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STEERABILITY ANALYSIS OF TRACKED VEHICLES: THEORY AND USER'S GUIDE FOR COMPUTER PROGRAM TVSTEER

by

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This report is a user's guide for the computer program TVSTEER, which predicts the steering performance of high-mobility/agility tracked vehicles in environments ranging from very soft soils to hard surfaces. In addition to a listing of the program (Appendix A), the report contains a glossary of the important variable names (Appendix B), typical sets of input and output data, a brief flowchart, and 10 sample runs. Appendix C describes a field direct shear device for use in measuring those engineering properties of soil which are required by the program TVSTEER. Appendix D is a notation.

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PREFACE

The study reported herein was conducted by personnel of the US Army Engineer Waterways Experiment Station (WES), Geomechanics Division (GD), Structures Laboratory (SL), for the Mobility Systems Division (MSD), Geotechnical Laboratory (GL). The work was part of Department of the Army Project No. 4A161102AT22, "Research in Soil and Rock Mechanics," Task Area 02, "Combat Engineering," Task CO, "Mobility (Combat Support)," Work Unit 004, "Wheel, Track, and Soil Dynamics Influence on Mobility," and was conducted between October 1985 and March 1986.

The study was conducted under the general supervision of Mr. Bryant Mather, Chief, SL; Dr. William F. Marcuson III, Chief, GL; Dr. John G. Jackson, Chief, GD; and Mr. Clifford J. Nuttall, Jr., Chief, MSD. The mathematical model was formulated by Drs. George Y. Baladi and Behzad Rohani. The logic and computer programming were accomplished by Dr. Baladi and Mr. D. E. Barnes. The report was written by Dr. Baladi, Mr. Barnes, and Mrs. Rebecca P. Berger.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

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LIST OF FIGURES

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
horsepower (550 foot-pounds (force) per second per ton (force)	83.82	watts per kilonewton
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (force)	4.448222	newtons
pounds (force)-inch-second squared	0.11306064	kilograms-square metres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic inch	0.0276799	kilograms per cubic centimetres
square inches	6.4516	square centimetres

STEERABILITY ANALYSIS OF TRACKED VEHICLES: THEORY AND USER'S GUIDE FOR COMPUTER PROGRAM TVSTEER

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

A terrain-tracked vehicle interaction model for predicting the steering performance of ground-crawling vehicles, referred to as TVSTEER, was developed in 1978 (Reference 1) and validated in 1981 and 1982 (References 2 and 3). The model treats both uniform (steady-state) and nonuniform (transient) motion.

In 1985, the Technical Management Committee (TMC) for the NATO Reference Mobility Model (NRMM) recommended the acceptance of TVSTEER as a mobility support model for evaluating high-mobility/agility tracked combat vehicles. The TMC also recommended that a TVSTEER user's guide be prepared by the US Army Engineer Waterways Experiment Station (WES) for the NATO community.

1.2 PURPOSE

This report summarizes the mathematical development of the terrain-tracked vehicle interaction model and presents a user's guide for the computer program TVSTEER.

1.3 SCOPE

The development of the terrain-vehicle interaction model is given in Chapter 2. A user's guide for the computer program TVSTEER, including typical input and output data, flowcharts of the main program and two subroutines, and several sample runs, is presented in Chapter 3. Appendix A presents the program listing for TVSTEER, and Appendix B is a glossary of important variables for the computer program. The description and use of a direct shear device for the measurement of pertinent soil properties are documented in Appendix C, while Appendix D is a notation.

CHAPTER 2

TERRAIN-VEHICLE INTERACTION MODEL

2.1 INTRODUCTION

The basic concepts of the theory of terrain-vehicle interaction were developed during the 1950's by Bekker (Reference 4). By assuming various load distributions along the tracks, Bekker was able to develop several mathematical expressions relating the characteristics of the vehicle and the tractive effort of the terrain during steering. By considering the lateral and longitudinal coefficients of friction between the track and the ground, Hayashi (Reference 5) developed simple equations for practical analysis of steering of tracked vehicles. Hayashi's work, however, did not include the effect of the centrifugal forces on steering performance of the vehicle. Kitano and Jyorzaki (Reference 6) developed a more comprehensive model for uniform turning motion including the effects of centrifugal forces. This model, however, is based on the assumption that ground pressure is concentrated under each road wheel and the terrain-track interaction is simulated by Coulomb-type friction. The model given by Kitano and Jyorzaki was extended by Kitano and Kuma (Reference 7) to include nonuniform (transient) motion, but the basic elements of the terrain-track interaction part of the model were retained. Baladi and Rohani (Reference 1) developed a model for uniform turning motion parallel to the development by Kitano and Jyorzaki insofar as the kinematics of the vehicle are concerned. In contrast to the development by Kitano and Jyorzaki (Reference 6), however, this model is based on a more comprehensive soil model. Baladi and Rohani (References 2 and 8) extended the WES terrain-vehicle model completed in 1979 to include nonuniform (transient) motion on level terrain. In addition, the WES soil model was modified to include a nonlinear failure envelope describing the shearing strength of the terrain material (Reference 2) and a nonuniform (transient) turning motion on sloping terrain (Reference 3).

2.2 SOIL MODEL

2.2.1 Strength Components

One of the most important properties of soil affecting trafficability is in situ shear strength. It has been found experimentally that the shear strength of purely cohesive soils is relatively independent of the confining stress, but strongly affected by the time rate of shearing. On the other hand, the shear strength of purely frictional soils is found to be relatively independent of the time rate of loading, but strongly dependent on confining pressure. The shearing resistance of most soils, however, is due to both the frictional and cohesive components. The cohesive and frictional components of strength are usually added together in order to obtain the total shear strength of the material. For static loading (very slow rate of deformation), the shear failure envelope is defined by the following nonlinear equation:

$$\tau_M = A - M \exp(-N\sigma) \qquad (2.1)$$

where

τ_M = the maximum shearing strength of the material

σ = the normal stress

A = the strength of the material when σ is large

$A - M = C$ = the strength of the material or cohesion when $\sigma = 0$

N = a material constant

Equation 2.1 is shown graphically in Figure 2.1.

For a linear shear failure envelope, the following equation can be used in place of Equation 2.1:

$$\tau_M = C + \sigma \tan \phi \qquad (2.2)$$

where ϕ is the angle of internal friction of the material. Equation 2.2 is shown graphically in Figure 2.2.

Equations 2.1 and 2.2 can be combined in the following relation:

$$\tau_m = [A - M \exp(-N\sigma)](1 - I) + (C + \sigma \tan \phi) I \qquad (2.3)$$

where

$$I = \begin{cases} 1 \text{ for linear failure envelope} \\ 0 \text{ for nonlinear failure envelope} \end{cases}$$

As noted previously, the shear strength of cohesive soils increases with the increasing rate of loading. For the range of loading rates asssociated with the motion of tracked vehicles, the contribution to cohesive strength due to dynamic loading can be expressed as $C_d[1 - \exp(-\Lambda\dot{\Delta})]$, where C_d and Λ are material constants and $\dot{\Delta}$ is the time rate of shearing deformation. In view of Equation 2.3, the dynamic failure criterion takes the following form:

$$\tau_m = [A - M \exp(-N\sigma)](1 - I) + (C + \sigma \tan \phi) I + C_d [1 - \exp(-\Lambda\dot{\Delta})] \quad (2.4)$$

When Λ equals zero, the dynamic failure criterion (Equation 2.4) reduces to the static failure criterion (Equation 2.3). Both are shown graphically in Figure 2.1 for nonlinear failure envelopes and Figure 2.2 for linear failure envelopes.

2.2.2 Shear Stress-Shear Deformation Relation

Prior to failure, the shear stress-shear deformation characteristics of a variety of soils can be expressed by the following mathematical expression (Reference 9):

$$\tau = \frac{G \tau_M \Delta}{\tau_M + G|\Delta|} \quad (2.5)$$

The behavior of Equation 2.5 is shown graphically in Figure 2.3, in which τ denotes shearing stress, Δ is shearing deformation, and G is the initial shear stiffness coefficient. Substituting τ_M from Equation 2.4 into Equation 2.5, the shear stress-shear deformation relation for soil becomes

$$\tau = \frac{G\{[A - M \exp(-N\sigma)](1 - I) + (C + \sigma \tan \phi) I + C_d [1 - \exp(-\Lambda\dot{\Delta})]\} \Delta}{G|\Delta| + [A - M \exp(-N\sigma)](1 - I) + (C + \sigma \tan \phi) I + C_d [1 - \exp(-\Lambda\dot{\Delta})]} \quad (2.6)$$

For purely cohesive soils, N equals zero ($\phi = 0$ if the failure envelope is linear) and τ is only a function of Δ and $\dot{\Delta}$. For cohesionless or granular soils, M equals A (or $C = 0$ if the failure envelope is linear), C_d is zero, and τ is a function of Δ and σ . For mixed soils exhibiting shearing resistance due to both frictional and cohesive components, τ is dependent on Δ , $\dot{\Delta}$, and σ . The qualitative behavior of Equation 2.6 for these three conditions is shown in Figure 2.4. It should be pointed out that Equation 2.6 reduces to the rigid plastic soil model often used in mobility studies when an extremely large value is specified for G and Λ is set to zero.

An appropriate test for determining the numerical values of the material constants in Equation 2.6 is an in situ direct shear test. A field direct shear device has been developed at WES for this purpose. A description of this device and the method of analysis of the data obtained from the direct shear test are documented in Appendix C (Reference 8).

2.3 DERIVATION OF TERRAIN-VEHICLE MODEL

2.3.1 Boundary Conditions

The geometry of the vehicle and the boundary conditions of the proposed model are shown schematically in Figure 2.5. The XYZ coordinates are the local coordinate system of which X is always the longitudinal axis of the vehicle and Y is a transverse axis parallel to the ground. These axes intersect at the center of geometry of the vehicle O . The Z axis is a vertical axis passing through the origin O . The center of gravity of the vehicle (CG) lies on the X axis and is displaced by a distance C_X from the origin. The numerical value of C_X is assumed to be positive if CG is displaced forward from the center of geometry of the vehicle. The XY coordinates of the instantaneous center of rotation (ICR) are $P + C_X$ and $\tilde{R}$, respectively, where P is the offset. The center of rotation and the radius of the trajectory of the CG are, respectively, CR and R_O . The height of the center of gravity measured from ground surface is denoted by H . The lengths of the track-ground contact, the track width, and the tread of the tracks are L , D , and B , respectively. As shown in Figure 2.5, the components of the inertial forces F_C in X and Y directions are, respectively, F_{CX} and F_{CY} . The weight of the vehicle is W .

2.3.2 Stress Distribution along the Tracks

Two types of stress (i.e., normal and shear stresses) exist along the track. As indicated in Figure 2.5, the normal stresses under the outer and inner tracks are denoted by $R_1(X)$ and $R_2(X)$, respectively. The components of the shear stress in X and Y directions are, respectively, $T_1(X)$ and $Q_1(X)$ for the outer track, and $T_2(X)$ and $Q_2(X)$ for the inner track. These stresses are dependent on the terrain type, vehicle configuration, and speed and turning radius of the vehicle.

The magnitude of normal stresses $R_1(X)$ and $R_2(X)$ can be determined in terms of the components of the inertial force, the track tensions, and the characteristics of the vehicle by considering the balance of vertical stresses and their moments in Figure 2.5. Thus,

$$R_1(x) = \frac{W}{dL^2}\left[\frac{1}{2} + 6xc_x - \frac{h}{b}\frac{F_{CY}}{W} - 6hx\frac{F_{CX}}{W} + \frac{dL^2 N_1(x)}{W}\right] \tag{2.7}$$

$$R_2(x) = \frac{W}{dL^2}\left[\frac{1}{2} + 6xc_x + \frac{h}{b}\frac{F_{CY}}{W} - 6hx\frac{F_{CX}}{W} + \frac{dL^2 N_2(x)}{W}\right] \tag{2.8}$$

where

$h = H/L$

$b = B/L$

$d = D/L$

$c_X = C_X/L$

$x = X/L$

$y = Y/L$

$z = Z/L$

$N_1(x)$ and $N_2(x)$ = contributions due to track tension.

