MAIN.T.	HAUL.T.	SLACK.T	L.E.CLR	CARRIAGE
1	33790	15.0		43300	18009		6.8	
2	32560	15.4		43307	21369		6.8	
3	28340	15.0		43303	24482		6.8	
4	31861	15.3		43302	23475		6.8	
5	31777	14.7		43301	24424		6.8	
6	40088	15.3		43300	21189		6.8	
7	49320	16.2		43299	19929		6.8	
8	57632	16.8		43298	20231		6.8	
9	101636	19.1		43299	27365		6.8	
10	186235	19.1		43300	51612		6.8	

Figure 21. Output of example 3 without considering the yarder payload capability.

barrel radius of 20 inches, the barrel width of 25 inches, 2300 foot haulback length before rigging and the maximum torque on haulback drum of 400,000 lbs-in., the solution changed as shown in figure 22. All the payloads in the first column except that of terrain point 1 are limited by the yarder capability. The payload of terrain point 1 is limited by the mainline safe working load of 43,300 pounds.

==PAYLOAD == RUNNING SKYLINE

T.P.	PAYLOAD	CLR	SKY. T.	MAIN.T.	HAUL.T.	SLACK.T	L.E.CLR	CARRIAGE
1	33790	15.0		43300	18009		6.8	
2	26038	15.4		35999	18250		6.8	
3	17889	15.0		30027	17841		6.8	
4	20774	15.3		30558	17399		6.8	
5	19164	14.7		28464	16919		6.8	
6	29228	15.3		32935	16755		6.8	
7	38542	16.2		34800	16548		6.8	
8	43576	16.8		33683	16332		6.8	
9	52607	19.1		23781	16039		6.8	
10	46923	19.1		12549	15794		6.8	

Figure 22. Output of example 3 with considering the yarder payload capability.

Example 4: Slackline

The same data set as the live skyline analysis can be used, but slackline information must be added.

- yarder data -

1 1/8 in. slackline SWL : 43300 lbs

The output of figure 23 shows the results of analysis. At T.P. 1, payload capability is limited by mainline safe working load. Payload capabilities at T.P. 2 through 9 are limited by skyline and mainline safe working loads. Payload capability at T.P. 10 is limited by both skyline and slackline safe working loads.

==PAYLOAD == SLACKLINE ANALYSIS

T.P.	PAYLOAD	CLR	SKY. T.	MAIN.T.	HAUL.T.	SLACK.T	L.E.CLR	CARRIAGE
1	59258	15.0	53015	43300			6.8	
2	52881	15.4	53300	43300		8325	6.8	
3	43747	15.0	53300	43300		14654	6.8	
4	49675	15.3	53300	43300		12674	6.8	
5	48238	14.7	53300	43290		14716	6.8	
6	63807	15.3	53300	43300		8090	6.8	
7	79738	16.2	53300	43300		5320	6.8	
8	92145	16.8	53300	43300		6010	6.8	
9	142949	19.1	53300	43304		20250	6.8	
10	173818	19.1	53300	35639		43300	6.8	

Figure 23: Output of example 4, where slackline tension is the tension on line segment 4.

Example 5: Highlead

To run the highlead analysis program, a desirable haulback tension must be entered by a user. Assuming the haulback tensions of 4000 pounds at all the T.P.'s, the ground profile in table 1 and the data set below, the analysis results can be obtained as shown in figure 24.

- System option -

highlead (uphill direction)

- yarder data -

choker line length : 12 ft

1 1/8 in. mainline SWL : 43300 lbs

unit weight : 2.34 lbs/ft

1 1/8 in. haulback SWL : 43300 lbs

unit weight : 2.34 lbs/ft

- spar height and location -

head spar location : T.P. 0 height : 40 ft

tail spar location : T.P. 11 height : 40 ft

- operating parameters -

Average log length : 32 ft

friction coefficient for log drag : 1.0

friction coefficient for mainline drag : 0.5

The output shows that a log will be totally dragged (no front end suspension) at all the T.P.'s. The `CLR' column represents the butt-rigging clearance.

\\

] HIGHLEAD ANALYSIS ^

##

INPUT HAULBACK TENSION :

T.P.	TENSION
1	4000
2	4000
3	4000
4	4000
5	4000
6	4000
7	4000
8	4000
9	4000
10	4000

##

\\

==PAYLOAD ==] HIGHLEAD ANALYSIS ^

##

T.P.	PAYLOAD	CLR	SKY. T.	MAIN.T.	HAUL.T.	SLACK.T	L.E.CLR	CARRIAGE
1	35761	3.8		43300	4000			
2	36823	3.4		43300	4000			
3	31505	1.3		43300	4000			
4	33556	1.9		43300	4000			
5	25886	0.0		43300	4000			
6	35271	2.8		43300	4000			
7	41470	3.8		43300	4000			
8	46487	4.6		43300	4000			
9	77576	8.2		43300	4000			
10	141128	11.1		43300	4000			

##

Figure 24. Outputs for example 5

Example 6: Multispan

Using the ground profile in table 2 and the data set below, the package provides the solutions in figure 25.

- system options -

multispan (uphill direction, partial suspension)

- yarder data -

carriage weight : 2000 lbs depth : .01 ft

choker line length : 12 ft

1.5 in. skyline SWL : 53300 lbs unit weight : 2.89 lbs/ft

1.25 in. skyline SWL: 43300 lbs unit weight : 2.34 lbs/ft

- spar height and location -

head spar height location : T.P. 0 height : 40 ft

tail spar height location : T.P. 9 height : 40 ft

intermediate spar location : T.P. 3 height : 40 ft

- operating parameters -

min. log end clearance : 4.6 ft

average log length : 32 ft

friction coefficient : 0.6

Information on yarding operations: When the unloaded skyline tension is 8250 pounds, the system has an adequate skyline length to inhaul the maximum payload with the skyline clearance as shown in figure 25. The maximum payload for carriage passage represents the maximum gross payload less carriage weight to pass an intermediate support jack successfully.

Payload analysis information: The maximum payload capabilities at all the terrain points are limited by the mainline safe working load. The `CARRIAGE' column represents the results of carriage passage check. As an example, the payload capability at T.P. 4 is over the maximum payload for carriage passage above and may not pass a support jack successfully.

T.P.	slope dist. (ft)	% slope
1	80	-35
2	95	-25
3	85	-40
4	105	-75
5	94	-83
6	84	-62
7	78	-45
8	55	23
9	68	25

Table 2. Ground profile data set 2

\\
] MULTISPAN ANALYSIS ^

HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH

UNLOADED SKYLINE TENSION REQUIRED : 8250 lbs
MIN. LOADED SKYLINE LENGTH REQUIRED : 725.0 ft
UNSTRETCHED SKYLINE LENGTH REQUIRED : 721.3 ft

MAXIMUM PAYLOAD FOR CARRIAGE PASSAGE

INTERMEDIATE SPAR # 1 : 14107 lbs

HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
\\
==PAYLOAD ==] MULTISPAN ANALYSIS ^

HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH

T.P.	PAYLOAD	CLR	SKY. T.	MAIN.T.	HAUL.T.	SLACK.T	L.E.CLR	CARRIAGE
1	39283	19.5	53300	22520			9.8	
2	34242	13.0	53300	19341			4.6	
			** INTERMEDIATE SPAR **					
4	15634	36.4	53300	10352			25.5	MAY NOT
5	11900	58.0	53300	6676			FULL	MAY PASS
6	11676	68.7	53300	6072			FULL	MAY PASS
7	13334	71.2	53300	6062			FULL	MAY PASS
8	17396	64.6	53300	6377			FULL	MAY NOT

HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH

Figure 25. Outputs of example 6

XI. THE EFFECT OF OPTIONAL PARAMETERS ON THE SYSTEM PAYLOADS

Log Dimensions

The effect of log taper on the load-carrying capability of a system by changing the log centroid distance from the leading end of a log. Using three logs of different taper such as 0%, 20% and 50% tapers, the live skyline payload analysis for the example in chapter X were done (table 3).

The results show the trends that 1) hooking a log top first provides more average payload capability than hooking a log butt first, and 2) the larger the taper the greater the effect. Unless the taper is extremely large, the effect is not significantly large. A series of the same analysis with the friction coefficient of 1.0 showed the same trend.

Yarder Capability of Running Skyline

The option to consider yarder payload capability in the running skyline analysis may or may not result in significant difference in payload capability of the system. If the yarder capability is larger than or equal to the maximum load capability of cable lines, there will not be any difference of the system payload capability. The two running skyline examples in chapter X show a significant difference of the system payload capability. In this case, the option of the yarder parameters limits the payloads at the most of terrain

Case	μ	Log Dimensions, in.	Average Payload, lbs	% Difference from Base Case
base	.6	R1=R2	38042	-
1	.6	R1=32, R2=40	39328	+ 3.4
2	.6	R1=40, R2=32	36340	- 4.5
3	.6	R1=20, R2=40	41947	+10.3
4	.6	R1=40, R2=20	33567	-11.8

Table 3. Results of the live skyline analysis by varying the log dimensions, where R1, R2 were defined in chapter III.

	Case 1		Case 2	
T.P.	Payload, lbs	Limiting Factor	Payload, lbs	Limiting Factor
1	33790	mainline	33790	mainline
2	32560	mainline	26038	yarder
3	28340	mainline	17889	yarder
4	28340	mainline	17889	yarder
5	28340	mainline	17889	yarder
6	28340	mainline	17889	yarder
7	28340	mainline	17889	yarder
8	28340	mainline	17889	yarder
9	28340	mainline	17889	yarder
10	28340	mainline	17889	yarder

Table 4. Comparison of running skyline payload zone analyses: (1)analysis without considering the yarder payload capability and (2)analysis considering the yarder payload capability.

points. The results of the payload zone analysis are shown in table 4.

Jack Friction Coefficient and Chord Slope Break

For the multispan, the effects of the jack friction coefficient and the chord slope break were tested. The first case in table 5 represents the result of the payload zone analysis of the multispan example problem in chapter X. The second and the forth cases represent, respectively, the result of analysis when the jack friction coefficient is increased by .4 and when the chord slope break is increased by one degree, which was obtained by increasing the slope grades of the second span by 2 %.

The increase of the jack friction coefficient results in about 6.5% increase of the average payload in both cases of the chord slope breaks. The increase of the chord slope break by one degree reduced the payload capability of the system by about 6% in both cases of the jack friction coefficients. The fifth column shows the maximum payload, which can pass the intermediate support jack successfully.

Slackline

For comparison, the slackline was analyzed by using the live skyline analysis program because LOGGERPC does not have

Case	μj	Chord Slope Break, deg	Average Payload, lbs	Max. Payload to Pass the Jack, lbs
Case 1	.0	17.1	19441	14107
Case 2	.4	17.1	20690	15920
Case 3	.0	18.1	18261	12259
Case 4	.4	18.1	19466	14098

Table 5. Results of the multispan analysis by varying the jack friction coefficient and/or the chord slope break.

T.P.	Live Skyline, lbs	Slackline, lbs
1	59258	59258
2	46891	52881
3	34284	43747
4	34284	43737
5	34284	43737
6	34284	43747
7	34284	43747
8	34284	43747
9	34284	43747
10	34284	43747

Table 6. Comparison of payloads between the live skyline analysis and slackline analysis.

a slackline option. Table 6 illustrates a comparison between the result of a live skyline analysis and the result of a slackline analysis. Both analyses were done with the same ground profile and operating parameters (those of the live skyline and the slackline examples in chapter X). The results of the slackline analysis shows much higher payload capability than that of the live skyline analysis. The difference of the average payload capability was 17.7 percent.

IX. SUGGESTIONS FOR FURTHER STUDY

1. Each analysis program provides the sum of the vertical and horizontal components of the line tensions inside the spans. The information may be used to provide a rough idea on how to rig up guylines. In order to provide more accurate information, the spar tree reactions must be be resolved considering the cable tensions outside the span such as the tension of skyline between the tail spar and the stump together.

2. Each analysis program assumes only nonclamping carriages. If clamping carriages were used, the solutions might differ. It is one of future developments that could be added to this programming model.

3. All the existing models including this program analyze cable systems based on statics only. The literature indicates that no practical attempt has been made to introduce dynamics into cable logging mechanics. The solutions, especially for downhill yarding, may be improved much more in accuracy if dynamics as well as statics were considered.

4. The procedures of multispan carriage passage check have been discussed in detail in chapter VII. A more efficient method to find the cable geometry is needed. Especially, the literature review shows there has been no

effort to check the carriage passage for the partial suspension case of the uphill yarding.

Equation 18 in chapter VII was derived to determine Ts, which is the critical skyline tension for the carriage passage over an intermediate support jack. The equation is not solvable unless the skyline geometry, when the loaded carriage approaches to the intermediate support jack, is not known. It may be solved using an assumption that the skyline clearance over the ground at the checking point is less than the jack clearance over the ground by one to three feet. Actually the difference between the latter and the former may be in that range. With the assumption, Wh and Wv, then Ts, for the partial suspension case can be determined.

5. For the multispan payload analysis considering the jack friction effect, the friction only at the left-side intermediate support jack of the loaded span was considered. For more accurate analysis, the friction forces at the other intermediate support jack(s), if any, and those forces at the blocks of head spar and tail spar must be considered together.

6. In this paper, the multispan jack friction effect was considered only in the payload analysis model. It can be also added to the load path analysis model.

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APPENDIX

i. Derivation of the Mainline Tension Components of the Live Skyline for the Partial Suspension Case

From figures 1, 3 and 4,

$\Sigma F_x = 0;\quad Wh = H1 + H3 - H2$

$\Sigma F_y = 0;\quad Wv = V1 + V2 + V3 - cwt$

$$\text{Then, } \tan\alpha = \frac{Wv}{Wh}$$

$$= \frac{V1 + V2 + V3 - cwt}{H1 + H3 - H2} \quad \ldots\ldots\ldots\ldots(1)$$

From figure 4,

$\Sigma M = 0;\quad 0 = R3(d3/2) - H3\ h3 + V3\ d3$

$V3 = H3(h3/d3) - R3/2 \quad \ldots\ldots\ldots\ldots(2)$

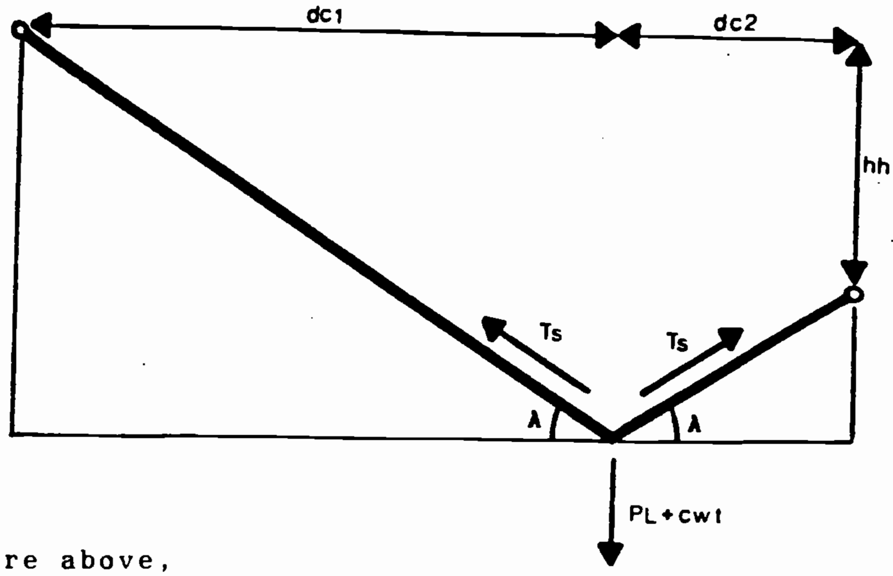
Eliminate V3 in (1) and (2),

$$\tan\alpha = \frac{V1 + V2 + [H3(h3/d3) - R3/2] - cwt}{H1 + H3 - H2}$$

Solve for H3,

$$H3 = \frac{\tan\alpha(H1 - H2) - (V1 + V2 - cwt) + R3/2}{h3/d3 - \tan\alpha}$$

ii. Derivation of the Critical Skyline Tension for Multispan Downhill Yarding Carriage Passage Check



From the figure above,

$$PL + cwt = 2Ts \sin\lambda$$

Thus, $Ts = (PL + cwt)/(2 \sin\lambda)$ ------ (1)

Then, $hh = hc1 - hc2$ ------------------- (2)

$\tan\lambda = hc1/dc1 = hc2/dc2$ --------- (3)

From (2) and (3),

$$hc1 = hh(dc1)/(dc1-dc2)$$

Then, $\lambda = \tan^{-1}(hc1/dc1) = \tan^{-1}[hh/(dc1-dc2)]$

Thus,

$$Ts = \frac{PL + cwt}{2\sin\{\tan^{-1}[hh/(dc1 - dc2)]\}}$$

If dL=dc1+dc2 and dc2 is very small,

$$Ts = \frac{PL + cwt}{2\sin[\tan^{-1}(hh/dL)]}$$

iii. Derivation of the Critical Skyline Tension for the Carriage Passage Check for the Partial Suspension of the Uphill Yarding