The components of the shear stress in the X and Y directions along both the outer and inner tracks can be obtained by combining Equations 2.6, 2.7, and 2.8. Thus (it is noted that R_1 and R_2 replace the normal stress σ in Equation 2.6),

$$T_i(x) = \frac{W\mu\delta_i}{L^2}\left\{\frac{\left[a - m\exp\left(\frac{-nr_i(x)}{d}\right)\right](1 - I) + \left[c + \frac{r_i(x)}{d}\tan\phi\right]I + c_d[1 - \exp(-\lambda\dot{\delta}_i)]}{\mu|\delta_i| + \left[a - m\exp\left(\frac{-nr_i(x)}{d}\right)\right](1 - I) + \left[c + \frac{r_i(x)}{d}\tan\phi\right]I + c_d[1 - \exp(-\lambda\dot{\delta}_i)]}\right\}\cos\gamma_i \tag{2.9}$$

$$Q_i(x) = \frac{W\mu\delta_i}{L^2}\left\{\frac{\left[a - m\exp\left(\frac{-nr_i(x)}{d}\right)\right](1 - I) + \left[c + \frac{r_i(x)}{d}\tan\phi\right]I + c_d[1 - \exp(-\lambda\dot{\delta}_i)]}{\mu|\delta_i| + \left[a - m\exp\left(\frac{-nr_i(x)}{d}\right)\right](1 - I) + \left[c + \frac{r_i(x)\tan\phi}{d}\right]I + c_d[1 - \exp(-\lambda\dot{\delta}_i)]}\right\}\sin\gamma_i \tag{2.10}$$

where

i = 1,2 (1 for the outer track and 2 for the inner track)

$r_i(x) = dL^2 R_i(x)/W$

$$\delta_i = \Delta_i/L$$

$$\dot{\delta}_i = \dot{\Delta}_i/L$$

$$\mu = GL^3/W$$

$$\lambda = \Lambda L$$

$$a = AL^2/W$$

$$m = ML^2/W$$

$$n = NW/L^2$$

$$c = CL^2/W$$

$$c_d = C_d L^2/W$$

The variables γ_1 and γ_2 in Equations 2.9 and 2.10 are the slip angles and can be written as

$$\left.\begin{aligned} \gamma_1 &= \tan^{-1} \frac{X - P - C_X}{C_1} = \tan^{-1} \frac{x - p - c_x}{\xi_1} \\ \gamma_2 &= \tan^{-1} \frac{X - P - C_X}{C_2} = \tan^{-1} \frac{x - p - c_x}{\xi_2} \end{aligned}\right\} \quad (2.11)$$

where

$$\xi_1 = C_1/L$$

$$\xi_2 = C_2/L$$

$$p = P/L$$

The parameter C_1 is the distance between the instantaneous center of rotation of the outer track IC_1 and its axis of symmetry, and C_2 is the distance between the instantaneous center of rotation of the inner track IC_2 and its axis of symmetry (Figure 2.6).

In order to use Equations 2.9 through 2.11, the normal stress contributions due to track tensions $N_1(x)$ and $N_2(x)$, the track slip velocities and displacements (i.e., $\dot{\Delta}_1$, Δ_1, $\dot{\Delta}_2$, and Δ_2), and the inertial forces F_{CX} and F_{CY} have to be determined. These factors are discussed in the following paragraphs.

2.3.3 Normal Stress Contribution Due to Track Tension

The effect of track tension on the normal stress distribution is influenced considerably by the motion of the vehicle. At relatively low speed, tractive effort is applied to the outer track, while braking force is applied to the inner track (Figure 2.7a). At high speed, on the other hand, tractive efforts are applied to both tracks (Figure 2.7b).

The angles Θ_a and Θ_d in Figure 2.7 are the approach and departure angles of the track envelope, respectively. The forces $\overline{T}_1$ and $\overline{T}_2$ are the track tensions in the outer and inner tracks, respectively. These forces can be obtained by integrating Equation 2.9. Thus,

$$\left.\begin{aligned} \overline{T}_1 &= dL^2 \int_{-\frac{1}{2}}^{\frac{1}{2}} T_1(x)\,dx \\ \overline{T}_2 &= dL^2 \int_{-\frac{1}{2}}^{\frac{1}{2}} T_2(x)\,dx \end{aligned}\right\} \qquad (2.12)$$

The normal stress distributions are influenced, however, by the vertical components of the forces $\overline{T}_1$ and $\overline{T}_2$; namely, n_1 , n_2 , and n_2' . The values of n_1 , n_2 , and n_2' are

$$n_1 = \overline{T}_1 \sin \Theta_d \qquad (2.13)$$

$$n_2 = \begin{Bmatrix} \overline{T}_2 \sin \Theta_a & \text{if} \quad \xi_2 \geq 0 \\ 0 & \text{if} \quad \xi_2 < 0 \end{Bmatrix} \qquad (2.14)$$

$$n_2' = \begin{Bmatrix} -\overline{T}_2 \sin \Theta_d & \text{if} \quad \xi_2 < 0 \\ 0 & \text{if} \quad \xi_2 \geq 0 \end{Bmatrix} \qquad (2.15)$$

With the determination of the forces n_1 , n_2 , and n_2' , the normal stress contributions due to track tension may be determined.

Since the tracks are assumed to be rigid, the normal stresses due to track tension may be distributed according to the following equations (Figure 2.8):

$$\left.\begin{aligned} N_1(x) &= ax + m_O && \text{for } \frac{\ell}{L} - \frac{1}{2} \le x \le \frac{1}{2} \\ N_1(x) &= ax + m_O + \frac{2n_1}{d\ell^2}\left(x + \frac{1}{2} - \frac{\ell}{L}\right) && \text{for } -\frac{1}{2} \le x \le \frac{\ell}{L} - \frac{1}{2} \end{aligned}\right\} \qquad (2.16)$$

and

$$\left.\begin{aligned} N_2(x) &= ax + m_I - \frac{2n_2}{d\ell^2}\left(x + \frac{1}{2} + \frac{\ell}{L}\right) && \text{for } \frac{1}{2} - \frac{\ell}{L} \le x \le \frac{1}{2} \\ N_2(x) &= ax + m_I && \text{for } \frac{\ell}{L} - \frac{1}{2} \le x \le \frac{1}{2} - \frac{\ell}{L} \\ N_2(x) &= ax + m_I + \frac{2n_2'}{d\ell^2}\left(x + \frac{1}{2} - \frac{\ell}{L}\right) && \text{for } -\frac{1}{2} \le x \le \frac{\ell}{L} - \frac{1}{2} \end{aligned}\right\} \qquad (2.17)$$

in which ℓ is the distance between two adjacent wheels, and a , m_O , and m_I can be determined by considering the equation of equilibrium of normal stresses and the moments of these stresses. Thus,

$$\int_{-\frac{1}{2}}^{\frac{1}{2}} (ax + m_O)\, dx + \int_{-\frac{1}{2}}^{\frac{\ell}{L} - \frac{1}{2}} \frac{2n_1}{d\ell^2}\left(x + \frac{1}{2} - \frac{\ell}{L}\right) dx = 0 \qquad (2.18)$$

$$\int_{-\frac{1}{2}}^{\frac{1}{2}} (ax + m_I)\, dx - \int_{\frac{1}{2} - \frac{\ell}{L}}^{\frac{1}{2}} \frac{2n_2}{d\ell^2} \left(x - \frac{1}{2} + \frac{\ell}{L}\right) dx$$

$$+ \int_{-\frac{1}{2}}^{\frac{\ell}{L} - \frac{1}{2}} \frac{2n_2'}{d\ell^2} \left(x + \frac{1}{2} + \frac{\ell}{L}\right) dx = 0 \qquad (2.19)$$

and

$$\int_{-\frac{1}{2}}^{\frac{1}{2}} (2ax + m_I + m_O)\left(\frac{1}{2} + \frac{\ell}{L} - x\right) dx - \int_{\frac{1}{2} - \frac{\ell}{L}}^{\frac{1}{2}} \frac{2n_2}{d\ell^2} \left(x - \frac{1}{2} + \frac{\ell}{L}\right)\left(\frac{1}{2} + \frac{\ell}{L} - x\right) dx$$

$$+ \int_{-\frac{1}{2}}^{\frac{1}{2}} \frac{2(n_1 + n_2')}{d\ell^2} \left(x + \frac{1}{2} - \frac{\ell}{L}\right)\left(\frac{1}{2} + \frac{\ell}{L} - x\right) dx = 0 \qquad (2.20)$$

Equations 2.18 through 2.20 contain three unknowns: a , m_O , and m_I . Completing the integrations results in

$$a = \frac{1}{dL^2}\left(3 - \frac{2\ell}{L}\right)(n_2 - n' - n_1) \qquad (2.21)$$

$$m_O = \frac{1}{dL^2} n_1 \qquad (2.22)$$

$$m_I = \frac{1}{dL^2} (n_2 + n_2') \qquad (2.23)$$

Substitution of Equations 2.21 through 2.23 into Equations 2.16 and 2.17 leads to

$$N_1(x) = \frac{1}{dL^2} \left[(3 - 2\beta)\,(n_2 - n_2' - n_1)\,x + n_1 \right] \quad \text{for} \quad \beta - \frac{1}{2} \le x \le \frac{1}{2}$$

$$N_1(x) = \frac{1}{dL^2} \left\{ \left[(3 - 2\beta)\,(n_2 - n_1' - n_1) + \frac{2n_1}{\beta^2} \right] x + \left(\frac{1 - \beta}{\beta} \right)^2 n_1 \right\} \qquad (2.24)$$

$$\text{for} \quad -\frac{1}{2} \le x \le \beta - \frac{1}{2}$$

and

$$N_2(x) = \frac{1}{dL^2} \left\{ \left[(3 - 2\beta)\,(n_2 - n_2' - n_1) - \frac{2n_2}{\beta^2} \right] x + \left(\frac{1 - \beta}{\beta} \right)^2 n_2 + n_2' \right\}$$

$$\text{for} \quad \frac{1}{2} - \beta \le x \le \frac{1}{2}$$

$$N_2(x) = \frac{1}{dL^2} \left[(3 - 2\beta)\,(n_2 - n_2' - n_1)\,x + n_2 + n_2' \right] \qquad (2.25)$$

$$\text{for} \quad \beta - \frac{1}{2} \le x \le \frac{1}{2} - \beta$$

$$N_2(x) = \frac{1}{dL^2} \left\{ \left[(3 - 2\beta)\,(n_2 - n_2' - n_1) + \frac{2n_2'}{\beta^2} \right] x + \left(\frac{1 - \beta}{\beta} \right)^2 n_2' + n_2 \right\}$$

$$\text{for} \quad -\frac{1}{2} \le x \le \beta - \frac{1}{2}$$

where

$$\beta = \frac{\ell}{L}$$

Note that Equations 2.14 and 2.15 dictate that either n^2 or n_2' in Equations 2.24 and 2.25 is zero.

2.3.4 Kinematics of the Vehicle

A tracked vehicle in transient motion is shown schematically in Figure 2.9. The XYZ coordinates are the local coordinate systems that are fixed with respect to the moving vehicle (also see Figure 2.5). The origin 0 of this coordinate system stays, for all time, at a distance C_X from the center of gravity of the vehicle. The $\Psi\Phi$ coordinate system is fixed on level ground, and its origin coincides with the center of gravity at time zero. The vehicle can maneuver on the $\Psi\Phi$ plane and the displacements of the center of gravity of the vehicle from this reference frame are $\Psi(t)$ and $\Phi(t)$.