Assuming ∂ =90 degrees in figure 12,

$$\Sigma Fx=0;\ Tm \cos\Omega = Ts \cos\lambda + Wh \quad \ldots\ldots\ldots(1)$$

$$\Sigma Fy=0;\ Ts + Tm \sin\Omega = Ts \sin\lambda + Wv + cwt \quad \ldots(2)$$

where $Tc = (Wh^2 + Wv^2)^{0.5}$

Tm : mainline tension at the carriage

Combine (1) and (2) by eliminating Tm,

$$Ts = \frac{Wv + cwt - Wh \tan\Omega}{1 - \cos\lambda(\tan\lambda - \tan\Omega)}$$

iv. Program Codes

```
10 '==========================================================
20 '                    INDEX OF VARIABLES
30 '==========================================================
100 'ALPHA =CHOKER LINE ANGLE TO THE HORIZONTAL
110 'BETA  =LOG-TO-GROUND ANGLE
120 'CDP   =CARRIAGE DEPTH
130 'CWT   =CARRIAGE WEIGHT
140 'CL    =SKYLINE CLEARANCE OVER GROUND
150 'CLC   =CARRIAGE CLEARANCE OVER GROUND
160 'D3    =HORIZONTAL LENGTH OF SEGMENT 3 OR MAINLINE
165 'DCL   =DISTANCE OF CHOKING POINT FROM LEADING-END OF LOG
170 'DIAH  =HAULBACK DIAMETER
180 'DIAM  =MAINLINE DIAMETER
190 'DIAS  =SKYLINE DIAMETER
200 'DIASL =SLACKLINE DIAMETER
210 'DL    =HORIZONTAL LENGTH OF SEGMENT 1
220 'DR    =HORIZONTAL LENGTH OF SEGMENT 2
230 'EYL   =TERRAIN POINT OF EXTERNAL YARDING LIMIT
240 'HS1   =LEFT-MOST SPAR HEIGHT
250 'HS2   =RIGHT-MOST SPAR HEIGHT
250 'HL    =VERTICAL LENGTH OF SEGMENT 1
260 'HR    =VERTICAL LENGTH OF SEGMENT 2
270 'H3    =VERTICAL LENGTH OF SEGMENT 3 OR MAINLINE
280 'HiL   =LOWER END HORIZONTAL TENSION COMPONENT OF SEGMENT i
290 'HiU   =UPPER END HORIZONTAL TENSION COMPONENT OF SEGMENT i
300 'IS(i) =HEIGHT OF iTH INTERMEDIATE SUPPORT
310 'L     =AVERAGE LOG LENGTH
320 'LC    =CHOKER LINE LENGTH
330 'LEC   =LOG END CLEARANCE OVER GROUND
340 'LED   =AVERAGE LEADING END DIAMETER OF LOG
350 'LLINE =HAULBACK LENGTH BEFORE RIGGING
353 'MJ    =FRICTION COEFFICIENT OF JACK FRICTION
357 'MU    =FRICTION COEFFICIENT OF CABLE DRAG
360 'MY    =FRICTION COEFFICIENT OF LOG DRAG
370 'NOFI  =NO OF INTERMEDIATE SUPPORT
380 'RAD   =RADIUS OF EMPTY HAULBACK DRUM
390 'S     =STRETCHED CABLE LENGTH
400 'So    =UNSTRETCHED CABLE LENGTH
420 'TAi   =SAFE WORKING LOAD OF CABLE i WHERE 1=SKYLINE, 3=MAINLINE
             4=HAULBACK AND 5=SLACKLINE
430 'TED   =TRAILING END DIAMETER OF LOG
435 'THETA =GROUND SLOPE ANGLE
440 'TORQ  =MAXIMUM HAULBACK DRUM TORQUE
450 'TP1   =LEFT-MOST TERRAIN POINT NUMBER
460 'TP2   =RIGHT-MOST TERRAIN POINT NUMBER
470 'TPIS(i)=TERRAIN POINT OF INTERMEDIATE SUPPORT i
480 'VjL   =LOWER END VERTICAL TENSION COMPONENT OF SEGMENT j
490 'VjU   =UPPER END VERTICAL TENSION COMPONENT OF SEGMENT j
500 'Wk    =UNIT WEIGHT OF CABLE k WHERE 1=SKYLINE, 2=MAINLINE
             3=HAULBACK AND 4=SLACKLINE
510 'WID   =WIDTH OF HAULBACK DRUM
```

```
10000 '======================================================================
10002 '                          MAKE DATA FILES
10004 '======================================================================
10000 CLS
10010 DIM HD(40),VD(40),SD(40),PS(40),T$(17),Z(50),M$(4)
10020 '===================== {Key Definitions} =============================
10030 ZERO$=CHR$(0)
10040 RIGHTKEY$=ZERO$+"M" : UP$=ZERO$+"H": DN$=ZERO$+"P"
10050 LEFTKEY$=ZERO$+"K": DEL$=ZERO$+"S": HOME$=ZERO$+"G"
10060 PGUP$=ZERO$+"I": PGDN$=ZERO$+"Q"
10070 A1$=CHR$(221):A2$=CHR$(222):A3$=STRING$(79,223):
      A4$=STRING$(79,220):A5$=STRING$(40,223):A6$=STRING$(40,220):
      S1$=STRING$(79,205):S2$=STRING$(1,179):S3$=STRING$(79," ")
10080 IF RES=1 THEN RES=0:GOTO 10230
10200 CLS
10210 LOCATE 12,1:PRINT STRING$(79,205):LOCATE 12,20:
      PRINT "!   ENTER YOUR";:COLOR 15,0:PRINT " DATA FILE DISK
      IN DRIVE B";:COLOR 7,0:PRINT "   !"
10220 GOSUB 29600
10230 CLS
10240 ON ERROR GOTO 30430
10250 DRV$="B"
10255 '========================= {Main Menu} ===============================
10260 M$(1)="PROFILE":M$(2)="OPTIONS & PARAMETERS":M$(3)="SYSTEM ANALYSIS"
10270 LOCATE 3,1:PRINT S1$:LOCATE 3,34:PRINT "  MAIN MENU  "
10280 LOCATE 5,6:PRINT M$(1):LOCATE 5,30:PRINT M$(2):LOCATE 5,57:PRINT M$(3)
10290 LOCATE 7,1:PRINT S1$
10300 Z=1:COLOR 0,7:LOCATE 5,5:PRINT STRING$(22," ");:LOCATE 5,6:
      PRINT M$(1):COLOR 7,0
10310 LOCATE 23,1:PRINT S1$
10320 LOCATE 25,15:PRINT "ESC -- EXIT TO SYSTEM";:LOCATE 25,48:
      PRINT STRING$(1,205)+STRING$(1,16);"  MOVE CURSOR";
10330 COL=5:ROW=5:FL$="0":GOSUB 13620
10340 IF Z=1 THEN FL$="PRO":GOTO 10380
10350 IF Z=2 THEN FL$="PAR":GOTO 10380
10360 IF Z=3 THEN 20000
10370 GOTO 10280
10380 KEY OFF:COLOR 7,0:CLS
10390 IF FL$="PAR" THEN GOTO 12860
10395 '=================== {Make a Ground Profile File} =====================
10400 GOSUB 12160
10410 GOSUB 12120
10420 LOCATE 1,37:INPUT "",CHO$
10430 IF CHO$="C" OR CHO$="L" OR CHO$="R" OR CHO$="M" OR CHO$="Q"
      THEN 10440 ELSE 10410
10440 IF CHO$="C" THEN CHO=1:GOSUB 15830:GOTO 10520
10450 WHILE CHO$="M"
10460    CHO=3:GOSUB 15830:GOSUB 12590
10470    IF D$="H" THEN C$=LEFT$(STR$(HD(1)),6) ELSE C$=LEFT$(STR$(SD(1)),6)
10480    GOTO 10570
10490 WEND
10500 IF CHO$="Q" THEN CLEAR:RES=1:GOTO 10010
10510 GOTO 10410
```

```
10520 LOCATE 1,3:PRINT "Do yoy want input ";:COLOR 15,0:PRINT "S";:
      COLOR 7,0:PRINT "lope dist. or ";:COLOR 15,0:PRINT "H";:
      COLOR 7,0:PRINT "orizon. dist.? ¦ "
10530 LOCATE 1,54: INPUT "",D$
10540 C$=""
10550 IF D$="S" OR D$="H" THEN 10560 ELSE LOCATE 1,54:PRINT "    ": GOTO 10520
10560 IF CHO=1 THEN LOCATE 1,3: PRINT STRING$(50," "):GOSUB 11960
10570 IF D$="H" THEN COL1=21 :COL2=37 ELSE COL1=54: COL2=69
10575 '=================== {Enter Ground Profile Data} =====================
10580 COLOR 7,0:MAXCHR=5: CURCOL=1:MAXROW=22:MINROW=6: PG=0:TP=1:ROW=6:
      CURCOL=1
10590 GOSUB 12090
10600 :
10610 N$="":NCHR=0:N=MAXCHR+1
10620 IF CURCOL=1 THEN COL=COL1 ELSE COL=COL2
10630 :
10640 LOCATE ROW,6:PRINT TP: LOCATE 2,55:PRINT TP
10650 COLOR 7,0:LOCATE ROW,COL:COLOR 0,7:FOR I=1 TO N:PRINT " ";:NEXT I:
      COLOR 7,0
10660 IF C$=" 0" THEN 10680
10670 COLOR 0,7:LOCATE ROW,COL:PRINT C$:COLOR 7,0
10680 KBD$="":DEF SEG=0:POKE 1050,PEEK(1052):DEF SEG:LOCATE ROW,COL:COLOR 0,7
10690 LOCATE ROW,COL: KBD$="":WHILE KBD$="":KBD$=INKEY$:WEND:
      KBD=ASC(LEFT$(KBD$,1)):COLOR 7,0
10700 WHILE (KBD>44 AND KBD<58) OR (KBD=8)
10710    WHILE KBD=8
10720      NN=0:NCHR=NCHR-1:IF NCHR<0 THEN NCHR=0:GOTO 11170
10730      IF NCHR=0 THEN N$="" ELSE N$=LEFT$(N$,NCHR)
10740      COL=COL-1:LOCATE ROW,COL:COLOR 0,7:PRINT " ":LOCATE ROW,COL:
         COLOR 7,0
10750      GOTO 10680
10760    WEND
10770    NCHR=NCHR+1:IF NCHR>MAXCHR THEN NCHR=MAXCHR:NN=1:GOTO 11170
         ELSE COL=COL+1
10780    N$=N$+KBD$
10790    WHILE N$=KBD$
10800       IF CURCOL=1 THEN COLOR 0,7:LOCATE ROW,COL1:FOR I=1 TO N:
         PRINT " ";:NEXT I:COL=COL1+1:GOTO 10830
10810       IF CURCOL=2 THEN COLOR 0,7:LOCATE ROW,COL2:FOR I=1 TO N:
         PRINT " ";:NEXT I:COL=COL2+1:GOTO 10830
10820    WEND
10830    LOCATE ROW,COL-1:COLOR 0,7:PRINT KBD$:COLOR 7,0
10840    GOTO 10680
10850 WEND
10860 IF N$="" THEN N$=C$
10870 WHILE KBD=13 OR (KBD$=UP$ AND ROW>MINROW) OR (KBD$=DN$ AND
      ROW<MAXROW) OR (KBD$=RIGHTKEY$ AND CURCOL=1) OR
      (KBD$=LEFTKEY$ AND CURCOL=2) OR   KBD$=HOME$
10880    OLDC$=C$
10890    GOSUB 11200: IF OLDC$=N$ THEN 10910
10900    GOSUB 11730
10910    GOSUB 11180:GOSUB 11690
10920    IF KBD=13 AND ROW=MAXROW AND CURCOL=2 THEN C$=N$:GOTO 10610
```

```
10930    IF KBD$=UP$ THEN ROW=ROW-1:TP=TP-1:GOTO 10610
10940    IF KBD$=DN$ THEN ROW=ROW+1:TP=TP+1:GOTO 10610
10950    IF KBD$=RIGHTKEY$ THEN CURCOL=2:GOTO 10610
10960    IF KBD$=LEFTKEY$ THEN CURCOL=1:GOTO 10610
10970    IF KBD$=HOME$ THEN CURCOL=1:ROW=MINROW:TP=1+17*PG:GOTO 10610
10980    WHILE KBD=13
10990       IF CURCOL=1 THEN CURCOL=2: GOTO 10610 ELSE
         CURCOL=1:ROW=ROW+1:TP=TP+1:GOTO 10610
11000 WEND:WEND
11010 WHILE KBD$=PGUP$
11020    IF PG=0 THEN 11170
11030    IF PG=1 THEN TP=0: GOSUB 12820: GOSUB 12700:GOSUB 11200:
         TP=1:PG=0: GOTO 11120
11040    IF PG=2 THEN TP=17:GOSUB 12820: GOSUB 12700:GOSUB 11200:
         TP=18:PG=1: GOTO 11120
11050 WEND
11060 WHILE KBD$=PGDN$
11070    IF PG=0 THEN TP=17:GOSUB 12820: GOSUB 12700:GOSUB 11200:
         TP=18:PG=1: GOTO 11120
11080    IF PG=1 THEN TP=34:GOSUB 12820:GOSUB 12700:GOSUB 11200:
         TP=35:PG=2:GOTO 11120
11090    IF PG=2 THEN 11170
11100    Z=1+17*PG
11110    IF D$="H" THEN C$=RIGHT$(STR$(HD(Z)),LEN(STR$(HD(Z)))-1) ELSE
         C$=RIGHT$(STR$(SD(Z)),LEN(STR$(SD(Z)))-1)
11120    ROW=MINROW: CURCOL=1:GOTO 10610
11130 WEND
11140 WHILE KBD$=CHR$(27)
11150    IF CHO=1 OR CHO=3 THEN LOCATE 25,1:PRINT S3$;:GOSUB 12000:
         GOSUB 12490:GOTO 10380
11160 WEND
11170 SOUND 500,1: GOTO 10680
11180 COLOR 7,0 :IF CURCOL=1 THEN LOCATE ROW,COL1 ELSE LOCATE ROW,COL2
11190 PRINT "       ";:RETURN
11200 :
11210 WHILE D$="H"
11220    IF KBD$=CHR$(13) THEN IF CURCOL=1 THEN C$=STR$(VD(TP)) :
         GOTO 11660 ELSE C$=STR$(HD(TP+1)) :GOTO 11660
11230    IF KBD$=UP$ THEN IF CURCOL=1 THEN C$=STR$(HD(TP-1)):
         GOTO 11660 ELSE C$=STR$(VD(TP-1)):GOTO 11660
11240    IF KBD$=DN$ THEN IF CURCOL=1 THEN C$=STR$(HD(TP+1)):
         GOTO 11660 ELSE C$=STR$(VD(TP+1)):GOTO 11660
11250    WHILE KBD$=PGUP$
11260       IF PG=1 AND TP<35 THEN C$=STR$(HD(1)):GOTO 11660
11270       IF PG=2 THEN C$=STR$(HD(18)):GOTO 11660
11280       IF PG=0 THEN 11170
11290    WEND
11300    WHILE KBD$=PGDN$
11310       IF PG=0 THEN C$=STR$(HD(18)):GOTO 11660
11320       IF PG=1 THEN C$=STR$(HD(35)):GOTO 11660
11330       IF PG=2 THEN 11170
11340    WEND
11350    IF KBD$=RIGHTKEY$ THEN  C$=STR$(VD(TP)):  GOTO 11660
```

```
11360    IF KBD$=LEFTKEY$ THEN C$=STR$(HD(TP)):GOTO 11660
11370    WHILE KBD$=HOME$
11380       IF TP<18 THEN C$=STR$(HD(1)):GOTO 11660
11390       IF TP>17 AND TP<35 THEN C$=STR$(HD(18)):GOTO 11660
11400       IF TP>34 THEN C$=STR$(HD(35)): GOTO 11660
11410    WEND
11420    C$="":RETURN
11430 WEND
11440 WHILE D$="S"
11450    IF KBD$=CHR$(13) THEN IF CURCOL=1 THEN C$=STR$(PS(TP)):
         GOTO 11660 ELSE C$=STR$(SD(TP+1)) :GOTO 11660
11460    IF KBD$=UP$ THEN IF CURCOL=1 THEN C$=STR$(SD(TP-1)):
         GOTO 11660 ELSE C$=STR$(PS(TP-1)):GOTO 11660
11470    IF KBD$=DN$ THEN IF CURCOL=1 THEN C$=STR$(SD(TP+1)):
         GOTO 11660 ELSE C$=STR$(PS(TP+1)):GOTO 11660
11480    WHILE KBD$=PGUP$
11490       IF PG=1 AND TP<35 THEN C$=STR$(SD(1)):GOTO 11660
11500       IF PG=2 THEN C$=STR$(SD(18)):GOTO 11660
11510       IF PG=0 THEN 11170