The velocities v_X and v_Y (relative to the origin of the $\Psi\Phi$ coordinate system) as well as the velocities v_Ψ and v_Φ are related to the instantaneous velocity v of the CG by

$$v = \sqrt{v_X^2 + v_y^2} = \sqrt{v_\Psi^2 + v_\Phi^2} \tag{2.26}$$

The side-slip angle α , which is the angle between the velocity vector v and the longitudinal X axis of the vehicle, is related to the velocities v_X and v_Y as

$$\alpha = \tan^{-1} \frac{v_Y}{v_X} , \quad \frac{d\alpha}{dt} = \left(v_X \frac{dv_Y}{dt} - v_Y \frac{dv_X}{dt} \right) \Big/ v^2 \tag{2.27}$$

The yaw angle ω and the directional angle Θ are related to α as

$$\Theta = \omega - \alpha , \quad \frac{d\Theta}{dt} = \frac{d\omega}{dt} - \frac{d\alpha}{dt} \tag{2.28}$$

Substitution of Equation 2.27 into Equation 2.28 leads to

$$\frac{d\Theta}{dt} = \frac{d\omega}{dt} - \left(v_X \frac{dv_Y}{dt} - v_Y \frac{dv_X}{dt} \right) \Big/ v^2 \tag{2.29}$$

The radius of curvature of the trajectory of the center of gravity (i.e., the distance between CR and CG (Figures 2.6 and 2.10) is

$$R_o = v \Big/ \frac{d\Theta}{dt} = \frac{v^3}{v^2 \frac{d\omega}{dt} - v_X \frac{dv_Y}{dt} + v_Y \frac{dv_X}{dt}} \tag{2.30}$$

The coordinates of the trajectory of the center of gravity of the vehicle can be written as

$$\left.\begin{aligned} \Psi(t) &= -\int_0^t v \cos\theta \, dt \\ \Phi(t) &= \int_0^t v \sin\theta \, dt \end{aligned}\right\} \qquad (2.31)$$

The coordinates of the instantaneous center of rotation (ICR) of the hull in the XY systems (X_I , Y_I) and the instantaneous radius of curvature (R_I) are (Figures 2.6 and 2.10)

$$\left.\begin{aligned} X_I &= P + C_X = v_Y \Big/ \frac{d\omega}{dt} + C_X \\ Y_I &= \tilde{R} = v_X \Big/ \frac{d\omega}{dt} \\ R_I &= \sqrt{\tilde{R}^2 + P^2} \end{aligned}\right\} \qquad (2.32)$$

The instantaneous velocities of an arbitrary point e of the hull are shown in Figure 2.10 and can be written as

$$\left.\begin{aligned} v_{eX} &= v_X + Y \frac{d\omega}{dt} \\ v_{eY} &= v_Y - (X - C_X) \frac{d\omega}{dt} \\ v_e &= \sqrt{\left(v_X + Y \frac{d\omega}{dt}\right)^2 + \left[v_Y - (X - C_X) \frac{d\omega}{dt}\right]^2} \end{aligned}\right\} \qquad (2.33)$$

2.3.5 Track Slip Velocity and Displacement

Assume that v_{s1} ($v_{s1} = \dot{\Delta}_1$) is the slip velocity of an arbitrary point e_1 of the outer track and v_{s2} ($v_{s2} = \dot{\Delta}_2$) is the slip velocity at point e_2 (e_1 and e_2 have the same abscissa) of the inner track (Figure 2.6). The X and Y components of these velocities are

$$\left.\begin{aligned} v_{sX1} &= C_1 \frac{d\omega}{dt} = \xi_1 L \frac{d\omega}{dt} \\ v_{sY1} &= (X - P - C_X) \frac{d\omega}{dt} = L(X - c_X) \frac{d\omega}{dt} - v_Y \end{aligned}\right\} \text{For the outer track} \qquad (2.34)$$

$$\left.\begin{aligned} v_{sX2} &= C_2 \frac{d\omega}{dt} = \xi_2 L \frac{d\omega}{dt} \\ v_{sY2} &= v_{sY1} \end{aligned}\right\} \text{ For the inner track} \tag{2.35}$$

As indicated in Figure 2.11, the angular velocity $d\omega/dt$ and the value of $\tilde{R}$ can be written as

$$\left.\begin{aligned} \frac{d\omega}{dt} &= \frac{1}{bL} (v_{X1} - v_{sX1} - v_{X2} + v_{sX2}) \\ \tilde{R} &= \frac{1}{2\frac{d\omega}{dt}} (v_{X1} - v_{sX1} + v_{X2} - v_{sX2}) \end{aligned}\right\} \tag{2.36}$$

where

v_{X1} = the velocity of the outer track in X direction

v_{X2} = the velocity of the inner track in X direction

The ratio of v_{X1} and v_{X2} is defined as the steering ratio ε. Thus,

$$\varepsilon = v_{X1}/v_{X2} \tag{2.37}$$

Substitution of Equations 2.32 and 2.37 into Equation 2.36 leads to

$$\left.\begin{aligned} v_{sX1} &= \varepsilon v_{X2} - \left(v_X + \frac{bL}{2} \frac{d\omega}{dt}\right) \text{ For the outer track} \\ v_{sX2} &= v_{X2} - \left(v_X - \frac{bL}{2} \frac{d\omega}{dt}\right) \text{ For the inner track} \end{aligned}\right\} \tag{2.38}$$

Comparison between Equations 2.37 and 2.38 and Equations 2.34 and 2.35 results in

$$\left.\begin{aligned} \xi_1 &= (\varepsilon v_{X2} - v_X) \Big/ \left(L \frac{d\omega}{dt}\right) - \frac{b}{2} \\ \xi_2 &= (v_{X2} - v_X) \Big/ \left(L \frac{d\omega}{dt}\right) + \frac{b}{2} \end{aligned}\right\} \tag{2.39}$$

The slip velocities and displacements of the outer and inner tracks can be obtained from Equations 2.34, 2.35, and 2.38. Thus,

$$\left.\begin{aligned}\frac{v_{s1}}{\sqrt{Lg}} &= \sqrt{\frac{L}{g}\frac{d\omega}{dt}}\sqrt{\xi_1^2 + \left[(x - c_X) - \frac{v_Y}{L\,\frac{d\omega}{dt}}\right]^2}\\ \frac{v_{s2}}{\sqrt{Lg}} &= \sqrt{\frac{L}{g}\frac{d\omega}{dt}}\sqrt{\xi_2^2 + \left[(x - c_X) - \frac{v_Y}{L\,\frac{d\omega}{dt}}\right]^2}\end{aligned}\right\} \qquad (2.40)$$

$$\frac{\Delta_1}{L} = \int_0^{t_1} \frac{v_{s1}}{L}\,dt + \frac{\Delta_{I1}}{L}, \quad \frac{\Delta_2}{L} = \int_0^{t_2} \frac{v_{s2}}{L}\,dt + \frac{\Delta_{I2}}{L} \qquad (2.41)$$

where

$t_1 = (L/2 - X)/v_{X1}$

$t_2 = (L/2 - X)/v_{X2}$

Δ_{I1} = initial displacement of the outer track

Δ_{I2} = initial displacement of the inner track

The values of Δ_{I1} and Δ_{I2} depend on the balance between all forces and moments applied on the vehicle at zero velocity. The forces applied on the vehicle at zero velocity are in turn dependent on the rolling resistance. Within the framework of the present model, the balance of forces and moments dictates that the initial displacements be numerically equal to the coefficient of rolling resistance f (i.e., $\frac{\Delta_{I1}}{L} = \frac{\Delta_{I2}}{L} = f$). The coefficient of rolling resistance f must be measured experimentally or calculated from empirical relations presented in Section 2.3.7 (Reference 10).

2.3.6 Inertial Forces

According to Figure 2.9, the relationship between the velocities v_Ψ and V_Φ and the velocities v_X and v_Y can be written as

$$\left.\begin{aligned}v_\Psi &= -v_X \cos\omega - v_Y \sin\omega\\ v_\Phi &= v_X \sin\omega - v_Y \cos\omega\end{aligned}\right\} \qquad (2.42)$$

The acceleration in Ψ and Φ direction, a_Ψ and a_Φ, can be written as

$$\left.\begin{aligned} a_\Psi &= \frac{dv_\Psi}{dt} \\ a_\Phi & \frac{dv_\Phi}{dt} \end{aligned}\right\} \qquad (2.43)$$

The forward and lateral accelerations, a_X and a_Y, can be written in terms of a_Ψ and a_Φ as

$$\left.\begin{aligned} a_X &= -a_\Psi \cos \omega + a_\Phi \sin \omega \\ a_Y &= -a_\Psi \sin \omega - a_\Phi \cos \omega \end{aligned}\right\} \qquad (2.44)$$

Substitution of Equations 2.42 and 2.43 into Equation 2.44 leads to

$$\left.\begin{aligned} a_X &= \frac{dv_X}{dt} + v_Y \frac{d\omega}{dt} \\ a_Y &= \frac{dv_Y}{dt} - v_X \frac{d\omega}{dt} \end{aligned}\right\} \qquad (2.45)$$

Hence, the X and Y components of the inertial force can be written as

$$\left.\begin{aligned} F_{CX} &= \frac{W}{g} a_X = \frac{W}{g}\left(\frac{dv_X}{dt} + v_Y \frac{d\omega}{dt}\right) \\ F_{CY} &= \frac{W}{g} a_Y = \frac{W}{g}\left(\frac{dv_Y}{dt} - v_X \frac{d\omega}{dt}\right) \end{aligned}\right\} \qquad (2.46)$$

where g is the acceleration of gravity.

2.3.7 Rolling Resistance

The rolling resistance R_s is a function of terrain type, vehicle speed, track condition, etc. Therefore, rolling resistance should be measured for every specific condition. In this formulation, however, the rolling resistance is assumed to be proportional to normal load. Thus,

$$R_s = \frac{W}{dL^2} \, \delta \int_{-\frac{1}{2}}^{\frac{1}{2}} [r_1(x) + r_2(x)]dx \qquad (2.47)$$

As stated above, the coefficient of rolling resistance δ can be measured experimentally or calculated from an empirical procedure. Rula and Nuttall (Reference 10) presented such an empirical procedure by which the coefficient of rolling resistance is calculated in terms of the vehicle characteristics and the WES cone index. The procedure involves the following steps.

1. Determine the mobility index (MI) for the tracked vehicle of interest using the following expression:

$$MI = \left\{ \frac{\begin{bmatrix}\text{contact}\\ \text{pressure}\\ \text{factor}\end{bmatrix} \begin{bmatrix}\text{weight}\\ \text{factor}\end{bmatrix}}{\begin{bmatrix}\text{track}\\ \text{factor}\end{bmatrix} \begin{bmatrix}\text{grouser}\\ \text{factor}\end{bmatrix}} + \begin{bmatrix}\text{bogie}\\ \text{factor}\end{bmatrix} - \begin{bmatrix}\text{clear-}\\ \text{ance}\\ \text{factor}\end{bmatrix} \right\} \begin{bmatrix}\text{engine}\\ \text{factor}\end{bmatrix} \begin{bmatrix}\text{transmis-}\\ \text{sion}\\ \text{factor}\end{bmatrix} \qquad (2.48)$$

where[1]

$$\text{Contact pressure factor} = \frac{\text{gross weight, lb}}{\text{area of tracks in contact with ground, in.}^2} \qquad (2.49)$$

Weight factor: (2.50)
- Less than 50,000 lb = 1.0
- 50,000 to 69,999 lb = 1.2
- 70,000 to 99,999 lb = 1.4
- 100,000 lb or greater = 1.8

$$\text{Track factor} = \frac{\text{track width, in.}}{100} \qquad (2.51)$$

Grouser factor: (2.52)
- Grousers less than 1.5 in. high = 1.0
- Grousers more than 1.5 in. high = 1.1

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[1] A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

$$\text{Bogie factor} = \frac{\text{gross weight, lb, divided by 10}}{(\text{total number of bogies on tracks in contact with ground})\ (\text{area, in.}^2\text{, of 1 track shoe})} \quad (2.53)$$

$$\text{Clearance factor} = \frac{\text{clearance, in.}}{10} \quad (2.54)$$

$$\text{Engine factor:} \quad \begin{Bmatrix} \geq 10 \text{ hp/ton of vehicle wt} = 1.00 \\ < 10 \text{ hp/ton of vehicle wt} = 1.05 \end{Bmatrix} \quad (2.55)$$

$$\text{Transmission factor:} \quad \text{Automatic} = 1.0;\ \text{manual} = 1.05 \quad (2.56)$$

2. Determine the vehicle cone index VCI_1 for one-pass traffic using the expression

$$VCI_1 = 7.0 + 0.2\ MI - \left(\frac{39.2}{MI + 5.6}\right) \quad (2.57)$$

3. The coefficient of rolling resistance is then determined by the following equation:*

$$\delta = 0.045 + \frac{2.3075}{CI - VCI_1 + 6.5} \quad (2.58)$$

where CI is the WES cone index for the particular terrain of interest. Note that CI must be equal to or greater than VCI_1 in order for the vehicle to complete one pass.

The value of CI must be determined experimentally. However, if such measurement is not available, CI can be estimated from the parameters C and ϕ in the soil model. The following empirical relation is often used to relate CI to C and ϕ :

$$CI = 12C\ (\text{in psi}) + 4\phi\ (\text{in degrees}) \quad (2.59)$$

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* In Reference 10, the rating cone index RCI rather than cone index CI is used to calculate δ . RCI is the product of measured cone index and remolding index RI , and is a valid description only for fine-grained soils and for sands with fines, poorly drained. RI is a ratio that expresses the change in strength of a fine-grained soil or a sand with fines, poorly drained, that may occur under traffic of a vehicle.

Rohani and Baladi (Reference 11) developed more accurate relationships between CI and the mechanical properties of soil (such as C, ϕ, the shear modulus G, and the density γ). These relationships are

$$CI = -C \cot \phi + \frac{2 \tan \tilde{\alpha} \, (1 + \sin \phi) G^{\tilde{m}}}{\left(\frac{\tilde{D}}{2} \gamma\right)^2 \tan^3 \phi} \left[\frac{3(\tan \tilde{\alpha} + \tan \phi)}{3 - \sin \phi}\right] \Omega$$

where (2.60)

$$\Omega = \frac{[C + \gamma(\tilde{Z} + \tilde{L}) \tan \phi]^{3-\tilde{m}} - [C + \gamma(\tilde{Z} + \tilde{L}) \tan \phi + (2 - \tilde{m})\gamma\tilde{L} \tan \phi](C + \gamma\tilde{Z} \tan \phi)^{2-\tilde{m}}}{(2 - \tilde{m})(3 - \tilde{m})}$$

For granular materials C = 0 and Equation 2.60 reduces to

$$CI = \frac{2 \tan \tilde{\alpha}(1 + \sin \phi) G^{\tilde{m}}}{\left(\frac{\tilde{D}}{2} \gamma\right)^2 \tan^3 \phi} \left[\frac{3(\tan \tilde{\alpha} + \tan \phi)}{3 - \sin \phi}\right] \Omega$$

where (2.61)

$$\Omega = \frac{[\gamma(\tilde{Z} + \tilde{L}) \tan \phi]^{3-\tilde{m}} - [\gamma (\tilde{Z} + \tilde{L}) \tan \phi + (2 - \tilde{m}) \gamma\tilde{L} \tan \phi](\gamma\tilde{Z} \tan \phi)^{2-\tilde{m}}}{(2 - \tilde{m})(3 - \tilde{m})}$$

For cohesive soil where $\tan \phi = 0$, the expression for CI is given by

$$CI = \frac{4}{3} C(1 + \ln \frac{G}{C}) + \frac{2\tilde{L}}{\tilde{D}} C + \gamma(\tilde{Z} + \tilde{L}/3) \qquad (2.62)$$

where

- C = cohesion
- ϕ = angle of internal friction
- G = shear modulus of the material
- γ = density of the material
- CI = cone index
- $\tilde{D}$ = diameter of the cone
- $\tilde{L}$ = length of the cone
- $2\tilde{\alpha}$ = apex angle of the cone

$\tilde{Z}$ = depth of penetration

$\bar{m}$ = $(4 \sin \phi)/[\sin \phi + 1)]$

In Equation 2.60 through 2.62, $\tilde{Z} = 0$ corresponds to a fully embedded cone. These equations express the cone index CI in terms of the soil parameters C , ϕ , γ , and G , the depth of penetration $\tilde{Z}$, and the geometry of the cone.

2.3.8 Equation of Motion

Steerability and stability of tracked vehicles depend on the dynamic balance between all forces and moments applied on the vehicle. According to Figure 2.5, the following three equations govern the motion of the vehicle:

$$\int_{-\frac{1}{2}}^{\frac{1}{2}} [t_1(x) + t_2(x)]\, dx - \delta \int_{-\frac{1}{2}}^{\frac{1}{2}} [r_1(x) + r_2(x)]dx = f_{CX} \tag{2.63}$$

$$\int_{-\frac{1}{2}}^{\frac{1}{2}} [q_1(x) + q_2(x)]\, dx = f_{CY} \tag{2.64}$$

$$- \int_{-\frac{1}{2}}^{\frac{1}{2}} [q_1(x) + q_2(x)]\,(x - c_X)\, dx + \frac{b}{2} \int_{-\frac{1}{2}}^{\frac{1}{2}} [t_1(x) - t_2(x)]\, dx$$

$$+ \frac{b}{2}\, \delta \int_{-\frac{1}{2}}^{\frac{1}{2}} [r_2(x) - r_1(x)]\, dx = \frac{I_z}{LW} \frac{d^2\omega}{dt^2} \tag{2.65}$$

where

$$t_1(x) = \frac{dL^2}{W} T_1(x)$$

$$t_2(x) = \frac{dL^2}{W} T_2(x)$$

$$q_1(x) = \frac{dL^2}{W} Q_1(x)$$

$$q_2(x) = \frac{dL^2}{W} Q_2(x)$$

$$f_{CX} = \frac{F_{CX}}{W}$$

$$f_{CY} = \frac{F_{CY}}{W}$$

I_z = mass moment of inertia about an axis passing through the CG of the vehicle and parallel to the Z axis (Figure 2.5)

Equations 2.63 through 2.65 are the equations of motion for the nonuniform (transient) motion. As will be shown below, the uniform turning motion can also be obtained from these equations.

2.3.9 Treatment of Sloping Terrain

Figure 2.12 shows schematically a tracked vehicle under nonuniform (transient) turning motion on a terrain with slope angle η. In this case, the weight of the vehicle W could be resolved into a normal component (normal to the terrain) W_N and a parallel component W_T. Thus,

$$\left.\begin{aligned} W_N &= W \cos \eta \\ W_T &= W \sin \eta \end{aligned}\right\} \tag{2.66}$$

In general, the longitudinal axis of the vehicle X makes an angle χ with the component W_T (Figure 2.12). Therefore, the component W_T could be resolved into two components. The first component W_{TX} is parallel to the X axis of the vehicle and the second component W_{TY} is parallel to the Y axis. Thus,

$$\left.\begin{aligned} W_{TX} &= W_T \cos \chi = W \sin \eta \cos \chi \\ W_{TY} &= W_T \sin \chi = W \sin \eta \sin \chi \end{aligned}\right\} \tag{2.67}$$

The angle χ is related to the yaw angle ω through the following relation

$$\chi = \omega + \nu \tag{2.68}$$

where ν is a constant. The numerical value of ν depends on the initial position of the vehicle (ν = 0, 90, 180, and 270 degrees corresponds, respectively, to the initial position of the vehicle at points 1, 2, 3, and 4 in Figure 2.12). Substitution of Equation 2.68 into Equation 2.67 leads to

$$\left.\begin{aligned} W_{TX} &= W \sin \eta \cos (\omega + \nu) \\ W_{TY} &= W \sin \eta \sin (\omega + \nu) \end{aligned}\right\} \tag{2.69}$$

In view of Equations 2.66 and 2.69, the normal stresses under the outer and inner tracks (Equations 2.7 and 2.8) become

$$\begin{aligned} R_1(x) = \frac{W}{dL^2} \Bigg\{ & \frac{\cos \eta}{2} + 6xc_x \cos \eta - \frac{h}{b}\left[\frac{F_{CY}}{W} - \sin \eta \sin(\omega + \nu)\right] \\ & - 6hx \left[\frac{F_{CX}}{W} + \sin \eta \cos(\omega + \nu)\right] + \frac{DLN_1(x)}{W} \Bigg\} \end{aligned} \tag{2.70}$$

$$\begin{aligned} R_2(x) = \frac{W}{dL^2} \Bigg\{ & \frac{\cos \eta}{2} + 6xc_x \cos \eta + \frac{h}{b}\left[\frac{F_{CY}}{W} - \sin \eta \sin(\omega + \nu)\right] \\ & - 6hx \left[\frac{F_{CX}}{W} + \sin \eta \cos(\omega + \nu)\right] + \frac{DLN_2(x)}{W} \Bigg\} \end{aligned} \tag{2.71}$$

Equations 2.70 and 2.71 can be combined with Equations 2.9 through 2.62 to develop the equations of motion for a sloping terrain. Thus,

$$\int_{-\frac{1}{2}}^{\frac{1}{2}} [t_1(x) + t_2(x)]\, dx - \delta \int_{-\frac{1}{2}}^{\frac{1}{2}} [r_1(x) + r_2(x)]\, dx \tag{2.72}$$

$$= f_{CX} + \sin \eta \cos (\omega + \nu)$$

$$\int_{-\frac{1}{2}}^{\frac{1}{2}} [q_1(x) + q_2(x)]\, dx = f_{CY} - \sin \eta \sin (\omega + \nu) \tag{2.73}$$

$$\int_{-\frac{1}{2}}^{\frac{1}{2}} [q_1(x) + q_2(x)]\, (x - c_x)\, dx + \frac{b}{2} \int_{-\frac{1}{2}}^{\frac{1}{2}} [t_2(x) - t_1(x)]\, dx \tag{2.74}$$

$$+ \frac{b}{2}\, \delta \int_{-\frac{1}{2}}^{\frac{1}{2}} [r_1(x) - r_2(x)]\, dx = \frac{I_z}{LW} \frac{d^2 W}{dt^2}$$

2.3.10 Sprocket Power

The steering performance of a tracked vehicle may be limited either by its stability or by the power available at the sprockets. The powers that must be available at the inner and outer track sprockets, PT1 and PT2 , respectively, are

$$\frac{PT1}{w \sqrt{Lg}} = V_{x1} \int_{-\frac{1}{2}}^{\frac{1}{2}} T_1(x)\, dx \tag{2.75}$$

$$\frac{PT1}{w\sqrt{Lg}} = V_{\chi 2} \int_{-\frac{1}{2}}^{\frac{1}{2}} T_2(x)\, dx \qquad (2.76)$$

where $T_1(x)$ and $T_2(x)$ are given by Equation 2.9. The total power PT and the differential power PTD required at the sprockets are:

$$PT = PT1 + PT2 \qquad (2.77)$$

$$PTD = PT1 - PT2 \qquad (2.78)$$

2.3.11 Power Output from the Engine

The power that must be available from the engine is related to the power available at the inner and outer track sprockets by the following relation:

$$PTT = \frac{1}{2\eta} \left\{ \frac{PT1}{\varepsilon} \left(\varepsilon + 1 + \frac{\varepsilon - 1}{\eta_{pm}} \right) + PT2 \left[\varepsilon + 1 - \frac{\eta_d (\varepsilon - 1)}{\eta_{pm}} \right] \right\} \qquad (2.79)$$

where

- ε = steering ratio
- η_d = differential efficiency
- η = overall efficiency of the planetaries of the final drives
- η_{pm} = pump/motion efficiency
- PT1 = power required by the outer track sprocket (Equation 2.75)
- PT2 = power required by the inner track sprocket (Equation 2.76)

The parameters η_d , η , and η_{pm} are vehicle dependent. If the values of these parameters are not available, however, it is recommended to use $\eta_d = 0.95$, $\eta = 0.95$, and $\eta_{pm} = 0.75$.

2.3.12 Uniform Turning Motion

The uniform turning motion can be obtained from the above nonuniform (transient) motion by setting

$$\frac{dw}{dt} = \frac{d\theta}{dt} = \text{constant}; \quad \frac{dw^2}{dt^2} = 0 \qquad (2.80)$$

$$\frac{dv_x}{dt} = \frac{dv_y}{dt} = 0 \qquad (2.81)$$

Equations of motion for either the nonuniform or the uniform motions constitute three equations that involve three unknowns. The three unknowns are either v_X, v_Y, and $d\omega/dt$ or ξ_1, ξ_2, and p. In order to obtain a complete solution for either of the two sets of unknowns, one of the following driving conditions must be specified:

1. Uniform (steady-state) motion
   a. Steering ratio for various vehicle velocities.
   b. Turning radius for various vehicle velocities.
   c. Vehicle velocity for various steering ratios.
   d. Vehicle velocity for various turning radii.
2. Nonuniform (transient) motion
   a. Time history of the steering ratio $\varepsilon(t)$ and time history of the velocity $v(t)$.
   b. Trajectory (given in terms of a time history of the instantaneous radius of curvature $RI(t)$).
   c. Time history of the steering ratio $\varepsilon(t)$ and the velocity of the vehicle at the beginning of the trajectory.
   d. Time history of the velocity of the individual tracks $V_{X1}(t)$ and $V_{X2}(t)$.

A computer program called TVSTEER was developed to solve Equations 2.72 through 2.74 for both uniform (steady-state) and nonuniform (transient) motion. In addition, the program TVSTEER contains an option for calculating the rolling resistance (Equations 2.48 through 2.58) and the cone index (Equations 2.60 through 2.62). A user's guide for the program TVSTEER is the subject of the remainder of this report.