11520    WEND
11530    WHILE KBD$=PGDN$
11540       IF PG=0 THEN C$=STR$(SD(18)):GOTO 11660
11550       IF PG=1 THEN C$=STR$(SD(35)):GOTO 11660
11560       IF PG=2 THEN 11170
11570    WEND
11580    IF KBD$=RIGHTKEY$ THEN C$=STR$(PS(TP)): GOTO 11660
11590    IF KBD$=LEFTKEY$ THEN C$=STR$(SD(TP)):GOTO 11660
11600    WHILE KBD$=HOME$
11610       IF TP<18 THEN C$=STR$(SD(1)):GOTO 11660
11620       IF TP>17 AND TP<35 THEN C$=STR$(SD(18)):GOTO 11660
11630       IF TP>34 THEN C$=STR$(SD(35)): GOTO 11660
11640    WEND
11650    C$="":RETURN
11670    RETURN
11680 WEND
11690 IF N$=" 0" THEN 11720
11700 WHILE NCHR>0 AND LEFT$(N$,1)<>"-": IF CURCOL=1 THEN
      LOCATE ROW,COL1+1:PRINT N$ :GOTO 11720 ELSE LOCATE ROW,COL2+1:
      PRINT N$:GOTO 11720: WEND
11710    IF CURCOL=1 THEN LOCATE ROW,COL1:PRINT N$ ELSE LOCATE ROW,COL2:
         PRINT N$
11720 RETURN
11730 ' ========={Calculating Corresponding Data for Ground Profile} =========
11740 WHILE D$="H"
11750 IF CURCOL=1 THEN HD(TP)=VAL(N$) ELSE VD(TP)=VAL(N$)
11760    IF VD(TP)=0 OR HD(TP)=0 THEN SD(TP)=0:PS(TP)=0:GOTO 11780
11770    SD(TP)=SQR(HD(TP)^2+VD(TP)^2):PS(TP)=VD(TP)/HD(TP)*100
11780    A$=STR$(SD(TP)):B$=STR$(PS(TP))
11790    SD$=LEFT$(A$,6):PS$=LEFT$(B$,6)
11800    LOCATE ROW,54:PRINT "      ":LOCATE ROW,54:PRINT SD$
11810    LOCATE ROW,69:PRINT "      ":LOCATE ROW,69:PRINT PS$
11820    GOTO 11920:WEND
11830 WHILE D$="S"
```

```
11840    IF CURCOL=1 THEN SD(TP)=VAL(N$) ELSE PS(TP)=VAL(N$)
11850    IF SD(TP)=0 OR PS(TP)=0 THEN VD(TP)=0:HD(TP)=0:GOTO 11870
11860    VD(TP)=SD(TP)*SIN(ATN(PS(TP)/100)): HD(TP)=SQR(SD(TP)^2-VD(TP)^2)
11870    A$=STR$(VD(TP)): B$=STR$(HD(TP))
11880    VD$=LEFT$(A$,6):HD$=LEFT$(B$,6)
11890    LOCATE ROW,21: PRINT "      ":LOCATE ROW,21:PRINT HD$
11900    LOCATE ROW,37: PRINT "      ":LOCATE ROW,37:PRINT VD$
11910    GOTO 11920:WEND
11920    RETURN
11930 '================= {Print Prompt and Template} =======================
11940 IF PROFN$<>"" THEN LOCATE 1,3: PRINT "FILE NAME: ";PROFN$
11950 IF FL$="PAR" THEN RETURN
11960 LOCATE 1,37: PRINT "INPUT DATA    : "
11970 LOCATE 1,53: IF D$="S" THEN PRINT "SLOPE DIST. & % SLOPE" ELSE
      PRINT "HOR. & VER. DIST"
11980 LOCATE 2,37: PRINT "TERRAIN POINT :"
11990 RETURN
12000 LOCATE 1,1: PRINT S3$:LOCATE 2,1:PRINT S3$
12010 COLOR 15,0:LOCATE 1,3: PRINT "S";:COLOR 7,0:PRINT "AVE":COLOR 15,0:
      LOCATE 1,11:PRINT "C";:COLOR 7,0:PRINT "URRENT":COLOR 15,0:
      LOCATE 1,22:PRINT "Q";:COLOR 7,0:PRINT "UIT :"
12020 LOCATE 1,29:INPUT "",AN$
12030 LOCATE 1,1:PRINT S3$:LOCATE 2,1:PRINT S3$
12040 IF AN$="S" THEN GOSUB 12460: RETURN
12050 IF FL$="PAR" THEN 12070
12060 IF AN$="Q" THEN 10380 ELSE GOSUB 11940:GOSUB 12090:GOTO 10610
12070 IF AN$="Q" AND FL$="PAR" THEN LOCATE ROW1,COL1:PRINT STRING$(34," "):
      RETURN ELSE GOSUB 11940:GOSUB 12100:GOTO 12990
12080 RETURN
12090 LOCATE 25,7:PRINT "ESC--MENU    PGDN--NEXT SCR    PGUP--FRONT SCR
      HOME--TOP OF SCR";:RETURN
12100 LOCATE 25,1:PRINT "ESC--MENU   PGDN--NEXT SCR   PGUP--FRONT SCR
      HOME--SYSTEM SEL  ";:PRINT STRING$(1,25);"--MOVE CURSOR";:RETURN
12110 '======================== {Submenu} ================================
12120 LOCATE 1,3:PRINT STRING$(75," ")
12130 COLOR 15,0: LOCATE 1,3:PRINT "C";:COLOR 7,0:PRINT "REATE":
      COLOR 15,0:LOCATE 1,12:PRINT "M";:COLOR 7,0:PRINT "ODIFY/RETRIEVE";
12140 COLOR 15,0:LOCATE 1,30:PRINT "Q";:COLOR 7,0:PRINT "UIT :"
12150 IF FL$="PAR" THEN RETURN
12160 LOCATE 3,1:PRINT STRING$(1,213);STRING$(77,205); STRING$(1,184)
12170 S8$=STRING$(1,209):S9$=STRING$(1,207)
12180 LOCATE 3,14:PRINT S8$:LOCATE 3,31:PRINT S8$:LOCATE 3,48:
      PRINT S8$:LOCATE 3,64:PRINT S8$
12190 LOCATE 5,1:PRINT STRING$(1,198);STRING$(77,205);STRING$(1,181)
12200 FOR I=4 TO 22
12210    LOCATE I,1:PRINT S2$
12220    LOCATE I,14:PRINT S2$
12230    LOCATE I,31:PRINT S2$
12240    LOCATE I,48:PRINT S2$
12250    LOCATE I,64:PRINT S2$
12260    LOCATE I,79:PRINT S2$
12270    IF I=4 THEN I=5:LOCATE I,1:PRINT STRING$(1,198):LOCATE I,14:
         PRINT STRING$(1,216):LOCATE I,31:PRINT STRING$(1,216):
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       LOCATE I,48:PRINT STRING$(1,216):LOCATE I,64:PRINT STRING$(1,216):
       LOCATE I,79:PRINT STRING$(1,181)
12280 NEXT I
12290 LOCATE 23,1:PRINT STRING$(1,212);STRING$(77,205);STRING$(1,190)
12300 LOCATE 23,14:PRINT S9$:LOCATE 23,31:PRINT S9$:LOCATE 23,48:
      PRINT S9$:LOCATE 23,64:PRINT S9$
12310 LOCATE 4,7: PRINT "T.P"
12320 LOCATE 4,18:PRINT "HORI. DIST."
12330 LOCATE 4,34:PRINT "VER. DIST."
12340 LOCATE 4,51:PRINT "SLOPE DIST."
12350 LOCATE 4,68:PRINT "% SLOPE"
12360 RETURN
12370 '======================= (Define File Names) ========================
12380 NAM$=DRV$+":"+PROFN$+"."+FL$: RETURN
12390 CLS:LOCATE 3,1:PRINT S1$
12400 FILES DRV$+":*."+FL$
12410 IF AN=1 THEN RETURN
12420 LOCATE 1,3:PRINT "FILE NAME TO RETRIEVE !"
12430 R=1:C=27:GOSUB 24870 :PROFN$=M$
12440 IF FL$="PAR" THEN CLS:GOSUB 13020:GOSUB 11940:GOSUB 12380:RETURN
12450 CLS:GOSUB 12160: GOSUB 11940:GOSUB 12380:RETURN
12460 LOCATE 1,3:PRINT "FILE NAME TO SAVE !"
12470 R=1:C=24:GOSUB 24870 :PROFN$=M$
12480 GOSUB 12380: RETURN
12490 '==================  (Open a Ground Profile File) ====================
12500 OPEN NAM$ FOR OUTPUT AS #1
12510 TP=0
12520 WRITE #1,D$
12530 TP=TP+1
12540 IF VD(TP)=0 THEN 12570
12550 WRITE #1, VD(TP);HD(TP);SD(TP);PS(TP)
12560 GOTO 12530
12570 CLOSE #1
12580 RETURN
12590 '==================  (Retrieve a Ground Profile File) ================
12600 GOSUB 12390
12610 TP=0
12620 OPEN NAM$ FOR INPUT AS #2
12630 INPUT #2,D$
12640 TP=TP+1
12650 INPUT #2, VD(TP),HD(TP),SD(TP),PS(TP)
12660 IF EOF(2) THEN 12680
12670 GOTO 12640
12680 CLOSE #2
12690 TP=0
12700 FOR I=6 TO 22
12710    TP=TP+1
12720    LOCATE I,6:PRINT TP
12730    IF HD(TP)=0 THEN GOTO 12810
12740    A1$=STR$(HD(TP)):A2$=STR$(VD(TP)):A3$=STR$(SD(TP)):A4$=STR$(PS(TP))
12750    HD$=LEFT$(A1$,6):VD$=LEFT$(A2$,6):SD$=LEFT$(A3$,6):PS$=LEFT$(A4$,6)
12760    LOCATE I,21:PRINT HD$
12770    LOCATE I,37:PRINT VD$
```

```
12780    LOCATE I,54:PRINT SD$
12790    LOCATE I,69:PRINT PS$
12800 NEXT I
12810 RETURN
12820 FOR I=6 TO 22
12830    LOCATE I,6:PRINT "   ":LOCATE I,20:PRINT "         ":LOCATE I,36:
         PRINT "        ":LOCATE I,53:PRINT "         ":LOCATE I,69:PRINT "         "
12840 NEXT I
12850 RETURN
12860 '=========== (Make a System Options and Parameters File) ===============
12870 T17$=STRING$(34," "): FL$="PAR"
12880 GOSUB 13000
12890 GOSUB 12120
12900 LOCATE 1,37:INPUT "",CHO$
12910 IF CHO$="C" THEN PG=1:GOSUB 15830:LOCATE 1,1:PRINT S3$:GOTO 12950
12920 WHILE CHO$="M":PG=1:GOSUB 15830:GOSUB 15710:T$=T$(Z1):COL=COL1:
      ROW=ROW1:GOTO 12960:WEND
12930 IF CHO$="Q" THEN CLEAR:RES=1:GOTO 10010
12940 GOTO 12890
12950 COL=1:Z1=1:ROW=5:T$=T$(1)
12960 COLOR 0,7:LOCATE ROW,COL:PRINT T17$;:LOCATE ROW,COL+1:PRINT T$:COLOR 7,0
12970 GOSUB 12100
12980 GOSUB 14530:GOSUB 13620 :ROW1=ROW:COL1=COL:' SELECT OPTION
12990 IF PG=1 OR PG=2 THEN N=8:GOSUB 13980
13000 IF PG=3 THEN N=8:GOSUB 14210
13010 IF PG=4 THEN N=8:GOSUB 14390
13020 '============(Print Prompts and Templates for Data input} ==============
13040 T$(1)="Live skyline---Uphill----Full":T$(2)="Live skyline---Uphill
----Partial"
13050 T$(3)="Standing-------Uphill----Full":T$(4)="Standing-------Uphill
----Partial"
13060 T$(5)="Multispan------Uphill----Full":T$(6)="Multispan------Uphill
----Partial":T$(7)="Multispan------Downhill--Full"
13070 T$(8)="Highlead-------Uphill"
13080 T$(9)="Running------Uphill------Full":T$(10)="Running------Uphill
------Partial":T$(11)="Running------Downhill----Full":T$(12)="Running
------Downhill----Partial"
13090 T$(13)="Slackline----Uphill------Full":T$(14)="Slackline----Uphill
------Partial":T$(15)="Slackline----Downhill----Full":T$(16)="Slackline
----Downhill----Partial"
13095 :
13100 LOCATE 3,1:PRINT S1$: LOCATE 3,34: PRINT STRING$(11," "):
      LOCATE 3,36:PRINT "OPTIONS"
13110 LOCATE 5,2:PRINT T$(1):LOCATE 6,2:PRINT T$(2)
13120 LOCATE 7,2:PRINT T$(3):LOCATE 8,2:PRINT T$(4)
13130 LOCATE 9,2:PRINT T$(5):LOCATE 10,2:PRINT T$(6):LOCATE 11,2:PRINT T$(7)
13140 LOCATE 12,2:PRINT T$(8)
13150 LOCATE 5,40:PRINT T$(9):LOCATE 6,40:PRINT T$(10):LOCATE 7,40:
      PRINT T$(11):LOCATE 8,40:PRINT T$(12)
13160 LOCATE 9,40:PRINT T$(13):LOCATE 10,40:PRINT T$(14):LOCATE 11,40:
      PRINT T$(15):LOCATE 12,40:PRINT T$(16)
13180 LOCATE 14,1:PRINT S1$:LOCATE 14,35:PRINT STRING$(11," "):
      LOCATE 14,37: PRINT "YARDER"
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13190 LOCATE 15,2:PRINT "CARRIAGE WEIGHT:            lbs"
13200 LOCATE 15,41:PRINT "LINE       SIZE      SWL    lb/ft"
13210 LOCATE 16,11:PRINT "DEPTH :            ft
13220 LOCATE 16,54:PRINT "(in)      (lb) "
13230 LOCATE 17,2:PRINT "CHOKER LENGTH  :            ft"
13240 LOCATE 17,41:PRINT "---------------------------------------"
13250 LOCATE 18,2:PRINT "(OPTIONAL FOR RUNNING SKYLINE)         SKYLINE"
13260 LOCATE 19,2:PRINT "DRUM RADIUS    :            in         MAINLINE"
13270 LOCATE 20,2:PRINT "     WIDTH     :            in         HAULBACK"
13280 LOCATE 21,2:PRINT "     TORQUE    :            lb-in      SLACK"
13290 LOCATE 22,2:PRINT "SKYLINE LENGTH :            ft"
13300 LOCATE 23,1:PRINT S1$;
13310 RETURN
13320 :
13330 P=10:LOCATE 14,1:PRINT S1$:LOCATE 14,25: PRINT STRING$(29," "):
      LOCATE 14,27:PRINT "SPAR LOCATION AND HEIGHT"
13340 LOCATE 15,2:PRINT "LEFT-END T.P.  :"
13350 LOCATE 16,2:PRINT "SPAR HEIGHT    :          ft "
13360 LOCATE 17,2:PRINT "RIGHT-END T.P. :          (OPTIONAL)"
13370 LOCATE 18,2:PRINT "SPAR HEIGHT    :          ft"
13380 LOCATE 20,2:PRINT "T.P. OF EXTERNAL YARDING LIMIT :"
13390 LOCATE 22,2:PRINT "NUMBER OF INTERMEDIATE SUPPORT :"
13400 LOCATE 15,51:PRINT "[INTERMEDIATE SUPPORT]"
13410 LOCATE 16,48:PRINT "NO      T.P.      HEIGHT(ft)"
13420 FOR I=1 TO 5: LOCATE 17+I,48:PRINT I:NEXT I
13430 LOCATE 17,46:PRINT STRING$(33,"-")
13440 RETURN
13450 :
13460 LOCATE 14,1:PRINT S1$:LOCATE 14,34:PRINT STRING$(14," "):
      LOCATE 14,36:PRINT "PARAMETERS"
13470 LOCATE 15,2:PRINT "MINIMUM LOG END CLEARANCE   :          ft"
13480 LOCATE 15,45:PRINT "<---------- for partial suspension"
13490 LOCATE 16,2:PRINT "MINIMUM SKYLINE CLEARANCE   :          ft"
13500 LOCATE 16,45:PRINT "<---------- for full suspension"
13510 LOCATE 17,2:PRINT "AVERAGE LOG LENGTH          :          ft"
13520 LOCATE 18,2:PRINT "LOG-TO-GROUND FRICTION COE. :"
13530 LOCATE 19,2:PRINT "----------------------------------  OPTIONAL
----------------------------------"
13540 LOCATE 20,2:PRINT "LEADING-END-DIAMETER OF LOG :          in"
13550 LOCATE 21,2:PRINT "TRAILING-END-DIAMETER OF LOG:          in"
13560 LOCATE 22,2:PRINT "CHOKING POINT DISTANCE      :          in"
13570 LOCATE 20,47:PRINT "FRICTION COEFFICIENT"
13580 LOCATE 21,47:PRINT "BETWEEN CABLE & JACK   :"
13590 LOCATE 22,47:PRINT "BETWEEN CABLE & GROUND :"
13600 LOCATE 23,1:PRINT S1$
13610 RETURN
13620 '==================== (Select a System Option) ========================
13630 KBD$="":DEF SEG=0:POKE 1050,PEEK(1052):DEF SEG
13640 KBD$="":WHILE KBD$="":KBD$=INKEY$:WEND:KBD=ASC(LEFT$(KBD$,1))
13650 IF FL$="0" THEN 13810
13660 WHILE KBD$=DN$ OR KBD$=UP$ OR KBD=13 OR KBD$=PGDN$
13670   WHILE KBD$=DN$
13680      IF Z1=8 THEN OLDR=ROW:OLDC=COL:ROW=5:COL=39:Z1=9:GOTO 13710
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13690       IF Z1=16 THEN OLDR=ROW:OLDC=COL:ROW=5:COL=1:Z1=1:T$(0)=T$(16):
            GOTO 13710
13700       OLDR=ROW:OLDC=COL:ROW=ROW+1:Z1=Z1+1
13710       GOSUB 13930:GOTO 13630
13720    WEND
13730    WHILE KBD$=UP$
13740       IF Z1=1 THEN OLDR=ROW:OLDC=COL:ROW=12:COL=39:Z1=16:T$(17)=T$(1):
            GOTO 13770
13750       IF Z1=9 THEN OLDR=ROW:OLDC=COL:ROW=12:COL=1:Z1=8:GOTO 13770
13760       OLDR=ROW:OLDC=COL:ROW=ROW-1:Z1=Z1-1
13770       GOSUB 13920:GOTO 13630
13780    WEND
13790    WHILE KBD$=PGDN$ OR KBD=13:C$=RIGHT$(STR$(Z(2)),LEN(STR$(Z(2)))-1):
         PG=2:RETURN:WEND
13800 WEND
13810 WHILE FL$="0"
13820    WHILE KBD$=RIGHTKEY$
13830       OLDC=COL
13840       IF Z=3 THEN OLDC=COL:COL=5:Z=1:GOSUB 13970:GOTO 13630
13850       IF Z=2 THEN COL=57:Z=Z+1:GOSUB 13950:GOTO 13630
13860       IF Z=1 THEN COL=30:Z=Z+1: GOSUB 13950:GOTO 13630
13870    WEND
13880    WHILE KBD=27:CLS:END:WEND
13890    IF KBD=13 THEN RETURN ELSE GOTO 13910
13900 WEND
13910 SOUND 500,2:GOTO 13630
13920 LOCATE OLDR,OLDC:COLOR 7,0:PRINT STRING$(34," "):LOCATE OLDR,OLDC+1:
      PRINT T$(Z1+1): GOTO 13940
13930 LOCATE OLDR,OLDC:COLOR 7,0:PRINT STRING$(34," "):LOCATE OLDR,OLDC+1:
      PRINT T$(Z1-1)
13940 COLOR 0,7:LOCATE ROW,COL:PRINT T17$;:LOCATE ROW,COL+1:PRINT T$(Z1):
      COLOR 7,0: RETURN
13950 LOCATE 5,OLDC:COLOR 7,0:PRINT STRING$(22," "):LOCATE 5,OLDC+1:
      PRINT M$(Z-1)
13960 COLOR 0,7:LOCATE 5,COL:PRINT STRING$(22," ");:LOCATE 5,COL+1:
      PRINT M$(Z):COLOR 7,0:RETURN
13970 LOCATE 5,OLDC:COLOR 7,0:PRINT STRING$(22," "):LOCATE 5,OLDC+1:
      PRINT M$(3):GOTO 13960
13980 '======================  {Enter Parameters} ==========================
13990 :
14000 C$=RIGHT$(STR$(Z(2)),LEN(STR$(Z(2)))-1)
14010 PT=2:RO=15:CO=21:MAXCHR=5:N$="":NCHR=0:GOSUB 15030
14020 PT=3:RO=16:CO=21:MAXCHR=3:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14010
14030 PT=4:RO=17:CO=21:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14020
14040 PT=5:RO=18:CO=54:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14030
14050 PT=6:RO=18:CO=63:MAXCHR=6:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14040
14060 PT=7:RO=18:CO=73:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14050
14070 PT=8:RO=19:CO=54:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14060
14080 PT=9:RO=19:CO=63:MAXCHR=6:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
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      GOTO 14070
14090 PT=10:RO=19:CO=73:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14080
14100 PT=11:RO=20:CO=54:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14090
14110 PT=12:RO=20:CO=63:MAXCHR=6:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14100

14120 PT=13:RO=20:CO=73:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14110
14130 PT=14:RO=21:CO=54:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14120
14140 PT=15:RO=21:CO=63:MAXCHR=6:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14130
14150 PT=16:RO=21:CO=73:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14140
14160 PT=17:RO=19:CO=21:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14150
14170 PT=18:RO=20:CO=21:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14160
14180 PT=19:RO=21:CO=21:MAXCHR=7:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14170
14190 PT=20:RO=22:CO=21:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14180
14200 :
14210 PT=21:RO=15:CO=19:LOCATE RO,CO:PRINT "0"
14220 C$=RIGHT$(STR$(Z(22)),LEN(STR$(Z(22)))-1)
14230 PT=22:RO=16:CO=19:MAXCHR=3:N$="":NCHR=0:GOSUB 15030
14240 PT=23:RO=17:CO=19:MAXCHR=2:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14230
14250 PT=24:RO=18:CO=19:MAXCHR=3:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14240
14260 PT=25:RO=20:CO=36:MAXCHR=2:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14250
14270 PT=26:RO=22:CO=36:MAXCHR=1:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14260
14280 PT=27:RO=18:CO=57:MAXCHR=2:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14270
14290 PT=28:RO=18:CO=67:MAXCHR=3:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14280
14300 PT=29:RO=19:CO=57:MAXCHR=2:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14290
14310 PT=30:RO=19:CO=67:MAXCHR=3:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14300
14320 PT=31:RO=20:CO=57:MAXCHR=2:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14310
14330 PT=32:RO=20:CO=67:MAXCHR=3:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14320
14340 PT=33:RO=21:CO=57:MAXCHR=2:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14330
14350 PT=34:RO=21:CO=67:MAXCHR=3:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14340
14360 PT=35:RO=22:CO=57:MAXCHR=2:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
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      GOTO 14350
14370 PT=36:RO=22:CO=67:MAXCHR=3:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14360
14380 :
14390 C$=RIGHT$(STR$(Z(37)),LEN(STR$(Z(37)))-1)
14400 PT=37:RO=15:CO=32:MAXCHR=4:N$="":NCHR=0:GOSUB 15030
14410 PT=38:RO=16:CO=32:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14400
14420 PT=39:RO=17:CO=32:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14410
14430 PT=40:RO=18:CO=32:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14420
14440 PT=41:RO=20:CO=32:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14430
14450 PT=42:RO=21:CO=32:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14440
14460 PT=43:RO=22:CO=32:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14450
14470 PT=44:RO=21:CO=72:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14460
14480 PT=45:RO=22:CO=72:MAXCHR=4:N$="":NCHR=0:GOSUB 15030:IF U=1 THEN U=0:
      GOTO 14470
14490 RETURN
14500 '======================= {Print Parameters} ===========================
14510 :
14520 ROW=ROW1:COL=COL1:GOTO 12950:RETURN
14530 :
14540 PT=2:GOSUB 15590:LOCATE 15,21:PRINT D$
14550 PT=3:GOSUB 15590:LOCATE 16,21:PRINT D$
14560 PT=4:GOSUB 15590:LOCATE 17,21:PRINT D$
14570 PT=5:GOSUB 15590:LOCATE 18,54:PRINT D$
14580 PT=6:GOSUB 15590:LOCATE 18,63:PRINT D$
14590 PT=7:GOSUB 15590:LOCATE 18,73:PRINT D$
14600 PT=8:GOSUB 15590:LOCATE 19,54:PRINT D$
14610 PT=9:GOSUB 15590:LOCATE 19,63:PRINT D$
14620 PT=10:GOSUB 15590:LOCATE 19,73:PRINT D$
14630 PT=11:GOSUB 15590:LOCATE 20,54:PRINT D$
14640 PT=12:GOSUB 15590:LOCATE 20,63:PRINT D$
14650 PT=13:GOSUB 15590:LOCATE 20,73:PRINT D$
14660 PT=14:GOSUB 15590:LOCATE 21,54:PRINT D$
14670 PT=15:GOSUB 15590:LOCATE 21,63:PRINT D$
14680 PT=16:GOSUB 15590:LOCATE 21,73:PRINT D$
14690 PT=17:GOSUB 15590:LOCATE 19,21:PRINT D$
14700 PT=18:GOSUB 15590:LOCATE 20,21:PRINT D$
14710 PT=19:GOSUB 15590:LOCATE 21,21:PRINT D$
14720 PT=20:GOSUB 15590:LOCATE 22,21:PRINT D$
14730 RETURN
14740 :
14750 PT=21:GOSUB 15590:LOCATE 15,19:PRINT D$
14760 PT=22:GOSUB 15590:LOCATE 16,19:PRINT D$
14770 PT=23:GOSUB 15590:LOCATE 17,19:PRINT D$
14780 PT=24:GOSUB 15590:LOCATE 18,19:PRINT D$
14790 PT=25:GOSUB 15590:LOCATE 20,36:PRINT D$
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14800 PT=26:GOSUB 15590:LOCATE 22,36:PRINT D$
14810 PT=27:GOSUB 15590:LOCATE 18,57:PRINT D$
14820 PT=28:GOSUB 15590:LOCATE 18,67:PRINT D$
14830 PT=29:GOSUB 15590:LOCATE 19,57:PRINT D$
14840 PT=30:GOSUB 15590:LOCATE 19,67:PRINT D$
14850 PT=31:GOSUB 15590:LOCATE 20,57:PRINT D$
14860 PT=32:GOSUB 15590:LOCATE 20,67:PRINT D$
14870 PT=33:GOSUB 15590:LOCATE 21,57:PRINT D$
14880 PT=34:GOSUB 15590:LOCATE 21,67:PRINT D$
14890 PT=35:GOSUB 15590:LOCATE 22,57:PRINT D$
14900 PT=36:GOSUB 15590:LOCATE 22,67:PRINT D$
14910 RETURN
14920 :
14930 PT=37:GOSUB 15590:LOCATE 15,32:PRINT D$
14940 PT=38:GOSUB 15590:LOCATE 16,32:PRINT D$
14950 PT=39:GOSUB 15590:LOCATE 17,32:PRINT D$
14960 PT=40:GOSUB 15590:LOCATE 18,32:PRINT D$
14970 PT=41:GOSUB 15590:LOCATE 20,32:PRINT D$
14980 PT=42:GOSUB 15590:LOCATE 21,32:PRINT D$
14990 PT=43:GOSUB 15590:LOCATE 22,32:PRINT D$
15000 PT=44:GOSUB 15590:LOCATE 21,72:PRINT D$
15010 PT=45:GOSUB 15590:LOCATE 22,72:PRINT D$
15020 RETURN
15030 '=================== (Enter Data for Parameters) =====================
15040 COL=CO:ROW=RO
15050 COLOR 7,0:LOCATE ROW,COL:COLOR 0,7:FOR I=1 TO N:PRINT " ";:NEXT I:
      COLOR 7,0
15060 IF C$="0" THEN 15080
15070 COLOR 0,7:LOCATE ROW,COL:PRINT C$:COLOR 7,0
15080 KBD$="":DEF SEG=0:POKE 1050,PEEK(1052):DEF SEG
15090 LOCATE RO,CO:KBD$="":WHILE KBD$="":KBD$=INKEY$:WEND:
      KBD=ASC(LEFT$(KBD$,1)):COLOR 7,0
15100 WHILE (KBD>44 AND KBD<58) OR (KBD=8)
15110    WHILE KBD=8
15120       NN=0:NCHR=NCHR-1:IF NCHR<0 THEN NCHR=0:GOTO 15560
15130       IF NCHR=0 THEN N$="" ELSE N$=LEFT$(N$,NCHR)
15140       COL=COL-1:LOCATE ROW,COL:COLOR 0,7:PRINT " ":LOCATE ROW,COL:
            COLOR 7,0
15150       GOTO 15080
15160    WEND
15170    NCHR=NCHR+1:IF NCHR>MAXCHR THEN NCHR=MAXCHR:NN=1:GOTO 15560
         ELSE COL=COL+1
15180    N$=N$+KBD$:IF N$=KBD$ THEN COLOR 0,7:LOCATE RO,CO:
         FOR I=1 TO N:PRINT " ";:NEXT I:COL=CO+1
15190    LOCATE ROW,COL-1:COLOR 0,7:PRINT KBD$:COLOR 7,0
15200    GOTO 15080
15210 WEND
15220 IF N$="" AND C$<>"0" THEN N$=C$
15230 WHILE KBD=13 OR KBD$=DN$ OR KBD$=UP$ OR KBD$=HOME$ OR
         (KBD$=PGUP$ AND PG>1) OR (KBD$=PGDN$ AND PG<4) OR KBD=27
15240    N=8:LOCATE RO,CO:COLOR 7,0:FOR I=1 TO N:PRINT " ";:NEXT I:
         LOCATE RO,CO:PRINT N$ : Z(PT)=VAL(N$)
15250    WHILE KBD$=DN$ OR KBD=13
```