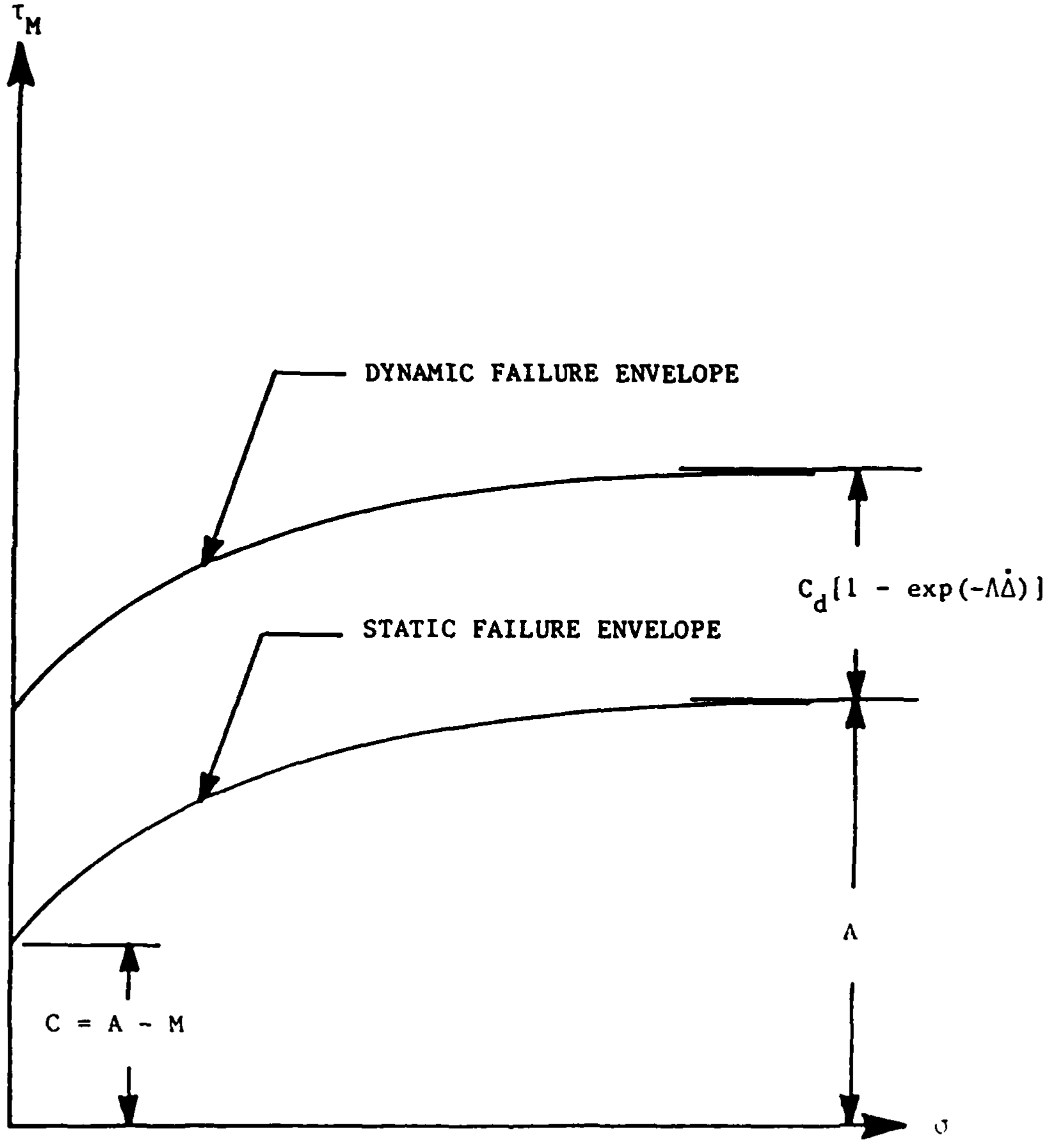


Figure 2.1. Nonlinear shear failure envelope for soil.

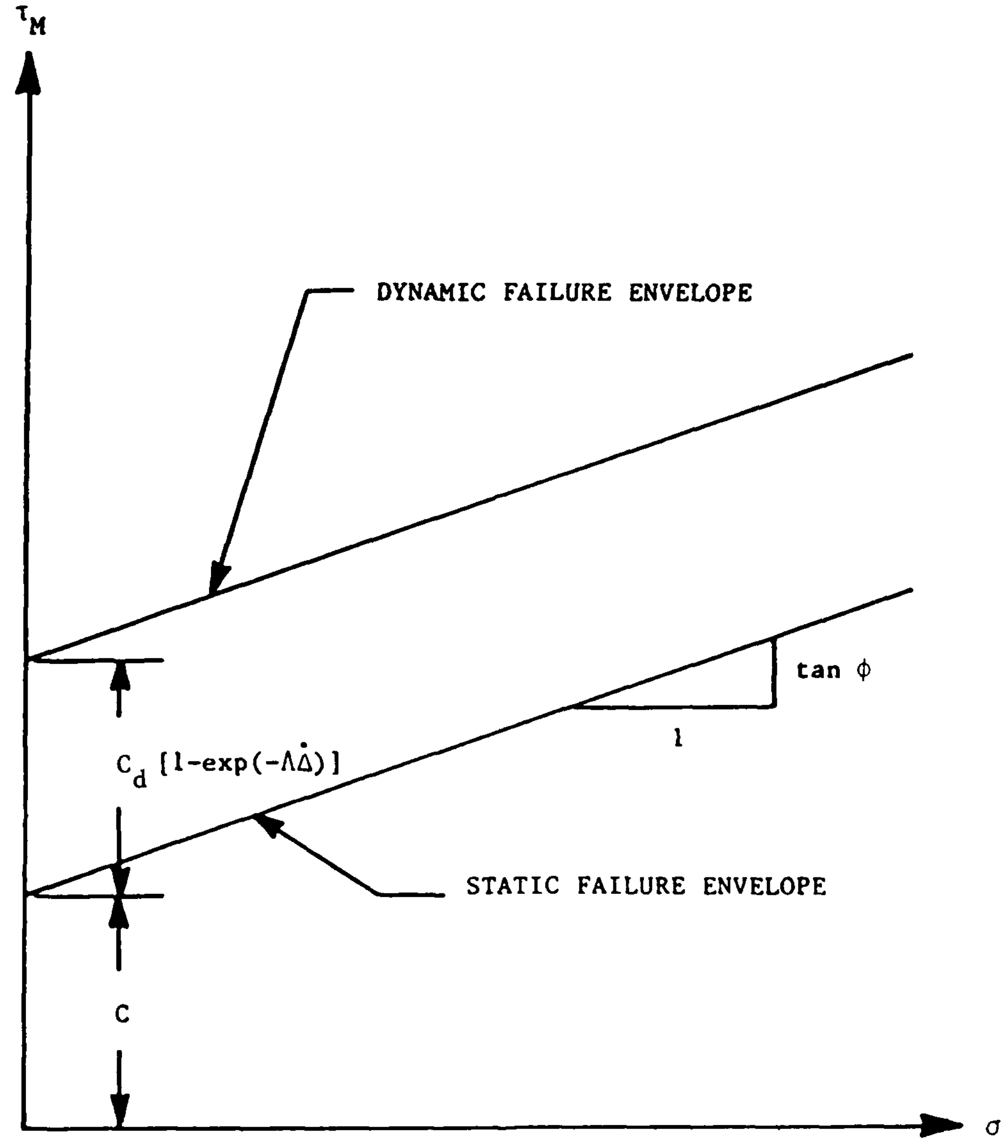


Figure 2.2. Linear shear failure envelope for soil.

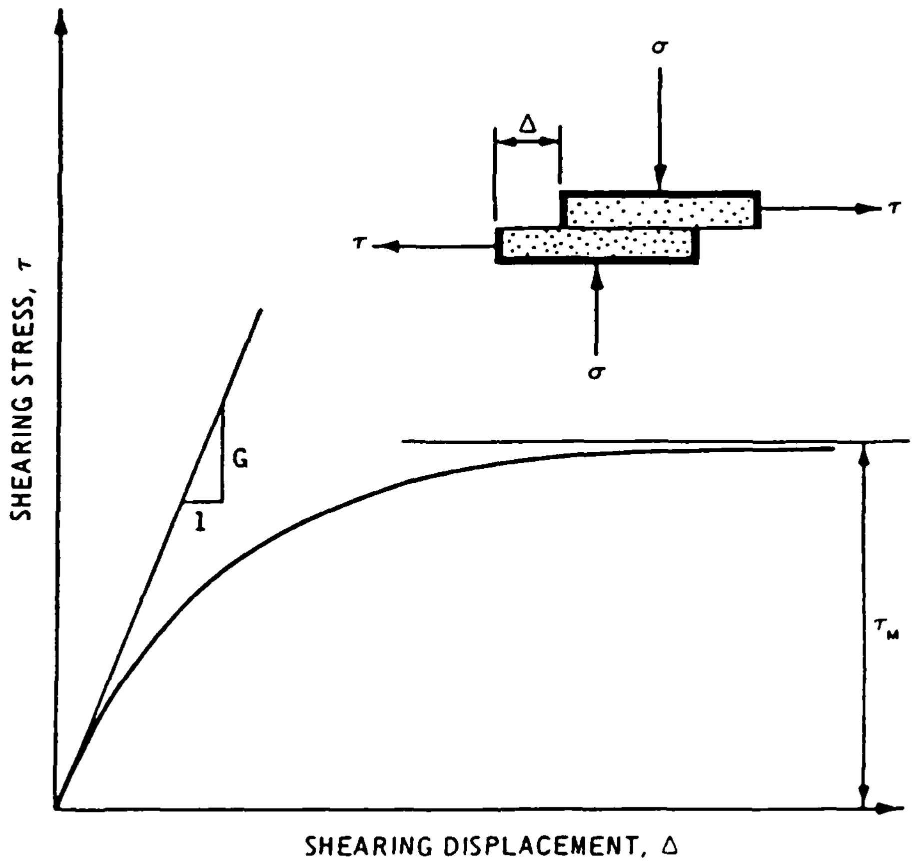


Figure 2.3. Proposed shear stress/deformation relation during shearing process.

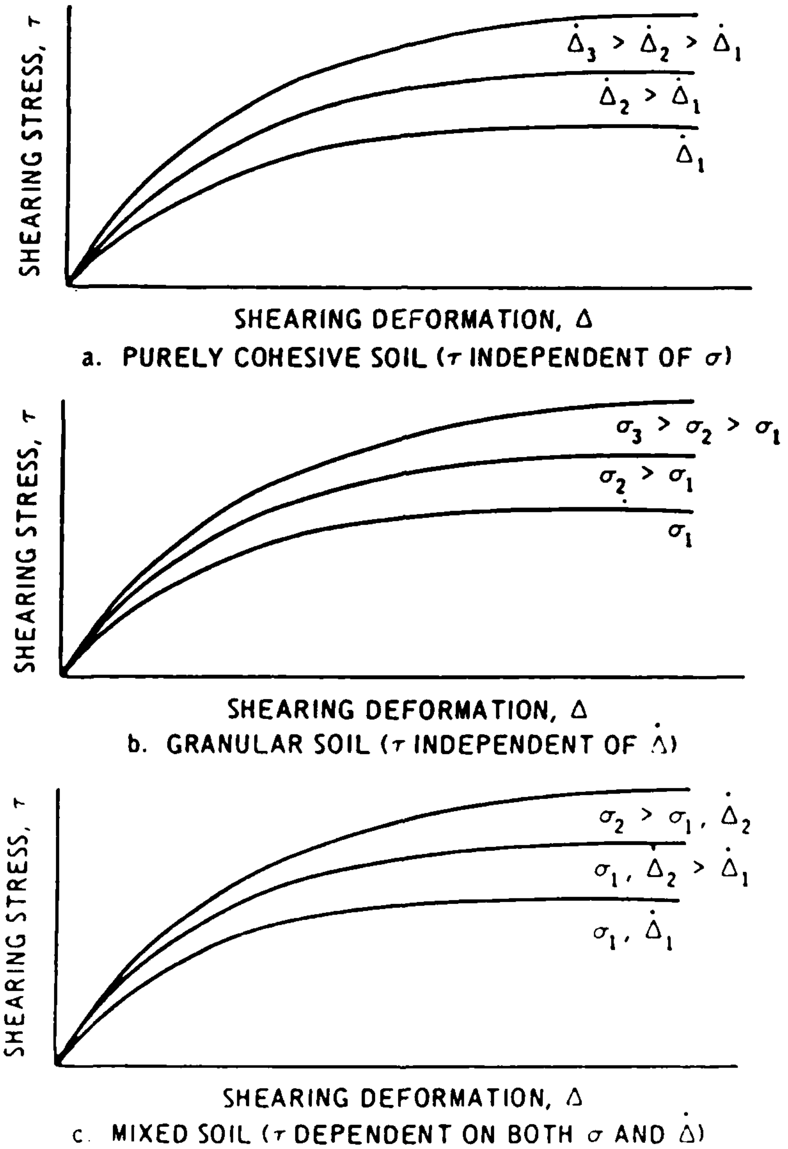


Figure 2.4. Qualitative behavior of the soil model for various types of soil.