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15260       IF PT=20 THEN C$=RIGHT$(STR$(Z(2)),LEN(STR$(Z(2)))-1):GOTO 14000
15270       IF PT=36 THEN C$=RIGHT$(STR$(Z(22)),LEN(STR$(Z(22)))-1):GOTO 14220
15280       IF PT=45 THEN C$=RIGHT$(STR$(Z(37)),LEN(STR$(Z(37)))-1):GOTO 14390
15290       C$=RIGHT$(STR$(Z(PT+1)),LEN(STR$(Z(PT+1)))-1):RETURN
15300    WEND
15310    WHILE KBD$=UP$
15320       IF PT=2 THEN C$=RIGHT$(STR$(Z(20)),LEN(STR$(Z(20)))-1):GOTO 14190
15330       IF PT=22 THEN C$=RIGHT$(STR$(Z(36)),LEN(STR$(Z(36)))-1):GOTO 14370
15340       IF PT=37 THEN C$=RIGHT$(STR$(Z(45)),LEN(STR$(Z(45)))-1):GOTO 14480
15350       C$=RIGHT$(STR$(Z(PT-1)),LEN(STR$(Z(PT-1)))-1):U=1:RETURN
15360 WEND
15370    WHILE KBD$=HOME$
15380       COL=COL1:ROW=ROW1
15390       IF PG=2 THEN 12970 ELSE GOSUB 15570:GOSUB 13180:GOSUB 14540:
            GOTO 12970
15400    WEND
15410    WHILE KBD$=PGDN$
15420       IF PG=2 THEN PG=3:GOSUB 15570:GOSUB 13320:GOSUB 14750:GOTO 14210
15430       IF PG=3 THEN PG=4:GOSUB 15570:GOSUB 13460:GOSUB 14930:GOTO 14390
15440       IF PG=4 THEN 15560
15450    WEND
15460    WHILE KBD$=PGUP$
15470       IF PG=2 THEN KBD$=HOME$:GOTO 15370
15480       IF PG=3 THEN PG=2:GOSUB 15570:GOSUB 13170:GOSUB 14540:GOTO 14000
15490       IF PG=4 THEN PG=3:GOSUB 15570:GOSUB 13320:GOSUB 14750:GOTO 14210
15500    WEND
15510    WHILE KBD=27:LOCATE 25,1:PRINT S3$;:GOSUB 12000
15520       IF AN$="S" THEN GOTO 30220 ELSE CLS:GOTO 12860
15530       GOSUB 15620: CLS:GOTO 12860
15540    WEND
15550 WEND
15560 SOUND 500,2: GOTO 15080
15570 :
15580 FOR I=15 TO 22:LOCATE I,1:PRINT S3$:NEXT I:RETURN
15590 D$=RIGHT$(STR$(Z(PT)),LEN(STR$(Z(PT)))-1)
15600 IF D$="0" THEN D$=""
15610 RETURN
15620 '=============== {Make a Parameters and Options File} ==================
15630 NO=1
15640 OPEN NAM$ FOR OUTPUT AS #1
15650 WRITE #1,COL1;ROW1;Z1
15660 NO=NO+1: IF NO>45 THEN 15690
15670 WRITE #1,Z(NO)
15680 GOTO 15660
15690 CLOSE #1
15700 RETURN
15710 '============={Retrieve a Parameters and Options File} =================
15720 NO=1
15730 GOSUB 12390
15740 OPEN NAM$ FOR INPUT AS #2
15750 INPUT #2, COL1, ROW1, Z1
15760 NO=NO+1
15770 INPUT #2, Z(NO)
```

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15780 IF EOF(2) THEN 15800
15790 GOTO 15760
15800 CLOSE #2
15810 GOSUB 14540
15820 RETURN
15830 '=================== {Clear Arrays and Variables} ======================
15840 D$="":COL1=0:ROW1=0:Z1=0
15850 ERASE SD,VD,HD,PS,Z
15860 RETURN


20000 '========================================================================
20002 '                          ANALYSIS PROGRAMS
20004 '========================================================================
20005 :
20008 DIM X(40), Y(40), S(40), A(40), XXIS(40), XIS(6),YIS(6),TU1(6),
TPIS(6),IS(6),NOTP(10),CL(6,10),DD(6),HH(6),SS(6),LSMIN(6),YY(6,10),
AA(6,10),DL(6,10)
20010 DIM DR(6,10),LS(6),H1(6,10),H3(6,10),H2(6,10),TU(6),TUF(6,10),
      CT(6),CS(6),PLMIN(6),PLTP(10),CPL(6),TS(6)
20020 DIM D3(6,10), HCOMP(6), VLCOMP(6), VUCOMP(6), HREACT(40,6),
      VREACT(40,6), ANGLE(40,6), LIFT(30),MAXPL(30),LEC(40),TH(30),CLR(40)
20030 DIM PL(40),TA1(40),TA3(40),TA4(40),TA5(50),ALPHA(40),BETA(40),WARN(40)
20032 AE=3500000*W1
20035 '====================== {Specify Data Files} ==========================
20040 GOSUB 24400
20050 GOSUB 24610
20070 ON SYST GOTO 21550, 22050, 22920, 22520, 20780, 20110
20090 '================== {Main Program of Slackline Option} =================
20110 CLS:GOSUB 29280:LOCATE 2,31:PRINT "SLACKLINE ANALYSIS"
20120 GOSUB 29370
20140 SPAN=X(TP2)-X(TP1): YHT=Y(TP1)+HS1-Y(TP2)-HS2
20150 FOR I=1 TO TP2-1
20160    TA=TA1: T3=TA3: T4=TA5: ITER1=0: ITER2=0
20170    IF I>EYL THEN 20720
20180    IF FP=0 THEN 20230
20190    DS=I:GOSUB 30110
20200    XSIN=LEC*COS(THETA)/L: BETA=ATN(XSIN/SQR(1-XSIN^2))
20210    GOSUB 25900     :REM CALC ALPHA
20220    CL=(L*SIN(BETA)+LC*SIN(ALPHA-THETA))/COS(THETA)+CDP
20230    DL=X(I)-X(TP1): DR=X(TP2)-X(I)
20240    HL=Y(TP1)+HS1-Y(I)-CL: HR=YHT-HL
20250    D4=DR: H4=HR: D3=DL: H3=HL
20260 :
20270    TU=TA: D=DL: H=HL: W=W1: GOSUB 25680
20280    H1L=HC: V1L=VL: T1L=SQR(H1L^2+V1L^2)
20290    IF HR<0 THEN TU2=T1L+W1*ABS(HR) ELSE TU2=T1L
20300    TU=TU2
20310    H=ABS(HR): D=DR: W=W1: GOSUB 25680
20320    H2L=HC: IF HR<0 THEN V2=VL ELSE V2=-VL-R
20330    IF ITER1>0 THEN H4L=0: V4=0: GOTO 20400
20340 :
20350    IF UD=0 AND HR<0 THEN TU=T4-W4*YHT : W=W4
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20360    IF UD=0 AND HR>0 THEN TU=T4-W4*HL  : W=W4
20370    IF UD=1 THEN TU=T3: W=W2
20380    H=ABS(H4): D=D4: GOSUB 25680
20390    H4L=HC: IF HR>0 THEN V4=-VL-R ELSE V4=VL
20400    IF UD=1 THEN W=W4 ELSE W=W2
20410    R3=W*SQR(H3^2+D3^2)
20420    IF FP=0 THEN H3L=H2L+H4L-H1L: GOTO 20490
20430    WHILE FP=1
20440       IF (UD=0 AND A(I+1)>0 AND MY<A(I+1)/100) OR (UD=1 AND ((A(I+1)>0)
            OR (A(I+1)<0 AND MY>(-A(I+1)/100)))) THEN ALPHA=-ABS(ALPHA)
20450       HH1=TAN(ALPHA)*(H1L-H2L-H4L)-(V1L+V2+V4-CWT)+R3/2
20460       HH2=H3/D3-TAN(ALPHA):GOTO 20480
20470    WEND
20480    H3L=HH1/HH2
20490    V3L=H3L*(H3/D3)-R3/2: V3U=V3L+R3
20500    TU3=SQR(H3L^2+V3U^2)
20510    IF ITER1>0 OR ITER2>0 OR (H4L=0 AND V4=0) THEN 20560
20520    IF UD=0 AND TU3<TA3 THEN 20690
20530    IF UD=0 AND TU3>TA3 THEN H4L=0: V4=0: GOTO 20410
20540    IF UD=1 AND TU3<TA5 THEN 20690
20550    IF UD=1 AND TU3>TA5 THEN H4L=0: V4=0: GOTO 20410
20560    IF AD=1 THEN 20620
20570    IF AD=4 THEN 20660
20580    IF UD=0 AND TU3<TA3 THEN AD=4: GOTO 20660
20590    IF UD=0 AND TU3>TA3 THEN AD=1: T4=0: GOTO 20620
20600    IF UD=1 AND TU3<TA5 THEN AD=4: GOTO 20660
20610    IF UD=1 AND TU3>TA5 THEN AD=1: T3=0: GOTO 20620
20620    IF UD=0 AND ITER1>0 THEN 28250
20630    IF UD=1 AND ITER1>0 THEN 28350
20640    IF UD=0 AND TU3>TA3 THEN 28250
20650    IF UD=1 AND TU3>TA5 THEN 28350
20660    IF UD=0 AND ITER2>=0 THEN 28450
20670    IF UD=1 AND ITER2>=0 THEN 28550
20680    AD=0
20690    GOSUB 28750
20700    PL(I)=PL:CLR(I)=CL:LEC(I)=L*SIN(BETA)/COS(THETA):TA1(I)=TA
20710    IF UD=0 THEN TA3(I)=TU3:TA5(I)=T4 ELSE TA3(I)=T3:TA5(I)=TU3
20720 NEXT I
20730 GOSUB 29380:GOSUB 29400:GOSUB 29420
20740 GOSUB 29600:CLEAR:RES=1:GOTO 10010
20760 '=============== (Main Program of Running Skyline Option) ==============
20780 CLS
20790 GOSUB 29280
20800 LOCATE 2,31:PRINT "RUNNING SKYLINE"
20810 GOSUB 29370
20820 SPAN=X(TP2)-X(TP1): YHT=Y(TP1)+HS1-Y(TP2)-HS2
20830 FOR I=1 TO TP2-1
20840    TA=TA4: ITER1=0
20850    IF I>EYL THEN 21480
20860    IF FP=0 THEN 20910
20870    DS=I: GOSUB 30110
20880    XSIN=LEC*COS(THETA)/L: BETA=ATN(XSIN/SQR(1-XSIN^2))
20890    GOSUB 25900
```

```
20900   CL=(L*SIN(BETA)+LC*SIN(ALPHA-THETA))/COS(THETA)+CDP
20910   DL=X(I)-X(TP1): DR=X(TP2)-X(I)
20920   HL=Y(TP1)+HS1-Y(I)-CL: HR=YHT-HL
20930   D4=DR: H4=ABS(HR): D3=DL: H3=HL
20940   IF TORQ=0 OR RAD=0 OR WID=0 OR LLINE=0 THEN 21030
20950   IF OPT=9 OR OPT=10 THEN LSL=SQR(HL^2+DL^2)+2*SQR(HR^2+DR^2)
20960   IF OPT=11 OR OPT=12 THEN LSL=2*SQR(HL^2+DL^2)+SQR(HR^2+DR^2)
20970   LOB=LLINE-LSL
20980   NWRAP=(-RAD+SQR(RAD^2+DIAH^2*LOB/.2618/WID))/DIAH
20990   ERAD=RAD+NWRAP*DIAS
21000   TA=TORQ/ERAD
21010   IF TA>TA4 THEN TA=TA4
21020 :
21030   TU=TA: D=DL: H=HL: W=W3: GOSUB 25680
21040   H1L=HC: V1L=VL: V1U=VU: T1L=SQR(H1L^2+V1L^2)
21050   IF HR<0 THEN TU2=T1L+W3*ABS(HR) ELSE TU2=T1L
21060   TU=TU2
21070   H=ABS(HR): D=DR: W=W3: GOSUB 25680
21080   H2L=HC: IF HR<0 THEN V2=VL:V2U=VL+R ELSE V2=-VL-R: V2U=VL
21090   IF UD=0 THEN H4L=H2L: V4=V2 ELSE H3L=H1L: V3L=V1L:
        V3U=V1L+W3*SQR(D3^2+H3^2)
21100   WHILE UD=0
21110      R3=W2*SQR(H3^2+D3^2)
21120      IF FP=0 THEN H3L=H2L+H4L-H1L:GOTO 21190
21130      WHILE FP=1
21140          IF A(DS+1)>0 AND MY<(A(DS+1)/100) THEN ALPHA=-ABS(ALPHA)
21150          HH1=TAN(ALPHA)*(H1L-H2L-H4L)-(V1L+V2+V4-CWT)+R3/2
21160          HH2=H3/D3-TAN(ALPHA):GOTO 21180
21170      WEND
21180      H3L=HH1/HH2
21190      V3L=H3L*H3/D3-R3/2:V3U=V3L+R3:TT=SQR(H3L^2+V3U^2):GOTO 21340
21200   WEND
21210   WHILE UD=1
21220      R4=W2*SQR(D4^2+H4^2)
21230      IF FP=0 THEN H4L=H1L+H3L-H2L:GOTO 21300
21240      WHILE FP=1
21250         IF A(DS+1)<0 THEN ALPHA=-ABS(ALPHA)
21260         HH1=TAN(ALPHA)*(H2L-H1L-H3L)-(V1L+V2+V3L-CWT)+R4/2
21270         HH2=H4/D4-TAN(ALPHA):GOTO 21290
21280      WEND
21290      H4L=HH1/HH2
21300      V4=H4L*(H4/D4)-R4/2:V4U=V4+R4:V4L=V4
21310      IF HR>0 THEN V4=-V4U
21320      TT=SQR(H4L^2+V4U^2):GOTO 21340
21330   WEND
21340   IF ITER1>0 THEN 28650
21350   IF TT>TA3 THEN 28650
21360   GOSUB 28750
21370   WHILE UD=0
21380      HREACT(I,0)=H1L+H3L:VREACT(I,0)=V1U+V3U:
           ANGLE(I,0)=ATN(VREACT(I,0)/HREACT(I,0))
21390      HREACT(I,1)=2*H2L: VREACT(I,1)=2*V2U
21400      ANGLE(I,1)=ATN(VREACT(I,1)/HREACT(I,1)):GOTO 21470
```

```
21410    WEND
21420    WHILE UD=1
21430       HREACT(I,0)=H1L+H3L:VREACT(I,0)=V1U+V3U:
           ANGLE(I,0)=ATN(VREACT(I,0)/HREACT(I,0)):HREACT(I,1)=H2L+H4L
21440       IF HR<0 THEN VREACT(I,1)=V2U+V4U ELSE VREACT(I,1)=V2U+V4L
21450       ANGLE(I,1)=ATN(VREACT(I,1)/HREACT(I,1)):GOTO 21470
21460    WEND
21470    TA4(I)=TA:TA3(I)=TT: PL(I)=PL: LEC(I)=L*SIN(BETA)/COS(THETA):
         CLR(I)=CL
21480 NEXT I
21490 GOSUB 29380:GOSUB 29400:GOSUB 29420
21500 GOSUB 29600:GOSUB 29660:GOSUB 29640:GOSUB 29670
21510 GOSUB 29600:CLEAR:RES=1:GOTO 10010
21530 '================ {Main Program of Live Skyline Option} ================
21550 CLS:GOSUB 29280:LOCATE 2,29:PRINT "LIVE SKYLINE ANALYSIS"
21560 GOSUB 29370
21570 SPAN=X(TP2)-X(TP1): YHT=Y(TP1)+HS1-Y(TP2)-HS2: TA=TA1
21580 FOR I=1 TO TP2-1
21590    IF I>EYL THEN 21680
21600    IF FP=0 THEN 21650
21610    DS=I:GOSUB 30110
21620    XSIN=LEC*COS(THETA)/L: BETA=ATN(XSIN/SQR(1-XSIN^2))
21630    GOSUB 25900
21640    CL=(L*SIN(BETA)+LC*SIN(ALPHA-THETA))/COS(THETA)+CDP
21650    DL=X(I)-X(TP1): DR=X(TP2)-X(I)
21660    HL=Y(TP1)+HS1-Y(I)-CL: HR=Y(TP2)+HS2-Y(I)-CL
21670    S(I)=SQR(DL^2+HL^2)+SQR(DR^2+HR^2)
21680 NEXT I
21690 FOR I=1 TO TP2-1
21700    PLMIN=999999!: LIFT(I)=0
21710    FOR J=I TO 1 STEP -1
21720       IF J=I THEN SL=S(J): GOTO 21740
21730       IF S(J)<=SL THEN SL=S(J): LIFT(I)=LIFT(I)+1
21740       DL=X(J)-X(TP1): DR=X(TP2)-X(J): D3=DL
21750       D1=DL: LL=SPAN: S=SL:TA=TA1
21760       GOSUB 25990
21770       HL=H: HR=YHT-H: H3=HL: Y0=Y(J)
21780       GOSUB 25050
21790       WHILE PLMIN>PL
21800          PLMIN=PL:CLR(I)=CLC+CDP:LEC(I)=L*SIN(BETA)/COS(THETA):
               TA1(I)=TA:TA3(I)=TU3
21810          HREACT(I,0)=H1L+H3L:VREACT(I,0)=V1U+V3U:
               ANGLE(I,0)=ATN(VREACT(I,0)/HREACT(I,0))
21820          HREACT(I,1)=H2L:VREACT(I,1)=V2L:
               ANGLE(I,1)=ATN(VREACT(I,1)/HREACT(I,1))
21830          GOTO 21850
21840       WEND
21850    NEXT J
21860    PL(I)=PLMIN
21870 NEXT I
21880  :
21890 GOSUB 29380
21900 LOCATE 2,3:PRINT "=LIFT="
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21910 LOCATE 5,16:PRINT "PICK-UP T.P.   LINE LENGTH    NUMBER OF LIFTS"
21920 LOCATE 6,5:PRINT STRING$(69,"-"):PR=6
21930 FOR K=1 TO TP2-1
21940    PR=PR+1:IF PR=22 THEN PR=7:GOSUB 29600:GOSUB 29640
21950    LOCATE PR,22:PRINT K
21960    LOCATE PR,33:PRINT USING "####.#";S(K):LOCATE PR,53:PRINT LIFT(K)
21970 NEXT K
21980 GOSUB 29600:LOCATE 5,1:PRINT S3$:LOCATE 6,1:PRINT S3$
21990 GOSUB 29640:GOSUB 29400:GOSUB 29420
22000 GOSUB 29600:GOSUB 29660:GOSUB 29640:GOSUB 29670
22010 GOSUB 29600:CLEAR:RES=1:GOTO 10010
22030 '============= {Main Program of Standing Skyline Option} ===============
22050 CLS:GOSUB 29280:LOCATE 2,28:PRINT "STANDING SKYLINE ANALYSIS"
22060 GOSUB 29290:GOSUB 29370
22070 SPAN=X(TP2)-X(TP1): YHT=Y(TP1)+HS1-Y(TP2)-HS2
22080 IF OPT%=7 THEN PHASE$="ON"
22090 SMIN=10^9
22100 FOR K=1 TO TP2-1
22110    IF K>EYL THEN 22210
22120    IF FP=0 THEN 22170
22130    THETA=ATN(-A(K+1)/100)
22140    XSIN=LEC*COS(THETA)/L: BETA=ATN(XSIN/SQR(1-XSIN^2))
22150    GOSUB 25900
22160    CL=(L*SIN(BETA)+LC*SIN(ALPHA-THETA))/COS(THETA)+CDP
22170    DL=X(K)-X(TP1): DR=X(TP2)-DL: D3=DL
22180    HL=Y(TP1)+HS1-Y(K)-CL :HR=YHT-HL: H3=HL
22190    S=SQR(HL^2+DL^2)+SQR(HR^2+DR^2)
22200    IF S<SMIN THEN SMIN=S : XSMIN=DL: PSMIN=XSMIN/SPAN : MINTP=K
22210 NEXT K
22220 TAVE=TA1-.5*W1*YHT
22230 SO=SMIN/(1+TAVE/AE)
22240 FOR I=1 TO TP2-1
22250    TA=TA1
22260    DL=X(I):DR=SPAN-DL:D3=DL
22270    D1=DL:S=SMIN:LL=SPAN
22280    GOSUB 25990
22290    HL=H: HR=YHT-HL: H3=HL: YO=Y(I)
22300    GOSUB 25050
22310    HREACT(I,0)=H1L+H3L:VREACT(I,0)=V1U+V3U
22320    HREACT(I,1)=H2L:VREACT(I,1)=ABS(V2L)
22330    ANGLE(I,0)=ATN(HREACT(I,0)/VREACT(I,0)):
         ANGLE(I,1)=ATN(HREACT(I,1)/VREACT(I,1))
22340    IF OPT%=7 THEN 26240
22350    PL(I)=PL:CLR(I)=CLC+CDP:TA3(I)=TU3:LEC(I)=L*SIN(BETA)/COS(THETA):
         TA1(I)=TA
22360 NEXT I
22370 IF OPT%=7 THEN 22460
22380 GOSUB 28060
22390 LOCATE 7,17:PRINT "UNLOADED SKYLINE TENSION REQUIRED     :          lbs
22400 LOCATE 7,58:PRINT USING "#####.#";TUU
22410 LOCATE 8,17:PRINT "UNLOADED SKYLINE LENGTH REQUIRED      :          ft
22420 LOCATE 8,58:PRINT USING "#####.#";SMIN;
22430 LOCATE 9,17:PRINT "UNSTRETCHED SKYLINE LENGTH            :          ft
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22440 LOCATE 9,58:PRINT USING "#####.#";SO
22450 GOSUB 29380:GOSUB 29600:GOSUB 29640
22460 GOSUB 29380:GOSUB 29400:GOSUB 29420
22470 GOSUB 29600:GOSUB 29660:GOSUB 29640:GOSUB 29670
22480 GOSUB 29600:CLEAR:RES=1:GOTO 10010
22500 '================ (Main Program of Highlead Option) ====================
22520 CLS:GOSUB 29280:LOCATE 2,31:PRINT "HIGHLEAD ANALYSIS"
22530 LOCATE 5,10: PRINT "INPUT HAULBACK TENSION ;"
22540 LOCATE 7,30:PRINT "T.P.":LOCATE 7,37:PRINT "TENSION"
22550 LOCATE 8,28:PRINT STRING$(16,"-")
22560 DIM GCTP1(40),GCTP2(40),GCA1(40),GCA2(40),GCA3(40)
22570 FOR I=1 TO TP2-1
22580    IF I>EYL THEN 22610
22590    LOCATE 8+I,32: PRINT USING "##";I
22600    LOCATE 8+I,38: INPUT "",TH(I)
22610 NEXT I
22620 SPAN=X(TP2)-X(TP1):YHT=Y(TP1)+HS1-Y(TP2)-HS2: TM=TA3
22630 LOCATE 5,1:PRINT S3$:GOSUB 29640:LOCATE 22,1:PRINT S3$
22640 GOSUB 29370
22650 FOR I=1 TO TP2-1
22660    IF I>EYL THEN 22850
22670    CL=LC: GOSUB 28830
22680    CL1=CL: ZCL1=ZCL
22690    CL=CL1*1.2: GOSUB 28830
22700    CL2=CL: ZCL2=ZCL
22710    MCL=(ZCL1-ZCL2)/(CL1-CL2)
22720    OLDCL=CL1:OLDZ=ZCL1:CL1=CL2: ZCL1=ZCL2
22730    CL2=CL2-ZCL2/MCL
22740    IF (OLDCL*CL1<0) AND ((CL2>OLDCL AND CL2>CL1) OR
         (CL2<OLDCL AND CL2<CL1)) THEN CL2=(OLDCL+CL1)/2
22750    CL=CL2: GOSUB 28830
22760    ZCL2=ZCL
22770    IF ABS(ZCL)>.001 THEN 22710
22780    IF CL<0 THEN ALPHA=THETA: CL=0: GOSUB 28880
22790    NN=WH/(SIN(THETA)+MY*COS(THETA))
22800    PL=WV+NN*(COS(THETA)-MY*SIN(THETA))
22810    HREACT(I,0)=H1L:HREACT(I,1)=H2L:VREACT(I,0)=V1U:
         VREACT(I,1)=V2U:ANGLE(I,0)=ATN(VREACT(I,0)/HREACT(I,0))
22820    IF HREACT(I,1)<>0 THEN ANGLE(I,1)=ATN(VREACT(I,1)/HREACT(I,1))
22830    H1L=0:H2L=0:V1U=0:V2U=0
22840    PL(I)=PL:CLR(I)=CL:LEC(I)=L*SIN(BETA)/COS(THETA):TA3(I)=TM:
         TA4(I)=TH(I)
22850 NEXT I
22860 GOSUB 29380:GOSUB 29400:GOSUB 29420:GOSUB 29600:GOSUB 29660
22870 GOSUB 29640:GOSUB 29670
22880 GOSUB 29600:CLEAR:RES=1:GOTO 10010
22900 '================ (Main Program of Multispan Option) ===================
22920 CLS
22930 GOSUB 29280
22940 LOCATE 2,31:PRINT "MULTISPAN ANALYSIS"
22950 GOSUB 29290: GOSUB 29370
22960 IF SYST=3 AND LP$<>"L" THEN FRICTION=1 ELSE FRICTION=0
22970 TPIS(1)=TPIS1: TPIS(2)=TPIS2: TPIS(3)=TPIS3:
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      TPIS(4)=TPIS4: TPIS(5)=TPIS5
22980 IS(1)=IS1: IS(2)=IS2: IS(3)=IS3: IS(4)=IS4: IS(5)=IS5
22990 FOR J=1 TO NOFI
23000    TPIS=TPIS(J):IS=IS(J)
23010    XXIS(TPIS)=X(TPIS)
23020    XIS(J)=XXIS(TPIS)
23030    YIS(J)=Y(TPIS)+IS
23040    NOTP(J)=(TPIS-1)-TPISOLD
23050    IF J=NOFI THEN NOTP(J+1)=(TP2-1)-TPIS
23060    TPISOLD=TPIS
23070 NEXT J
23080 IF FP=0 THEN 23210
23090 :
23100 FOR II=1 TO NOFI+1
23110    FOR KK=1 TO NOTP(II)
23120       BB=BB+1
23130       THETA=ATN(-A(BB+1)/100)
23140       XSIN=LEC*COS(THETA)/L: BETA=ATN(XSIN/SQR(1-XSIN^2))
23150       GOSUB 25900  :REM  CALCULATE ALPHA
23160       CL(II,KK)=(L*SIN(BETA)+LC*SIN(ALPHA-THETA))/COS(THETA)+CDP
23170       IF KK=NOTP(II) THEN BB=BB+1
23180    NEXT KK
23190 NEXT II
23200 BB=0
23210 :
23220 YIS(0)=Y(0)+HS1: NOFI1=NOFI+1
23230 YIS(NOFI1)=Y(TP2)+HS2
23240 XIS(NOFI1)=X(TP2)
23250 SMIN=10^10
23260 :
23270 IF FRICTION=1 THEN GOSUB 26370: GOTO 23410
23280 TU1(0)=TA1 :SUMSS=0
23290 FOR J=1 TO NOFI1
23300    J1=J-1
23310    DD(J)=XIS(J)-XIS(J1)
23320    HH(J)=YIS(J1)-YIS(J)
23330    D=DD(J) : H=HH(J)
23340    TU1(J)=TU1(J1)-W1*HH(J1): TU=TU1(J) : W=W1
23350    GOSUB 25480
23360    SS(J)=S
23370    SUMSS=SUMSS+SS(J)
23380 HCOMP(J)=HC : VLCOMP(J)=VL : VUCOMP(J)=VLCOMP(J)+SS(J)*W1
23390 NEXT J
23400 :
23410 A=0
23420 IF PHASE$="ON" THEN 23670
23430 FOR I=1 TO NOFI1
23440    LSMIN(I)=99999!:I1=I-1
23450    FOR J=1 TO NOTP(I)
23460       A=A+1 :IF X(A)>X(EYL) AND EYL>0 THEN EYLI=I:EYLJ=J:GOTO 23600
23470       YY(I,J)=Y(A) : D3(I,J)=X(A)
23480       AA(I,J)=A(A)
23490       DL(I,J)=X(A)-XIS(I1)
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23500       IF FP=1 THEN CL=CL(I,J)
23510       HL=YIS(I1)-Y(A)-CL
23520       DR(I,J)=XIS(I)-XIS(I1)-DL(I,J)
23530       HR=YIS(I1)-YIS(I)-HL
23540       LS=(DL(I,J)^2+HL^2)^.5+(DR(I,J)^2+HR^2)^.5
23550       IF LSMIN(I)>LS THEN LSMIN(I)=LS : TPMINS=A
23560       IF J=NOTP(I) THEN A=A+1 :AA(I,J+1)=A(A)
23570    NEXT J
23580    S=SUMSS-SS(I)+LSMIN(I)
23590    IF SMIN>S THEN SMIN=S : TPMIN=TPMINS : SPAN=I
23600 NEXT I
23610 :
23620 TAVE=TA1-.5*W1*(Y(TP1)+HS1-Y(TP2)-HS2)
23630 S0=SMIN/(1+TAVE/AE)
23640 IF FRICTION=1 THEN GOSUB 26700: GOTO 24190
23650 PRINT
23660 IF OPT%=8 THEN 24350
23670 :
23680 IF B>0 THEN 23720
23690 FOR I=1 TO NOFI1
23700    I1=I-1
23710    IF PHASE$="ON" AND B>0  THEN 24360
23730    YHT=YIS(I1)-YIS(I)
23740    LS(I)=SMIN-(SUMSS-SS(I))
23750    S=LS(I): LL=DD(I)
23760    IF PHASE$="ON" AND K=0 THEN K=1
23770    IF PHASE$="ON" THEN JJ=K:GOTO 23800
23780    FOR JJ=1 TO NOTP(I)
23790 :
23800       D1=DL(I,JJ)
23810       GOSUB 25990
23820       H1(I,JJ)=H: H2(I,JJ)=YHT-H1(I,JJ)
23830       H3(I,JJ)=H1(I,JJ)+Y(0)+HS1-YIS(I1)
23840       IF PHASE$="ON" THEN 23860
23850    NEXT JJ
23870    IF ITER>0 OR (B=OLDB AND B>0) THEN 23910
23880    FOR K=1 TO NOTP(I)
23900       IF PHASE$="ON" AND B=OLDB AND B>0  THEN 24360
23910       TA=TU1(I):DL=DL(I,K):HL=H1(I,K):DR=DR(I,K):HR=H2(I,K)
23920       H3=H3(I,K):D3=D3(I,K):Y0=YY(I,K):A(I+1)=AA(I,K+1)
23930       IF ITER>0 OR ITER1>0 THEN 23940 ELSE B=B+1
23940       GOSUB 25050
23950       IF PHASE$="ON" THEN 26140
23960       PL(B)=PL: CLR(B)=CLC+CDP: TA3(B)=TU3: ALPHA(B)=ALPHA*57.3:
            LEC(B)=L*SIN(BETA)/COS(THETA): IF TTA=0 THEN TA1(B)=TA1
            ELSE TA1(B)=TTA:TTA=0
23970 :
23980       HREACT(B,I1)=HCOMP(I1)-H1U
23990       VREACT(B,I1)=V1U-VLCOMP(I1)
24000       IF I=1 THEN HREACT(B,I1)=HCOMP(I1)-H1U-H3L :
            VREACT(B,I1)=V1U+V3U-VLCOMP(I1)
24010       ANGLE(B,I1)=ATN(VREACT(B,I1)/HREACT(B,I1))
24020       HREACT(B,I)=HCOMP(I+1)-H2L
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24030       VREACT(B,I)=V2L-VUCOMP(I+1)
24040       ANGLE(B,I)=ATN(VREACT(B,I)/HREACT(B,I))
24050       FOR PP=0 TO NOFI1
24060          IF PP=I OR PP=I1 THEN 24110
24070          HREACT(B,PP)=HCOMP(PP)-HCOMP(PP+1)
24080          VREACT(B,PP)=VUCOMP(PP+1)-VLCOMP(PP)
24090          IF PP=0 THEN HREACT(B,PP)=HCOMP(PP)-HCOMP(PP+1)-H3L :
               VREACT(B,PP)=VUCOMP(PP+1)-VLCOMP(PP)+V3U
24100          ANGLE(B,PP)=ATN(VREACT(B,PP)/HREACT(B,PP))
24110       NEXT PP
24120       OLDB=B
24130       IF K=NOTP(I) THEN B=B+1
24140       IF FRICTION=1 THEN 27080
24150    NEXT K
24160    K=1
24170 NEXT I
24180 IF PHASE$="ON" THEN 24320
24190 CHK=1: GOSUB 27120
24200 IF OPT=7 THEN GOSUB 29880 ELSE GOSUB 27830
24210 LOCATE 7,17:PRINT "UNLOADED SKYLINE TENSION REQUIRED   :            lbs"
24220 LOCATE 7,56:PRINT USING "#####";TU(0):IF NOINFO=1 THEN LOCATE 7,56:
      PRINT "LESS THAN 3000 lbs"
24230 LOCATE 8,17:PRINT "MIN. LOADED SKYLINE LENGTH REQUIRED :            ft"
24240 LOCATE 8,56:PRINT USING "####.#";SMIN
24250 LOCATE 9,17:PRINT "UNSTRETCHED SKYLINE LENGTH REQUIRED :            ft"
24260 LOCATE 9,56:PRINT USING "####.#";SO
24270 IF CPL(1)<>0 OR CPL(2)<>0 OR CPL(3)<>0 OR CPL(4)<>0 OR CPL(5)<>0 THEN
      LOCATE 12,17:PRINT "MAXIMUM PAYLOAD FOR CARRIAGE PASSAGE" ELSE 24310
24280 FOR IDS=1 TO NOFI:IF CPL(IDS)=0 THEN 24300 ELSE IDS1=IDS1+1
24290    LOCATE 13+IDS1,20:PRINT "INTERMEDIATE SPAR #";IDS;"
         :            lbs":LOCATE 13+IDS1,56:PRINT USING "######";CPL(IDS);
24300 NEXT IDS
24310 GOSUB 29380:GOSUB 29600:GOSUB 29640
24320 GOSUB 29380:GOSUB 29400:GOSUB 29420
24330 GOSUB 29600:GOSUB 29660:GOSUB 29640:GOSUB 29670
24340 GOSUB 29600:CLEAR:RES=1:GOTO 10010
24350 PHASE$="ON": B=0
24360 :
24370 TAVE=TA1-.5*W1*(Y(TP1)+HS1-Y(TP2)-HS2)
24380 SMIN=SO*(1+TAVE/AE)
24390 GOTO 23260
24400 '====================== {Open a Profile file} ========================
24410 PRINT
24420 CLS:FL$="PRO":M$="":AN=1:GOSUB 12390 :AN=0
24430 LOCATE 1,3:PRINT "INPUT PROFILE FILE NAME :"
24440 R=1:C=29:GOSUB 24860:F$=DRV$+":"+M$+"."+FL$
24450 OPEN F$ FOR INPUT AS #1
24460 INPUT #1,D$
24470 X(0)=0:Y(0)=10000:S(0)=0:A(0)=0
24480 N=0
24490 FOR I=1 TO 100
24500    INPUT #1,HO,VE,S(I),A(I)
24510    A=ATN(A(I)/100)
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24520    X(I)=X(I-1)+S(I)*COS(A)
24530    Y(I)=Y(I-1)+S(I)*SIN(A)
24540    N=N+1
24550    IF EOF(1) THEN 24570
24560 NEXT I
24570 CLOSE #1
24580 :
24590 S(0)=0: A(0)=0
24600 RETURN
24610 '================ {Open a Parameters and Options File} =================
24620 CLS:FL$="PAR":M$="":AN=1:GOSUB 12390 :AN=0
24630 LOCATE 1,3:PRINT "INPUT FILE NAME OF OPTIONS AND PARAMETERS :";
24640 R=1:C=47:GOSUB 24860:F$=DRV$+":"+M$+"."+FL$
24650 OPEN F$ FOR INPUT AS #1
24660 INPUT #1, C,C,OPT,CWT,CDP,LC,DIAS,TA1,W1,DIAM,TA3,W2,DIAH,TA4,W3,DIASL,
      TA5,W4,RAD,WID,TORQ,LLINE,TP1,HS1,TP2,HS2,EYL,NOFI,TPIS1,IS1,TPIS2,
      IS2,TPIS3,IS3,TPIS4,IS4,TPIS5,IS5,LEC,CL,L,MY,LED,TED,DCL,MJ,MU
24670 CLOSE #1
24680 IF TP2=0 THEN TP2=N
24690 TP1=0: IF MY=0 THEN MY=.6
24700 IF OPT=1 OR OPT=3 OR OPT=5 OR OPT=7 OR OPT=9 OR OPT=11 OR OPT=13
      OR OPT=15 THEN FP=0:L=0:LC=0 ELSE FP=1
24710 IF OPT=11 OR OPT=12 OR OPT=15 OR OPT=16 THEN UD=1 ELSE UD=0
24720 IF LED=0 OR TED=0 THEN EPS=L/2:GOTO 24770
24730 DCL=DCL/12:LED=LED/12:TED=TED/12
24740 EPS1=(L+DCL)*(LED^2+3*TED^2+2*LED*TED)
24750 EPS2=4*(LED^2+TED^2+LED*TED)
24760 EPS=EPS1/EPS2-DCL
24770 IF EYL=0 OR UD=1 THEN EYL=TP2-1
24780 IF OPT=1 OR OPT=2 THEN SYST=1
24790 IF OPT=3 OR OPT=4 THEN SYST=2
24800 IF OPT=5 OR OPT=6 OR OPT=7 THEN SYST=3
24810 IF OPT=8 THEN SYST=4
24820 IF OPT=9 OR OPT=10 OR OPT=11 OR OPT=12 THEN SYST=5
24830 IF OPT=13 OR OPT=14 OR OPT=15 OR OPT=16 THEN SYST=6
24840 WHILE OPT=7: IF TA4>0 THEN TA3=TA4:GOTO 24850 ELSE 24850:WEND
24850 RETURN
24860 '=============== {Enter File Names To Call Data Files} =================
24870 COLOR 0,7:LOCATE R,C:FOR I=1 TO 8:PRINT " ";:NEXT I:COLOR 7,0
24880 NCHR=0:M$="":KBD$="":IF FL$="PRO" THEN NN=0
24890 KBD$="":DEF SEG=0:POKE 1050,PEEK(1052):DEF SEG
24900 KBD$="":WHILE KBD$="":KBD$=INKEY$:WEND:KBD=ASC(LEFT$(KBD$,1))
24910 WHILE (KBD>47 AND KBD<58) OR (KBD>64 AND KBD<91) OR
         (KBD>96 AND KBD<122) OR KBD=8
24920    WHILE KBD=8
24930       NN=0:NCHR=NCHR-1:IF NCHR<0 THEN NCHR=0:GOTO 25040
24940       IF NCHR=0 THEN M$="" ELSE M$=LEFT$(M$,NCHR)