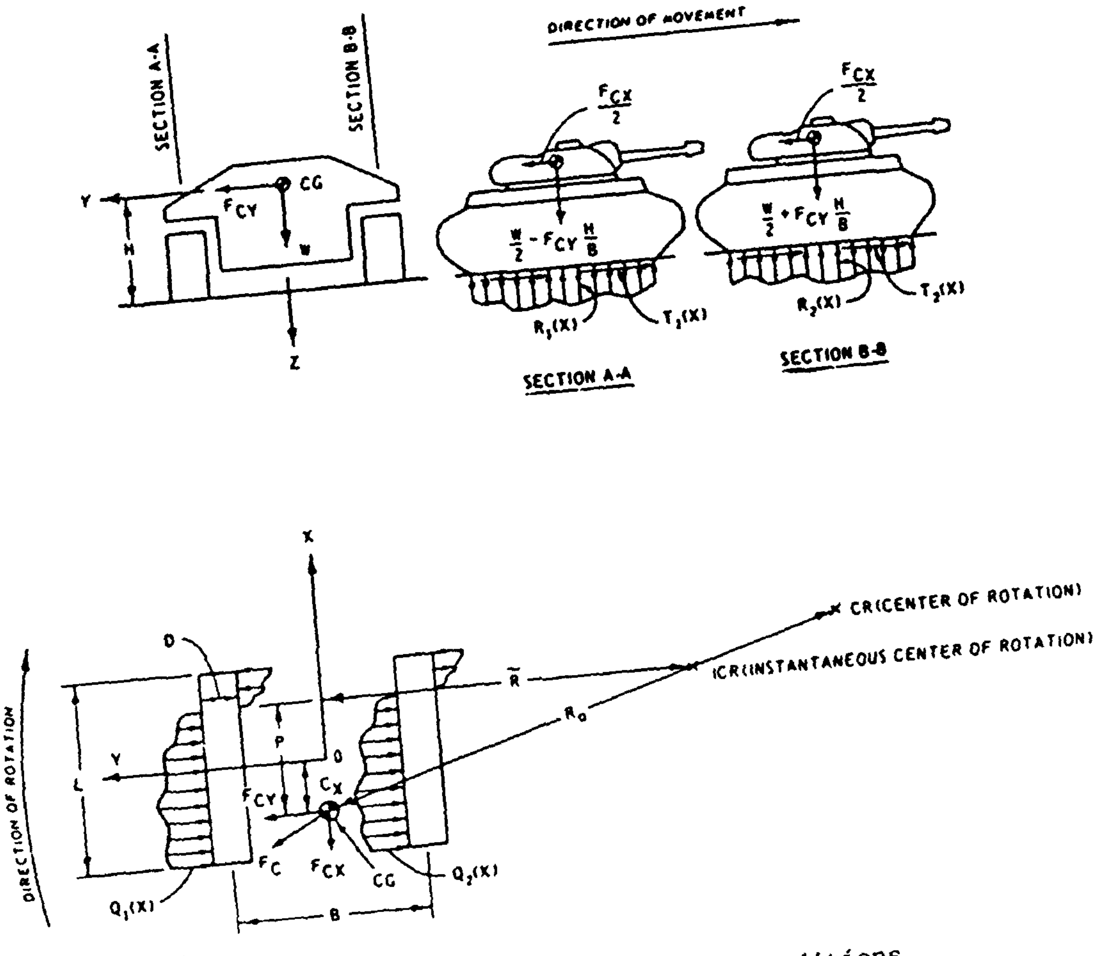


Figure 2.5. Geometry and boundary conditions of the terrain-vehicle model.

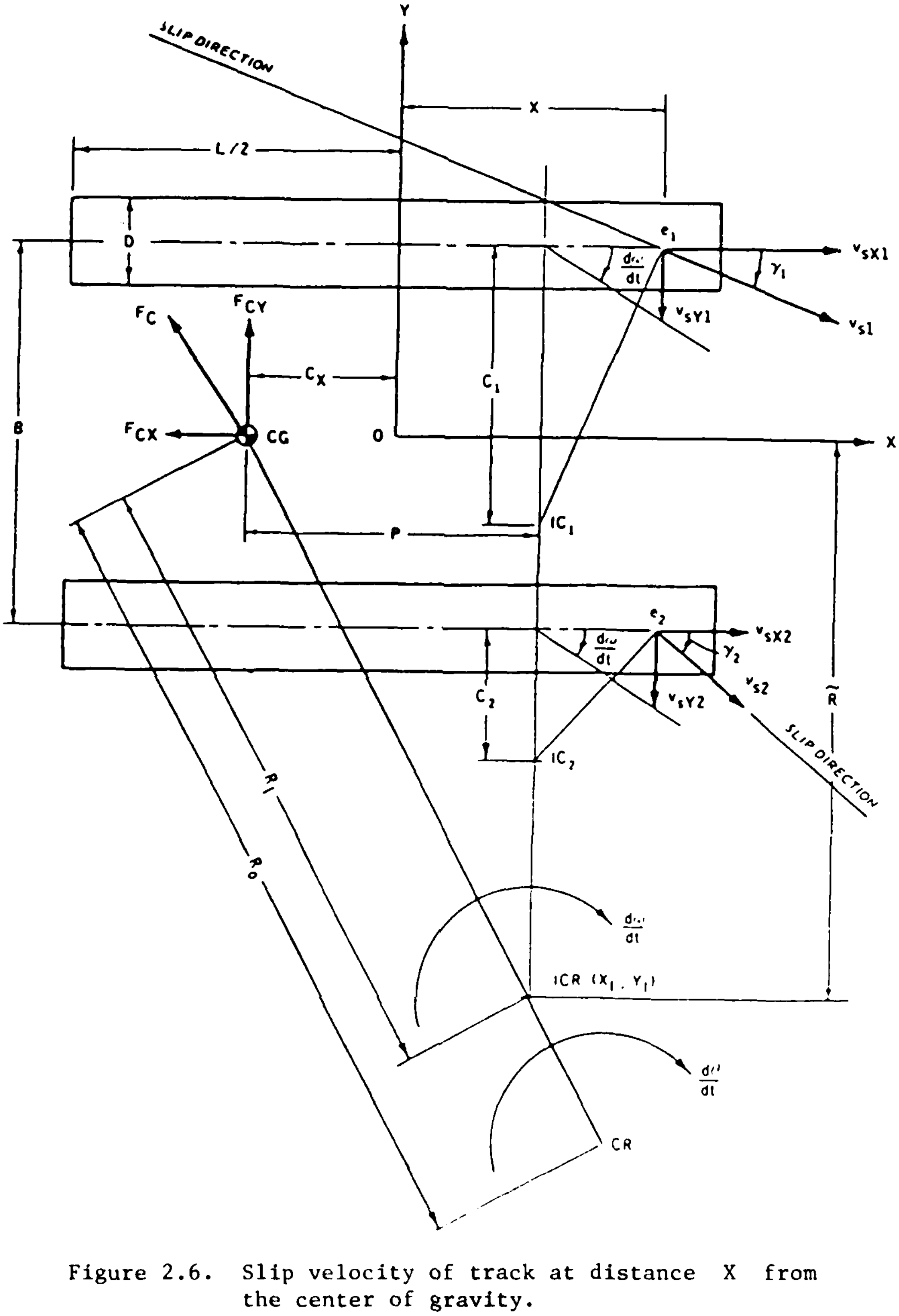


Figure 2.6. Slip velocity of track at distance X from the center of gravity.

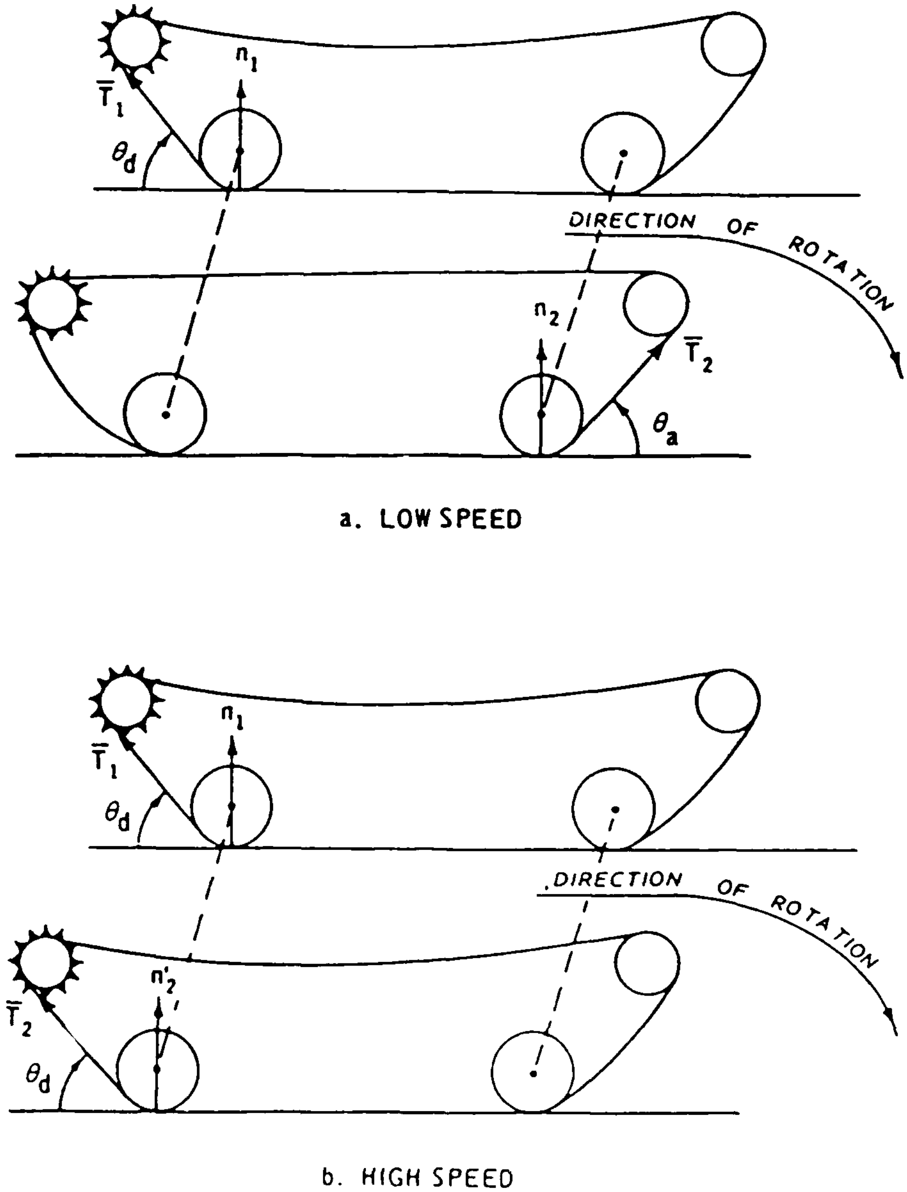


Figure 2.7. Track tension at low and high speeds.

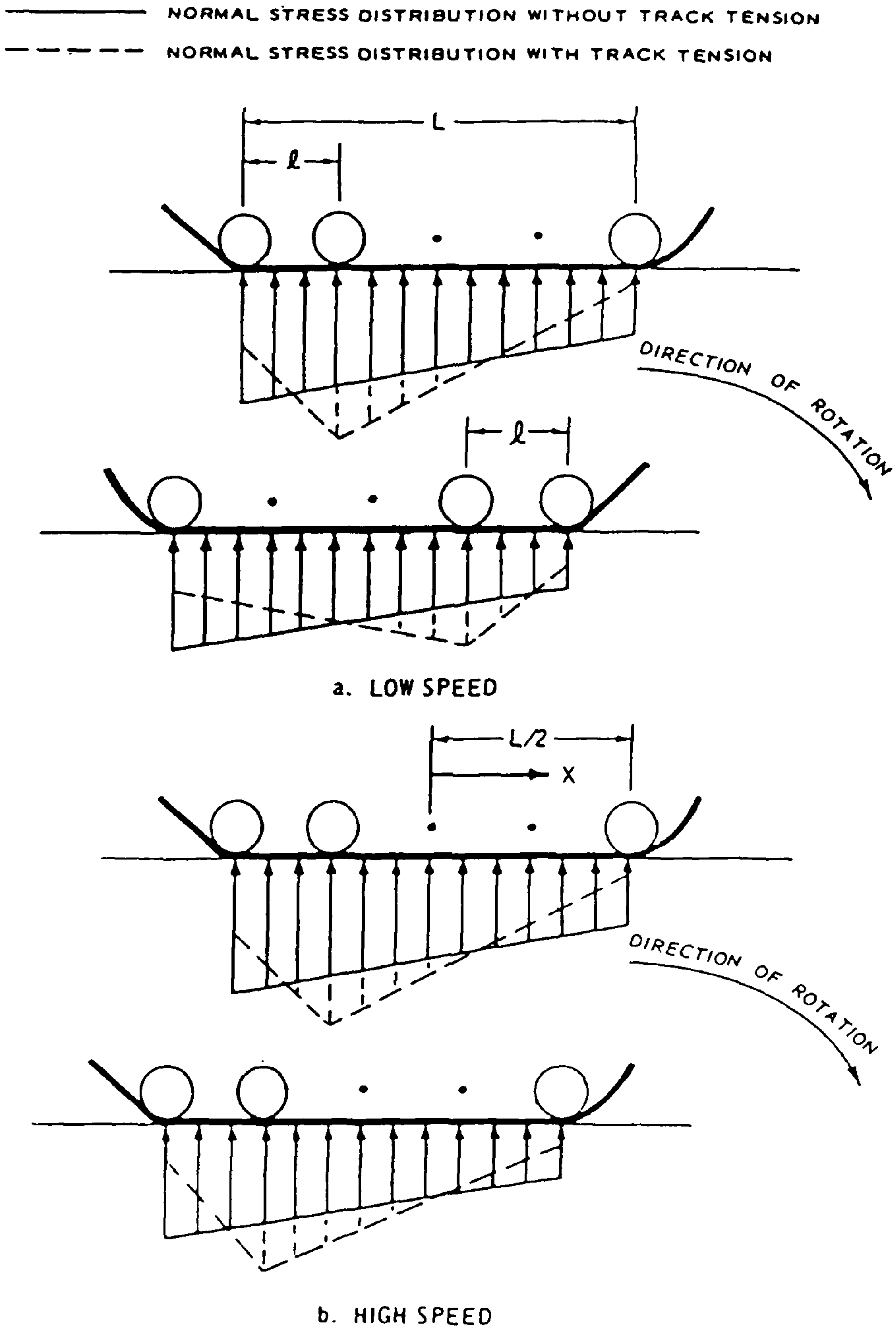


Figure 2.8. Effect of track tension on normal stress distribution.