24950       C=C-1:LOCATE R,C:COLOR 0,7:PRINT " ":LOCATE R,C:COLOR 7,0
24960       GOTO 24890
24970    WEND
24980    IF NN=1 THEN 25040
24990    NCHR=NCHR+1:IF NCHR>8 THEN NCHR=8:NN=1:GOTO 25040 ELSE C=C+1
25000    LOCATE R,C-1:COLOR 0,7:PRINT KBD$:M$=M$+KBD$:COLOR 7,0
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25010     GOTO 24900
25020 WEND
25030 IF KBD=13 THEN RETURN
25040 SOUND 500,2:GOTO 24890
25050 '======================== (Payload Analysis) =========================
25060 TU=TA : D=DL : H=HL : W=W1
25070 GOSUB 25680
25080 H1L=HC: V1L=VL : H1U=H1L : V1U=V1L+R
25090 T1L=SQR(H1L^2+V1L^2)
25100 IF HR<0 THEN TU2=T1L+W1*ABS(HR) ELSE TU2=T1L
25110 TU=TU2
25120 H=ABS(HR):D=DR: W=W1
25130 GOSUB 25680
25140 H2L=HC
25150 IF HR<0 THEN V2=VL :V2L=-VL-R ELSE V2=-VL-R : V2L=VL
25160 CLC=Y(TP1)+HS1-H3-Y0-CDP
25170 IF CLC>LC+L THEN BETA=0:GOTO 25360
25180 IF OPT=2 THEN DS=J:GOSUB 30110:GOSUB 25770:GOTO 25200
25190 GOSUB 25750
25200 R3=W2*SQR(H3^2+D3^2)

25210 IF A(DS+1)>0 AND MY<(A(DS+1)/100) THEN ALPHA=-ABS(ALPHA)
25220 HH1=TAN(ALPHA)*(H1L-H2L)-(V1L+V2-CWT)+R3/2
25230 HH2=H3/D3-TAN(ALPHA)
25240 H3L=HH1/HH2
25250 V3L=H3L*H3/D3-.5*R3 :V3U=V3L+R
25260 TU3=SQR(H3L^2+(V3L+R3)^2)
25270 IF CHK=1 OR PHASE$="ON" THEN 25300
25280 IF ITER1>0 THEN 26040
25290 IF TU3>TA3 THEN 26040
25300 WV=V1L+V2+V3L-CWT
25310 GOSUB 28780
25350 GOTO 25470
25360 D=D3: H=H3 : W=W2
25370 H3L=H2L-H1L
25380 M=H3L/W2
25390 GOSUB 25600
25400 V3L=.5*W2*(H*COTH+S)-W2*S: V3U=V3L+W2*S
25410 TU3=W2/2*(S*(4*M^2/(S^2-H^2)+1)^.5+H)
25420 TL3=SQR(H3L^2+V3L^2)
25430 IF CHK=1 OR PHASE$="ON" THEN 25460
25440 IF ITER1>0 THEN 26040
25450 IF TU3>TA3 THEN 26040
25460 PL=V1L+V2+V3L-CWT
25470 RETURN
25480 '====== (Calc Cable Length & Tension Compo. on Catenary Assumpt.) ======
25490 E=D/2: R=W*SQR(D^2+H^2): NHV=0
25500 IF UCT=1 AND TU<E*R/SQR(H^2+D^2) THEN LTU=LTU+1000:GOTO 27140
25510 M=-R*(H/D)*(E/D)+SQR((R*(H/D)*(E/D))^2-(1+(H/D)^2)*(R^2*(E/D)^2-TU^2))
25520 M=M/(W*(1+(H/D)^2))
25530 IF ABS(M-M1)<10 THEN 25570 ELSE NHV=NHV+1
25540 IF NHV>15 THEN LTU=LTU+1000:GOTO 27140
25550 GOSUB 25600
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25560 R=W*S:M1=M:GOTO 25500
25570 HC=W*M
25580 VL=(HC*H+R*E)/D-R: VU=VL+R
25590 RETURN
25610 X=.5*D/M
25620 SINH=.5*EXP(X)-.5*EXP(-X)
25630 COSH=.5*EXP(X)+.5*EXP(-X)
25640 COTH=COSH/SINH
25650 S=SQR(H^2+(2*M*SINH)^2)
25660 E=D/2-(H/S)*(M-.5*D*COTH)
25670 RETURN
25680 '======= {Calc Cable Length & Tension Comp. on Rigid Link Assum.} ======
25690 E=D/2: R=W*SQR(D^2+H^2)
25700 M=-R*(H/D)*(E/D)+SQR((R*(H/D)*(E/D))^2-(1+(H/D)^2)*(R^2*(E/D)^2-TU^2))
25710 M=M/(W*(1+(H/D)^2))
25720 HC=M*W
25730 VL=(HC*H+R*E)/D-R : VU=VL+R
25740 RETURN
25750 '========== {Calculate Log and Chokerline Geomtry Angles} ==============
25760 DS=I:GOSUB 30110
25770 XSIN=LEC/L:BETA0=ATN(XSIN/SQR(1-XSIN^2))
25780 BETA=BETA0 : GOSUB 25900
25790 BETA1=BETA : Z1=Z
25800 BETA=BETA1+.1: GOSUB 25900
25810 BETA2=BETA : Z2=Z
25820 MMM=(Z1-Z2)/(BETA1-BETA2)
25830 OLDB=BETA1:OLDZ=Z1:BETA1=BETA2 : Z1=Z2
25840 BETA2=BETA2-Z2/MMM
25850 IF (OLDB*BETA1)<0 AND ((BETA2>OLDB AND BETA2>BETA1) OR
   (BETA2<OLDB AND BETA2<BETA1)) THEN BETA2=(OLDB+BETA1)/2
25860 BETA=BETA2 : GOSUB 25900
25870 Z2=Z
25880 IF ABS(Z)>.000001 THEN 25820
25890 RETURN
25900 AL1=COS(THETA)-MY*SIN(THETA)
25910 AL2=SIN(THETA)+MY*COS(THETA)
25920 AL3=COS(THETA)-SIN(THETA)*TAN(BETA)
25930 AL4=L/EPS*(1+MY*TAN(BETA))
25940 ALPHA=ATN((1-AL3/AL4*AL1)/(AL3/AL4*AL2))
25950 B1=CLC*COS(THETA)-LC*SIN(ALPHA-THETA)
25960 Z=B1/L-SIN(BETA)
25970 RETURN
25980 '================== {Calculate Elliptical Load Path} ===================
25990 C=S^2+D1^2-(LL-D1)^2-YHT^2
26000 ROOT=SQR(-4*(D1*S)^2*(S^2-YHT^2)+(C*S)^2)
26010 DUMMY=1
26020 H=(C*YHT+ROOT*DUMMY)/2/(S^2-YHT^2)
26030 RETURN
26040 '=========== {Check If Mainline Tension Exceeds Its SWL} ===============
26045 '--------------- If so, then adjust skyline tension --------------------
26050 IF ITER1>0 THEN 26090
26060 ITER1=ITER1+1
26070 TAOLD=TA:TU3OLD=TU3
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26080 TA=(TA3/TU3)*TAOLD :GOTO 25060
26090 IF ABS(TU3-TA3)<10 THEN ITER1=0:IF CLC<LC+L THEN 25300 ELSE 25460
26100 MM3=((TU3-TA3)-(TU3OLD-TA3))/(TA-TAOLD)
26110 TAOLD=TA:TU3OLD=TU3
26120 TA=TAOLD-(TU3OLD-TA3)/MM3
26130 GOTO 25060
26140 '=============== (Check If The Trial Payload Obtained) =================
26145 '                    If not, adjust skyline tension
26146 '------------------- (Multispan Load Path Analysis) --------------------
26150 IF ITER>0 THEN 26190
26160 ITER=ITER+1
26170 TA1OLD=TA1 : PLOLD=PL
26180 TA1=.99*TA1 : GOTO 24360
26190 IF ABS(PL-PLA)<5 THEN ITER=0: PL(B)=PL:CLR(B)=CLC+COP:
      TA1(B)=TA1:TA3(B)=TU3:LEC(B)=L*SIN(BETA)/COS(THETA): GOTO 23970
26200 MM=((PL-PLA)-(PLOLD-PLA))/(TA1-TA1OLD)
26210 TA1OLD=TA1 : PLOLD=PL
26220 TA1=TA1OLD-(PLOLD-PLA)/MM
26230 GOTO 24360
26240 '--------------- (Standing Skyline Load Path Analysis) -----------------
26250 IF ITER>0 THEN 26290
26260 ITER=ITER+1
26270 TA1OLD=TA1 : PLOLD=PL
26280 TA1=.99*TA1 : GOTO 26340
26290 IF ABS(PL-PLA)<5 THEN ITER=0: PL(I)=PL:CLR(I)=CLC+COP:TA3(I)=TU3:
      LEC(I)=L*SIN(BETA)/COS(THETA): IF TTA=0 THEN TA1(I)=TA1 :GOTO 22360
      ELSE TA1(I)=TTA:TTA=0:GOTO 22360
26300 MM=((PL-PLA)-(PLOLD-PLA))/(TA1-TA1OLD)
26310 TA1OLD=TA1 : PLOLD=PL
26320 TA1=TA1OLD-(PLOLD-PLA)/MM
26330 GOTO 26340
26350 TAVE=TA1-.5*W1*YHT
26360 SMIN=SO*(1+TAVE/AE): GOTO 22250
26370 '======== (Multispan Payload Analysis Considering Jack Friction) =======
26375 '---------------- Calc skyline length of unloaded spans ----------------
26380 FOR J=1 TO NOFI1
26390    J1=J-1
26400    DD(J)=XIS(J)-XIS(J1)
26410    HH(J)=YIS(J1)-YIS(J)
26420 NEXT J
26430 TU1(1)=TA1
26440 TU=TA1:H=HH(1):D=DD(1):W=W1: GOSUB 25480
26450 HCOMP1=HC: VL1=VL: VU1=VU
26460 SS(1)=S
26470 SUMSS=SS(1)
26480 HCOMP(1)=HC: VLCOMP(1)=VL: VUCOMP(1)=VU 26490 FOR I=2 TO NOFI+1
26500      TU=SQR(VL1^2+HCOMP1^2): H=HH(I): D=DD(1)
26510      GOSUB 25680
26520      HCOMP2=HC: VL2=VL: VU2=VU
26530      HR=ABS(HCOMP1)-ABS(HCOMP2)
26540      VR= ABS(VL1)-ABS(VU2)
26550      RR=SQR(HR^2+VR^2)
26560      FF=RR*MJ
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26570    HF=FF*SIN(ATN(VR/HR))
26580    VF=FF*COS(ATN(VR/HR))
26590    HNEW=HCOMP1+HF
26600    VNEW=VL1+VF
26610    TU1(I)=SQR(HNEW^2+VNEW^2)
26620    TU=TU1(I)
26630    GOSUB 25480
26640    HCOMP1=HC: VL1=VL: VU1=VU
26650    SS(I)=S
26660    SUMSS=SUMSS+SS(I)
26670    HCOMP(I)=HC: VLCOMP(I)=VL: VUCOMP(I)=VU
26680 NEXT I
26690 RETURN
26700 '----------- Calc multispan payload considering jack friction ----------
26710 FOR I=1 TO NOFI1
26720    I1=I-1
26730    YHT=YIS(I1)-YIS(I)
26740    LS(I)=SMIN-(SUMSS-SS(I))
26750    S=LS(I): LL=DD(I)
26760    FOR JJ=1 TO NOTP(I)
26770       IF JJ>EYLJ AND I=EYLI THEN 26820
26780       D1=DL(I,JJ)
26790       GOSUB 25990
26800      H1(I,JJ)=H: H2(I,JJ)=YHT-H1(I,JJ)
26810      H3(I,JJ)=H1(I,JJ)+Y(0)+HS1-YIS(I1)
26820    NEXT JJ
26830 NEXT I
26840 FOR I=2 TO NOFI+1
26850    TU=TU1(I-1): H=HH(I-1): D=DD(I-1): W=W1
26860    GOSUB 25680
26870    HCOMP1=HC: VL1=VL: VU1=VU
26880    FOR J=1 TO NOTP(I)
26890       TU=SQR(HCOMP1^2+VL1^2): H=H1(I,J): D=DL(I,J): W=W1
26900       GOSUB 25680
26910       HCOMP2=HC: VL2=VL: VU2=VU
26920       HR=ABS(HCOMP1)-ABS(HCOMP2)
26930       VR=ABS(VU2)-ABS(VL1)
26940       RR=SQR(HR^2+VR^2)
26950       FF=RR*MJ
26960       HF=FF*SIN(ATN(VR/HR))
26970       VF=FF*COS(ATN(VR/HR))
26980       HNEW=HCOMP1+HF
26990       VNEW=VL1+VF
27000       TUF(I,J)=SQR(HNEW^2+VNEW^2)
27010    NEXT J
27020 NEXT I
27030 FOR I=1 TO NOFI1
27040    I1=I-1
27050    FOR K=1 TO NOTP(I)
27060       IF I>1 THEN TU1(I)=TUF(I,K)
27070       GOTO 23890
27080    NEXT K
27090 K=1
```

```
27100 NEXT I
27110 RETURN
27120 '============== (Unloaded Skyline Tension of Multispan) ================
27130 LTU=1000
27140 UCT=1:DELTA=5000
27150 TU(0)=LTU:GOSUB 27360:LUZ=UZ
27160 TU(0)=LTU+DELTA:IF TU(0)>TA1 THEN NOINFO=1:RETURN
27170 GOSUB 27360
27180 IF ABS(UZ)<.05 THEN RETURN
27190 IF UZ*LUZ<0 THEN NBS=NBS+1:DELTA=-DELTA/2
27200 IF NBS>3 THEN NBS=0:INIT=TU(0):GOTO 27240
27210 LUZ=UZ:LTU=TU(0)
27220 GOTO 27160
27230 :
27240 TU(0)=INIT: GOSUB 27360
27250 T1=TU(0) :UZ1=UZ
27260 TU(0)=1.1*TU(0):GOSUB 27360
27270 T2=TU(0):UZ2=UZ
27280 UM=(UZ1-UZ2)/(T1-T2)
27290 OLDT1=T1:OLDUZ1=UZ1:T1=T2:UZ1=UZ2
27300 T2=T2-UZ2/UM
27310 IF (OLDUZ1*UZ1<0) AND ((T2>OLDT1 AND T2>T1) OR (T2<OLDT1 AND T2<T1))
      THEN T2=(T1+OLDT1)/2
27320 TU(0)=T2:GOSUB 27360
27330 UZ2=UZ
27340 IF ABS(UZ)>.05 THEN 27280
27350 RETURN
27360 SUMS=0
27370 FOR UI=1 TO NOFI1
27380    TU(UI)=TU(UI-1)-W1*HH(UI-1):TU=TU(UI)
27390    W=W1:D=DD(UI):H=HH(UI):GOSUB 25480
27400    IF NN=1 THEN NN=0:GOTO 27180
27410    S(UI)=S
27420    SUMS=SUMS+S(UI)
27430 NEXT UI
27440 UTAVE=TU(0)-.5*W1*(Y(TP1)+HS1-Y(TP2)-HS2)
27450 USO=SUMS/(1+UTAVE/AE)
27460 UZ=USO-SO
27470 RETURN
27480 '============= (Carriage Passage Check for Uphill Yarding) ===============
27485 '------ Determine cable geometry for the critical skyline tension --------
27490 FOR CK=1 TO NOIS
27500    CT(0)=CT+W1*HH(CK)
27510 NEXT CK
27520 CDL=1
27530 CHL=5:GOSUB 27650
27540 CHL1=CHL:CZH1=CZH
27550 CHL=IS(NOIS)*.5 : GOSUB 27650
27560 CHL2=CHL: CZH2=CZH
27570 CMM=(CZH1-CZH2)/(CHL1-CHL2)
27580 IF ABS(CZH)<.001 THEN RETURN
27590 OLDCHL1=CHL1:OLDCZH1=CZH1:CHL1=CHL2:CZH1=CZH2
27600 CHL2=CHL2-CZH2/CMM
```

```
27610 IF (OLDCHL1*CHL1)<0 AND ((CHL2>OLDCHL1 AND CHL2>CHL1) OR
      (CHL2<OLDCHL1 AND CHL2<CHL1)) THEN CHL2=(CHL1+OLDCHL1)/2
27620 CHL=CHL2: GOSUB 27650
27630 CZH2=CZH
27640 GOTO 27570
27650 :
27660 SUMS=0
27670 FOR CI=1 TO NOFI1
27680    CT(CI)=CT(CI-1)-W1*HH(CI-1):TU=CT(CI)
27690    W=W1:D=DD(CI):H=HH(CI):GOSUB 25480
27700    CS(CI)=S
27710    SUMS=SUMS+CS(CI)
27720 NEXT CI
27730 CDR=DD(LSP)-CDL: IF OPT=7 THEN CHR=HH(LSP)+CHL ELSE CHR=HH(LSP)-CHL
27740 CLSL=SQR(CDL^2+CHL^2)
27750 D=CDR:H=CHR:TU=CT(LSP)-W1*CHL:W=W1
27760 GOSUB 25480
27770 CLSR=S
27780 CLSS=CLSL+CLSR+SUMS-CS(LSP)
27790 CTAVE=CT(1)-.5*W1*(Y(TP1)+HS1-Y(TP2)-HS2)
27800 LSO=CLSS/(1+CTAVE/AE)
27810 CZH=SO-LSO
27820 RETURN
27830 '----------- Check if a carriage passes the jack successfully ------------
27840 FOR NOIS=1 TO NOFI
27850    LSP=NOIS+1
27860    GOSUB 27990
27870    IF TS>TU(0) THEN CT=TS: GOSUB 27480  ELSE  GOTO 27930
27880    TA=CT(NOIS+1):DL=CDL:HL=CHL:DR=CDR:HR=CHR
27890    H3=YIS(0)-YIS(NOIS)+CHL  :D3=XIS(NOIS)+CDL
27900    TPIS=TPIS(NOIS)
27910    YO=Y(TPIS)-CDL*A(TPIS+1)/100
27920    GOSUB 25050 :CPL(NOIS)=PL
27930    FOR I=TPIS(NOIS)+1 TO TPIS(NOIS)+NDTP(NOIS+1)
27940       IF TS<TU(0) THEN WARN(I)=2: GOTO 27960
27950       IF CPL(NOIS)<PL(I) THEN WARN(I)=1 ELSE WARN(I)=2
27960    NEXT I
27970 NEXT NOIS
27980 RETURN
27990 '------ Calculate the critical skyline tension for carriage passage-----
28000 LAMDA=ATN(ABS(HH(LSP)/DD(LSP)))
28010 AAL=ATN(ABS(HH(NOIS)/DD(NOIS)))
28020 TS1=PL+W2*DD(LSP)/2*COS(LAMDA)*(1+TAN(AAL)*TAN(LAMDA))
28030 TS2=1-COS(LAMDA)*(TAN(LAMDA)-TAN(AAL))
28040 TS=TS1/TS2
28050 RETURN
28060 '========== (Unloaded Skyline Tension for Standing Skyline) ============
28070 TU=SMIN*W1:GOSUB 28200
28080 T1=TU:UZ1=UZ
28090 TU=TU*1.1:GOSUB 28200
28100 T2=TU:UZ2=UZ
28110 UM=(UZ1-UZ2)/(T1-T2)
28120 DLDT1=T1:DLDUZ1=UZ1:T1=T2:UZ1=UZ2
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28130 T2=T2-UZ2/UM
28140 IF (OLDUZ1*UZ1)<0 AND ((T2>OLDT1 AND T2>T1) OR (T2<OLDT1 AND T2<T1))
      THEN T2=(OLDT1+T1)/2
28150 TU=T2:GOSUB 28200
28160 UZ2=UZ
28170 IF ABS(UZ)>.05 THEN 28110
28180 TUU=TU
28190 RETURN
28200 D=SPAN:H=YHT:W=W1:GOSUB 25480
28210 UTAVE=TU-.5*W1*YHT
28220 USO=S/(1+UTAVE/AE)
28230 UZ=USO-SO
28240 RETURN
28250 '================== (Cable Segment Tension Check) ======================