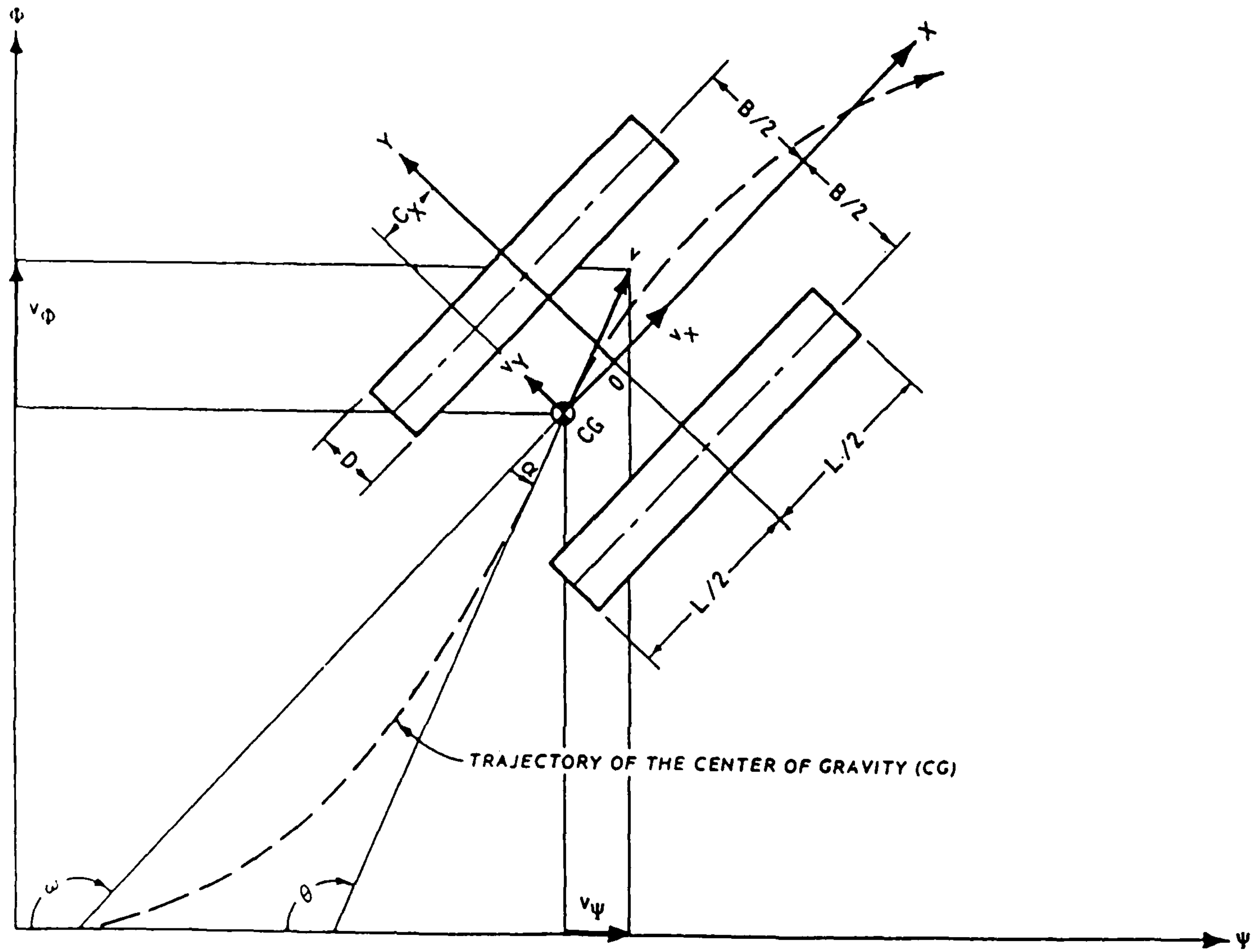


Figure 2.9. Tracked vehicle in transient motion.

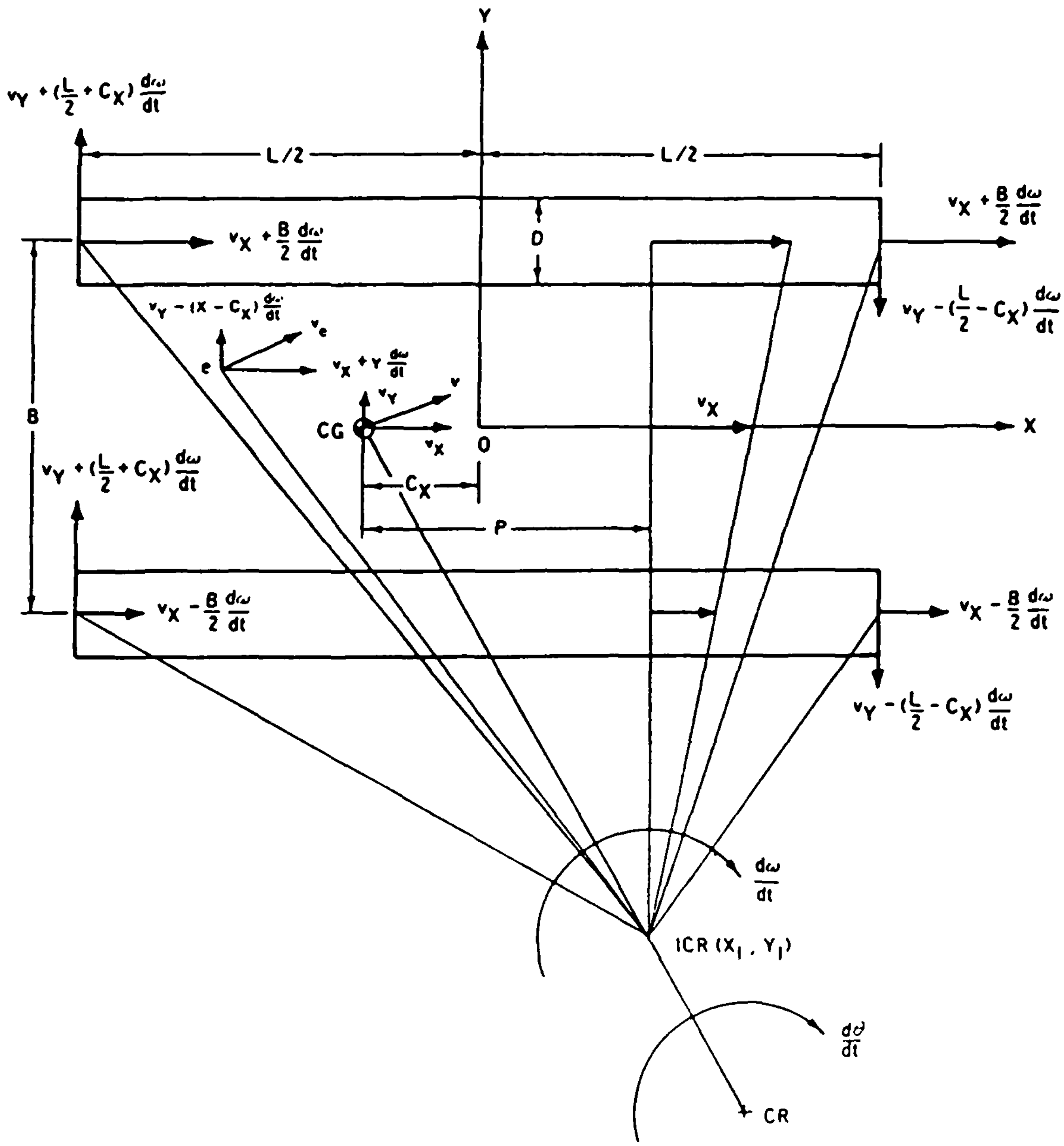


Figure 2.10. Track speeds and velocities of an arbitrary point of the hull.

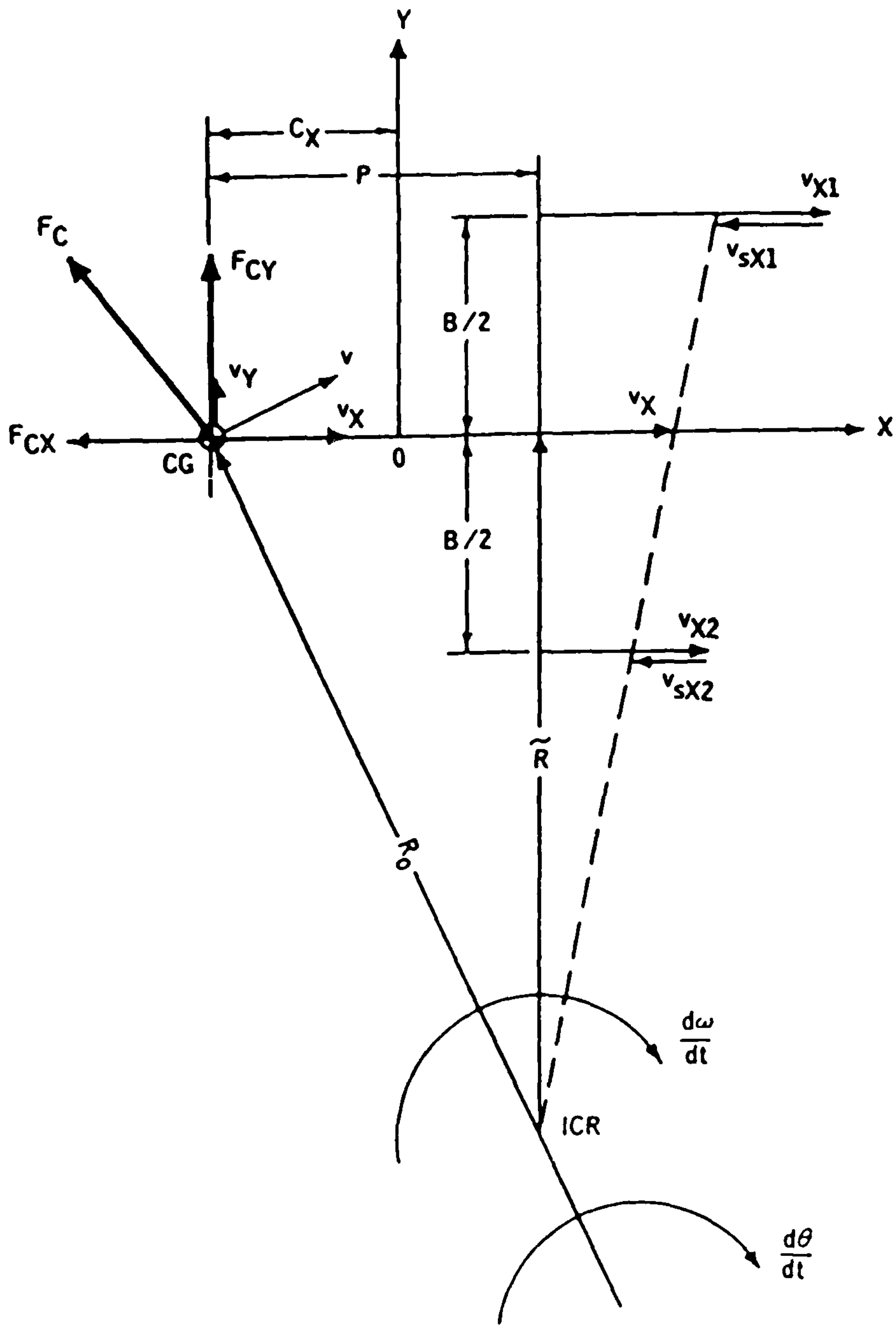


Figure 2.11. Schematic representation of vehicle and track speeds, track slip velocity, centrifugal forces, and turning radius.