28255 '----------------------------- Slackline --------------------------------
28260 IF ITER1>0 THEN 28300
28270 ITER1=ITER1+1
28280 TAOLD=TA: TU3OLD=TU3
28290 TA=(TA3/TU3)*TAOLD : GOTO 20270
28300 IF ABS(TU3-TA3)<10 THEN 20680
28310 MM=((TU3-TA3)-(TU3OLD-TA3))/(TA-TAOLD)
28320 TAOLD=TA: TU3OLD=TU3
28330 TA=TAOLD-(TU3OLD-TA3)/MM
28340 GOTO 20270
28350 :
28360 IF ITER1>0 THEN 28400
28370 ITER1=ITER1+1
28380 TAOLD=TA: TU3OLD=TU3
28390 TA=(TA5/TU3)*TAOLD : GOTO 20270
28400 IF ABS(TU3-TA5)<10 THEN 20680
28410 MM=((TU3-TA5)-(TU3OLD-TA5))/(TA-TAOLD)
28420 TAOLD=TA: TU3OLD=TU3
28430 TA=TAOLD-(TU3OLD-TA5)/MM
28440 GOTO 20270
28450 :
28460 IF ITER2>0 THEN 28500
28470 ITER2=ITER2+1
28480 T4OLD=T4: TU3OLD=TU3
28490 T4=(TA3/TU3)*T4OLD : GOTO 20340
28500 IF ABS(TU3-TA3)<10 THEN 20680
28510 MM=((TU3-TA3)-(TU3OLD-TA3))/(T4-T4OLD)
28520 T4OLD=T4: TU3OLD=TU3
28530 T4=T4OLD-(TU3OLD-TA3)/MM
28540 GOTO 20340
28550 :
28560 IF ITER2>0 THEN 28600
28570 ITER2=ITER2+1
28580 T3OLD=T3: TU3OLD=TU3
28590 T3=(TA5/TU3)*T3OLD : GOTO 20340
28600 IF ABS(TU3-TA5)<10 THEN 20680
28610 MM=((TU3-TA5)-(TU3OLD-TA5))/(T3-T3OLD)
28620 T3OLD=T3: TU3OLD=TU3
28630 T3=T3OLD-(TU3OLD-TA5)/MM
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28640 GOTO 20340
28650 '---------------------- Running skyline --------------------------------
28660 IF ITER1>0 THEN 28700
28670 ITER1=ITER1+1
28680 TAOLD=TA: TTOLD=TT
28690 TA=(TA3/TT)*TAOLD : GOTO 21030
28700 IF ABS(TT-TA3)<10 THEN 21360
28710 MM=((TT-TA3)-(TTOLD-TA3))/(TA-TAOLD)
28720 TAOLD=TA: TTOLD=TT
28730 TA=TAOLD-(TTOLD-TA3)/MM
28740 GOTO 21030
28750 '================ {Payload Calculation for Log Drag} ===================
28760 IF FP=0 THEN PL=V1L+V2+V3L+V4-CWT: GOTO 28820
28770 WV=V1L+V2+V3L+V4-CWT
28780 P1=COS(THETA)-SIN(THETA)*TAN(BETA)
28790 P2=L/EPS*(1+MY*TAN(BETA))
28800 P3=COS(THETA)-MY*SIN(THETA)
28810 PL=WV/(1-P1/P2*P3)
28820 RETURN
28830 '===================== {Highlead Cable Geometry} =======================
28840 DS=I:GOSUB 30110
28850 CLC=CL: GOSUB 25750
28860 IF BETA<0 THEN BETA=0: X=CL*COS(THETA)/LC: ALPHA=THETA+ATN(X/SQR(1-X^2))
28870 DR=X(TP2)-X(I)
28880 IF TH(I)<W3*DR/2 THEN H2L=0: V2=0: GOTO 28940
28890 HR=Y(I)+CL-Y(TP2)-HS2
28900 D=DR: H=ABS(HR): W=W3
28910 IF HR<0 THEN TU=TH(I)-W3*(Y(TP1)+HS1-Y(TP2)-HS2): GOSUB 25680:
      H2L=HC: V2=VL: V2U=VL+R
28920 IF HR>0 THEN TU=TH(I)-W3*(Y(TP1)+HS1-Y(I)-CL): GOSUB  25680:
      H2L=HC: V2=-VU :V2U=VU-R
28930 '======= {Check If The Mainline of Highlead Drags on The Ground} =======
28935 '                If so, determine a new cable geometry.
28940 GOSUB 29070
28950 IF GCA1=GA0 THEN 29010
28960 GCTP1(I)=CP1: GCTP2(I)=CP2
28970 GCA1(I)=ATN(GCA1): GCA2(I)=ATN(GCA2): GCA3(I)=ATN(GCA3)
28980 NR=ABS(TM*(SIN(GCA3(I)-GCA1(I))+SIN(GCA2(I)-GCA3(I))))
28990 H1L=(TM-MU*NR)*COS(GCA2(I)): V1L=(TM-MU*NR)*SIN(GCA2(I))
29000 GOTO 29040
29010 HL=Y(TP1)+HS1-Y(I)-CL: DL=X(I)
29020 D=DL: H=HL: TU=TM: W=W2: GOSUB 25680
29030 H1L=HC: V1L=VL: V1U=VU
29040 WH=H1L-H2L: WV=V1L+V2
29050 ZCL=ABS(WV/WH)-TAN(ALPHA)
29060 RETURN
29070 :
29080 GX1=X(TP1): GY1=Y(TP1)+HS1
29090 GX2=X(I): GY2=Y(I)+CL
29100 GA0=ABS((GY1-GY2)/(GX1-GX2))
29110 GCA1=GA0
29120 FOR K=1 TO I-1
29130    GX2=X(K): GY2=Y(K)
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29140    GA=ABS((GY1-GY2)/(GX1-GX2))
29150    IF GA<GCA1 THEN GCA1=GA: CP1=K: CX1=GX2: CY1=GY2
29160 NEXT K
29170 IF GCA1=GA0 THEN RETURN
29180 GX1=X(I): GY1=Y(I)+CL
29190 GCA2=0
29200 FOR K=I-1 TO CP1 STEP -1
29210    GX2=X(K): GY2=Y(K)
29220    GA=ABS((GY1-GY2)/(GX1-GX2))
29230    IF GA>GCA2 THEN GCA2=GA: CP2=K: CX2=GX2: CY2=GY2
29240 NEXT K
29250 IF CX1=CX2 THEN GCA3=0: GOTO 29270
29260 GCA3=ABS((CY1-CY2)/(CX1-CX2))
29270 RETURN
29275 ====== {Option to Select Payload Analysis or Load Path Analysis} =======
29280 CLS:LOCATE 1,20:PRINT A6$:LOCATE 2,20:PRINT A1$:LOCATE 2,59:
      PRINT A2$:LOCATE 3,20:PRINT A5$:LOCATE 4,1:PRINT S1$:LOCATE 23,1:
      PRINT S1$:RETURN
29290 LOCATE 6,18:PRINT "Do you want ";:COLOR 15,0:PRINT "P";:COLOR 7,0:
      PRINT "ayload analysis or ";:COLOR 15,0:PRINT "L";:COLOR 7,0:
      PRINT "oad path ?"
29300 LOCATE 6, 65:INPUT "",LP$
29310 WHILE SYST=2: IF LP$="P" THEN OPT%=0 :GOTO 29350 ELSE OPT%=7:
      GOTO 29330:WEND
29320 WHILE SYST=3: IF LP$="P" THEN OPT%=0 :GOTO 29350 ELSE OPT%=8:
      GOTO 29330:WEND
29330 LOCATE 7,18:PRINT "TRIAL PAYLOAD  (lbs)                        ?"
29340 LOCATE 7,65:INPUT "", PLA
29350 LOCATE 6,1:PRINT S3$;:LOCATE 7,1:PRINT S3$;
29360 RETURN
29370 LOCATE 4,70 :COLOR 23:PRINT " WAIT ";:COLOR 7,0: RETURN
29380 LOCATE 4,69 :COLOR 7,0:PRINT STRING$(8,205);:RETURN
29390 '======================== {Print Outputs} ============================
29400 LOCATE 2,3:IF OPT%=7 OR OPT%=8 THEN PRINT "== LOAD PATH =="
      ELSE PRINT "==PAYLOAD =="
29410 LOCATE 5,1:PRINT " T.P.   PAYLOAD    CLR  SKY. T.  MAIN.T.
      HAUL.T.   SLACK.T  L.E.CLR   CARRIAGE": LOCATE 6,1:
      PRINT STRING$(79,"-"): RETURN
29420 PR=6:IF EYL=0 OR EYL>(TP2-1) THEN PO1=1:PO2=TP2-1 :GOTO 29440
29430 IF UD=1 THEN PO1=1:PO2=TP2-1 ELSE PO1=1:PO2=EYL
29440 FOR PO=PO1 TO PO2
29450    IF UD=1 AND SYST=3 THEN TA4(PO)=TA3(PO):TA3(PO)=0
29460    PR=PR+1:IF PO=16 OR PO=31 THEN PR=7:GOSUB 29600:GOSUB 29640
29470    FOR I=1 TO NOFI:IF PO=TPIS(I) THEN LOCATE PR,30:
            PRINT "** INTERMEDIATE SPAR **":GOTO 29580 ELSE NEXT I
29480    LOCATE PR,3:PRINT PO:LOCATE PR,10:PRINT USING "######";PL(PO):
         LOCATE PR,18:PRINT USING "###.#";CLR(PO)
29490    WHILE TA1(PO)<>0:LOCATE PR,25:PRINT USING "######";TA1(PO):
         GOTO 29500:WEND
29500    WHILE TA3(PO)<>0:LOCATE PR,34:PRINT USING "######";TA3(PO):
         GOTO 29510:WEND
29510    WHILE TA4(PO)<>0:LOCATE PR,44:PRINT USING "######";TA4(PO):
         GOTO 29520:WEND
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29520    WHILE TA5(PO)<>0:LOCATE PR,53:PRINT USING "######";TA5(PO):
         GOTO 29530:WEND
29530    LOCATE PR,62:IF LEC(PO)<>0 THEN PRINT USING "##.#";LEC(PO)
         ELSE IF SYST<>4 THEN PRINT "FULL"
29540    WHILE SYST=3 AND (WARN(PO)=1 OR WARN(PO)=2)
29550       IF WARN(PO)=1 THEN LOCATE PR,72:PRINT "MAY NOT" :GOTO 29580
29560       IF WARN(PO)=2 THEN LOCATE PR,72:PRINT "MAY PASS":GOTO 29580
29570    WEND
29580 NEXT PO
29590 RETURN
29600 LOCATE 25,26:PRINT "PRESS ANY KEY TO CONTINUE";:GOTO 29620
29610 LOCATE 25,23:COLOR 15,0:PRINT "ERROR! ";:COLOR 7,0:
      PRINT "PRESS ANY KEY TO CONTINUE";
29620 A$=INKEY$:IF A$="" THEN 29620
29630 RETURN
29640 IF SPAR=1 THEN SPAR=0:FOR I=8 TO 22:LOCATE I,1:PRINT S3$;:NEXT I:RETURN
29650 FOR I=7 TO 22:LOCATE I,1:PRINT S3$;:NEXT I:RETURN
29660 LOCATE 5,1:PRINT S3$:LOCATE 6,1:PRINT S3$:RETURN
29670 LOCATE 2,1:PRINT "=SPAR REACTION=";
29680 IF SYST=3 THEN N1=0:N2=2:SP=1 ELSE N1=0:N2=1:SP=1
29690 LOCATE 5,1:PRINT "  T.P.       SPAR  #";SP;
      "              SPAR  #";SP+1;"              SPAR  #";SP+2;
29700 LOCATE 6,1:PRINT "      HORIZON  VERTIC ANGLE   HORIZON
      VERTIC ANGLE  HORIZON   VERTIC ANGLE";
29710 LOCATE 7,1:PRINT STRING$(79,"-"):PR=7:SPAR=1
29720 IF EYL=0 OR UD=1 THEN EYL=TP2-1
29730 FOR BB=1 TO EYL
29740    PR=PR+1:IF BB=16 OR BB=31 THEN PR=8:SPAR=1:GOSUB 29600:GOSUB 29640
29750    LOCATE PR,3: PRINT BB
29760    C=6
29770    WHILE SYST=3:IF HREACT(BB,PP-1)=0 THEN LOCATE PR,30:
         PRINT "** INTERMEDIATE SPAR **":GOTO 29840 ELSE GOTO 29780:WEND
29780    FOR PP=N1 TO N2
29790       LOCATE PR,C:PRINT USING "######"; ABS(HREACT(BB,PP));
29800       LOCATE PR,C+10:PRINT USING "######";ABS(VREACT(BB,PP));
29810       LOCATE PR,C+17:PRINT USING "##.#"  ;ABS(ANGLE(BB,PP)*57.3);
29820       C=C+24
29830    NEXT PP
29840 NEXT BB
29850 IF SYST<>3 THEN 29870
29860 IF NOFI1>PP-1 THEN SPAR=1:GOSUB 29600:GOSUB 29640:PR=7: N1=PP :
      IF (NOFI1-N1)<=2 THEN N2=NOFI1 : SP=SP+3 : GOTO 29730 ELSE N2=N1+2:
      SP=SP+3 : GOTO 29730
29870 RETURN
29875 '======= (Multispan Carriage Passage Check for Downhill Yarding)========
29880 CD2=1
29890 FOR I=1 TO NOFI
29900    CD1=DD(I)-CD2
29910    CH1=HH(I)*CD1/(CD1+1)
29920    CH2=CH1/CD1
29930    FOR J=TPIS(I-1)+1 TO TPIS(I)-1
29940       TS(J)=(PL(J)+CWT)/2/SIN(ATN(CH1/CD1))
29950       SUMH=0
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29960        FOR CI=1 TO I
29970           SUMH=SUMH+HH(CI)
29980        NEXT CI
29990        TS(0)=TS(J)+W1*SUMH
30000        IF TS(0)<TU(0) THEN WARN(J)=2:GOTO 30080
30010        LSP=I:NDIS=I:CT(0)=TS(0)
30020        GOSUB 27520
30030        TA=TS(J):DL=CDR:DR=CDL:HL=CHR:HR=CHL
30040        H3=YIS(0)-YIS(I)+CHL:D3=XIS(I)-CDL:TPIS=TPIS(I)
30050        Y0=Y(TPIS)+CDL*A(TPIS+1)/100
30060        GOSUB 25050:CPL=PL
30070        IF CPL>PL(J) THEN WARN(J)=2 ELSE WARN(J)=1
30080     NEXT J
30090 NEXT I
30100 RETURN
30110 '================== {Define Ground Slope in Radians} ===================
30120 WHILE UD=0
30130    IF (A(DS+1)<0) OR (A(DS+1)>0 AND MY>ABS(A(DS+1)/100)) THEN
         THETA=ATN(-A(DS+1)/100) ELSE THETA=ATN(A(DS+1)/100)
30140    GOTO 30200
30150 WEND
30160 WHILE UD=1
30170    IF (A(DS+1)>0) OR (A(DS+1)<0 AND MY>ABS(A(DS+1)/100)) THEN
         THETA=ATN(A(DS+1)/100) ELSE THETA=ATN(-A(DS+1)/100)
30180    GOTO 30200
30190 WEND
30200 RETURN
30210 '========================== {Error Trap} ===============================
30220 WHILE Z1<>8 AND (Z(2)=0 OR Z(3)=0)
30230    IF Z(2)=0 THEN GOSUB 30400:PRINT "CARRIAGE WEIGHT":GOTO 30410
30240    IF Z(3)=0 THEN GOSUB 30400:PRINT "CARRIAGE DEPTH":GOTO 30410
30250 WEND
30260 WHILE (Z(5)=0 OR Z(7)=0) AND (Z1<8 OR Z1>12):GOSUB 30400:
      PRINT "SKYLINE INPUT":GOTO 30410:WEND
30270 WHILE Z(9)=0 OR Z(10)=0:GOSUB 30400:PRINT"MAINLINE INPUT":
      GOTO 30410:WEND
30280 WHILE Z1>7 AND Z1<13 AND (Z(12)=0 OR Z(13)=0):GOSUB 30400:
      PRINT"HAULBACK INPUT":GOTO 30410:WEND
30290 WHILE Z1>12 AND (Z(15)=0 OR Z(16)=0):GOSUB 30400:
      PRINT "SLACKLINE INPUT":GOTO 30410:WEND
30300 WHILE Z(22)=0 OR Z(24)=0:GOSUB 30400:PRINT "SPAR HEIGHT INPUT":
      GOTO 30410:WEND
30310 WHILE Z1=2 OR Z1=4 OR Z1=6 OR Z1=8 OR Z1=10 OR Z1=12 OR Z1=14 OR Z1=16
30320    IF Z(4)=0 THEN GOSUB 30400:PRINT "CHOKER LINE LENGTH":GOTO 30410
30330    IF Z(37)=0 AND Z1<>8 THEN GOSUB 30400:PRINT "LOG-END-CLEARANCE":
         GOTO 30410
30340    IF Z(39)=0 THEN GOSUB 30400:PRINT "AVERAGE LOG LENGTH":GOTO 30410
30350    GOTO 30370
30360 WEND
30370 WHILE (Z(38)<Z(39)+Z(4)) AND (Z1=1 OR Z1=3 OR Z1=5 OR Z1=7 OR Z1=9
      OR Z1=11 OR Z1=13 OR Z1=15):GOSUB 30400:PRINT "MINIMUM SKYLINE
      CLEARANCE (CLEARANCE<LOG LENGTH + CHOKER LENGTH)":GOTO 30410:WEND
30380 WHILE Z(39)=0:GOSUB 30400:PRINT "AVERAGE LOG LENGTH":GOTO 30410:WEND
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30390 GOTO 15530
30400 LOCATE 1,1:PRINT S3$:LOCATE 1,3:COLOR 23:PRINT "ERROR!";:
      COLOR 7,0:PRINT " CHECK ":LOCATE 1,16:RETURN
30410 GOSUB 29600:LOCATE 1,1:PRINT S3$:AN$="C":PROFN$="":GOTO 12070
30420 :
30430 LOCATE 25,1:PRINT S3$;:LOCATE 25,3
30440 IF ERR=61 THEN PROFN$="":GOSUB 30550:PRINT "DISK FULL ";:AN$="C":
      GOTO 14110
30450 IF ERR=70 THEN PROFN$="":GOSUB 30550:PRINT"DISK WRIGHT PROTECTED ";:
      AN$="C":GOTO 30530
30460 IF ERR=71 THEN PROFN$="":GOSUB 30550:PRINT "DISK NOT READY ";:
      AN$="C":GOTO 30540
30470 IF ERR=53 THEN PROFN$="":GOSUB 30550:PRINT "FILE NOT FOUND IN ";
      DRV$;": ";:GOTO 30540
30480 IF ERR=25 THEN GOSUB 30550:PRINT "PRINTER IS NOT READY ";:GOTO 30540
30490 IF ERR=11 THEN GOSUB 30550:PRINT "DIVISION BY ZERO IN LINE ";ERL;
      :GOTO 30540
30500 IF ERR=7 THEN GOSUB 30550:PRINT "OUT OF MEMORY IN LINE ";ERL;:GOTO 30540
30510 GOSUB 30550:PRINT "IN LINE ";ERL;
30520 GOTO 30540
30530 GOSUB 29600:RESUME 12030
30540 GOSUB 29610:CLEAR:RES=1:GOTO 10010
30550 LOCATE 2,2:COLOR 23:PRINT "ERROR! ";:COLOR 7,0:LOCATE 2,9:RETURN
```