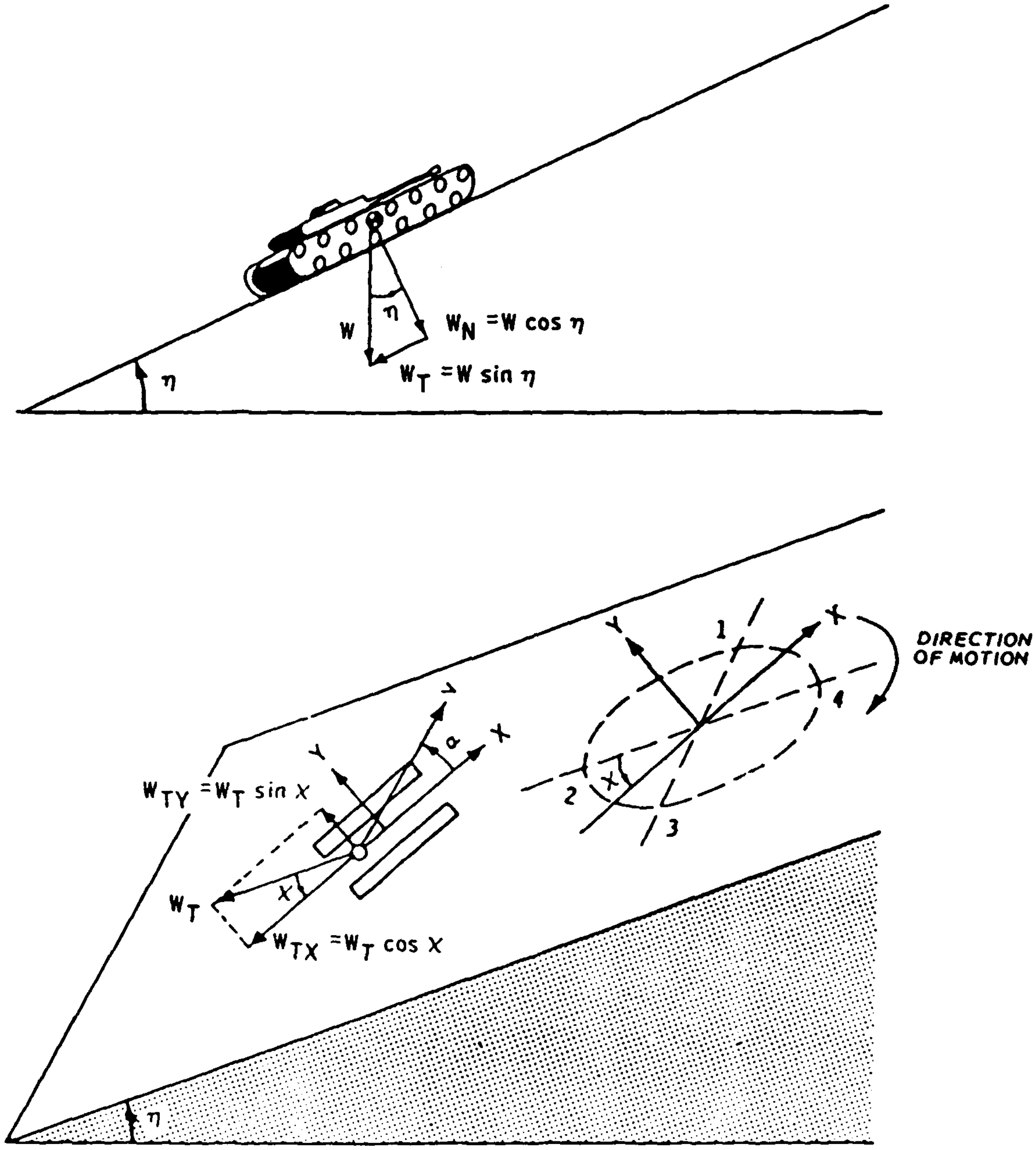


Figure 2.12. Effect of sloping terrain on transient motion.

CHAPTER 3

USER'S GUIDE FOR TVSTEER

3.1 INTRODUCTION

The computer program TVSTEER is used for predicting the steering performance of high-mobility/agility tracked vehicles in uniform turning motion (steady-state) and/or nonuniform (transient) motion. It incorporates the theory presented in Chapter 2 of this report and uses a Newtonian iterative technique to solve the equations of motion. The purpose of this user's guide is to explain input requirements for solving a particular problem, how to run the various options of the program (i.e., steady-state, transient, rolling resistance calculation, cone index calculation, etc.), and to describe the output generated by the program.

TVSTEER consists of (a) the main program (see flowchart in Figure 3.1), (b) two driver subroutines, one called STEADY (see flowchart in Figure 3.2) for uniform turning motion and the other called TRANS (see flowchart in Figure 3.3) for nonuniform motion, (c) subroutine AGIL which solves the equations of motion, (d) subroutine MIVCI for computing the one-pass vehicle cone index (VCI), and (e) subroutine CONE for computing the WES cone index (CI). A complete program listing is presented in Appendix A. The subroutines MIVCI and CONE compute the VCI and CI whenever these two quantities are not specified in the input.

The driver subroutine STEADY can be utilized for each of the following input conditions:

1. Input steering ratio and velocity increment.
2. Input turning radius and velocity increment.
3. Input vehicle velocity for various steering ratios.
4. Input vehicle velocity for various turning radii.

For cases 1 and 2, the subroutine STEADY increases the velocity until the vehicle becomes unstable. In addition, if the available power is specified, the program will produce and print a complete set of output when this power is reached. Note that in case the subroutine STEADY does not converge at some velocity, it will search for a smaller velocity increment at which it can converge (the smallest velocity increment specified in the code is 0.03 mph). For case 3, the steering ratio is incremented while the vehicle velocity is held constant. For case 4, however, the turning radius is decremented while the vehicle velocity is held constant.

Similarly, the driver subroutine TRANS can be utilized for each of the following driving conditions:

1. Input the time histories of the steering ratio and the velocity.

2. Input the time histories of the turning radius and the velocity. (The program can be modified, however, to input the trajectory instead of the time history of the turning radius.)

3. Input the time history of the steering ratio and the velocity of the vehicle at the beginning of the trajectory.

4. Input the time histories of the individual track velocities.

In cases 1 and 2, the actual velocity used by the program could be less than the input velocity if the calculated power exceeds a specified available power. In case 3, the velocity of the vehicle is adjusted to keep the required power between 95 and 100 percent of the available power. If the vehicle becomes unstable during this process, the velocity and/or the steering ratio will be adjusted in an attempt to stabilize it. Note that all time history input can be described by mathematical functions or can be digitized.

This user's guide contains a description of typical input and output, a glossary of the important variables, flowcharts (Figures 3.1-3.3), a listing of the program TVSTEER (Appendix A), and several sample runs. Figures 3.4 and 3.5 illustrate sample inputs for a steady-state run and a transient run, respectively. A total of ten sample output are illustrated in Figures 3.6-3.15. Figures 3.6 through 3.9 contain sample output for a steady-state motion corresponding to cases 1 through 4, respectively. Figures 3.10 through 3.13 portray sample output for a transient motion corresponding to cases 1 through 4, respectively. All the above examples are calculated using a linear soil model and zero track tension. To demonstrate the effect of the track tension, case 1 of the steady-state motion was repeated and the results are illustrated in Figure 3.14. Also, case 1 of the steady state motion was repeated for a nonlinear soil model. The result of this case is shown in Figure 3.15.

Program TVSTEER has been coded in Honeywell FORTRAN 77 for the time-sharing subsystem of the Honeywell DPS-8 digital computer currently in operation at WES. The processor time for each sample run is shown at the end of the output.

3.2 INPUT

TVSTEER requires input from the keyboard describing the vehicle, the soil properties along with the slope of the terrain and the directional angle of the vehicle, and the driving conditions (i.e., steady-state or transient motions, cases, etc.). Note that the program could be modified to read input from a file. All input except the radius of curvature and the velocity are in the non-SI units of inches, seconds, pounds, and degrees. The input for the radius of curvature and the velocity are in feet and miles per hour, respectively. These quantities, however, are converted internally in the program to inches and inches per second.

3.2.1 Input to the Main Program

The first line of input contains the test title:

TESTN -- Identification label of up to 40 alphanumeric characters

The second line of input contains the following vehicle parameters:

WT = Weight of the vehicle, lb.

L = Length of the track in contact with the ground, in.

H = Height of the center of gravity, in.

D = Track width, in.

B = Track tread (distance between the center lines of the tracks), in.

SL = Distance between the center lines of adjacent wheels (if the model is to be run without using track tension set SL = 0), in.

CX = Abscissa of the center of gravity of the vehicle, in.

THETAD = Departure angle of the track envelope (THETAD is used only when running with track tension), deg.

THETAA = Approach angle of the track envelope (THETAA is used only if running with track tension and/or computing VCI1), deg.

IZ = Mass moment of inertia of the vehicle about an axis passing through its center of gravity and parallel to the Z axis (not needed for steady-state), in-lb/sec^2.

VCI1 = Vehicle cone index for one-pass traffic. (VCI1 may be computed using subroutine MIVCI by inputting VCI1 = 0. MIVCI will ask for additional input as explained below.)

The third line of input contains the following variables which are needed by subroutine MIVCI:

- GH = Height of the grouser, in.
- NB = Total number of bogies on track in contact with ground.
- TSL = Track shoe length, in.
- HP = Specified engine horsepower, hp.
- TRNT = Type of transmission (0 for manual, 1 for automatic).

Note that the above line of input is skipped if VCI1 is specified.

The fourth line of input contains the following soil model parameters:

- CI = WES cone index (CI may be computed using subrouting CONE by inputting CI = 0, subroutine CONE will ask for additional input as explained below).
- A = Material constant in failure envelope (Equals C for linear soil model), psi.
- SM = Material constant in failure envelope (Equals 0 for linear soil model), psi.
- SN = Material constant in failure envelope, 1/psi.
- SXI = Variable used to determine the type of soil model used (0 for nonlinear failure envelope, 1 for linear failure envelope).
- CD = Added cohesive strength due to dynamic loading, psi.
- CLAMDA = Material constant related to rate effect, sec/in.
- PHI = Angle of internal friction, deg.
- G = Shear modulus, psi/in.
- SF = Coefficient of rolling resistance. (SF will be computed by the code when SF = 0.)
- ETA = Angle of sloping terrain, deg.
- CHI = Directional angle of the vehicle on sloping terrain (for transient motion CHI is the initial angle), deg.
- C = Static cohesive component of shear strength (C is computed by code as C = A - SM), psi.

The fifth line of input contains the following variables which are needed by subroutine CONE:

- CL = Cone length, in.
- DI = Cone diameter, in.

GAMA = Density, psi/in.

Z = Depth of penetration, in.

Note that the above line of input is skipped if CI is specified.

The last line of input for the main program is the type of run:

IRUN = Run type (0 for steady-state, 1 for transient).

3.2.2 Input to Subroutine STEADY (Steady-State Driver)

The first line of input is:

ICASE = Case number: 1, 2, 3, 4 or ? (to have an input menu displayed, enter ?).

The content of the second line of input is determined by the case number as follows:

1. For ICASE = 1:
   - E = Steering ratio
   - DV = Velocity increment, mph (converted internally to in/sec).
   - HPAV = Horsepower available (if HPAV = 0, the power check is skipped), hp.
2. For ICASE = 2:
   - RØ = Radius of the trajectory (turning radius) of the center of gravity of the vehicle, ft (converted internally to in).
   - DV = See ICASE = 1.
   - HPAV = See ICASE = 1.
3. For ICASE = 3:
   - E = Initial steering ratio.
   - DE = Steering ratio increment.
   - NP = Number of points that will be calculated.
4. For ICASE = 4:
   - RØ = Initial radius of the trajectory (turning radius) of the center of gravity of the vehicle, ft (converted internally to in).
   - DR = Turning radius decrement, ft.
   - NP = Number of points that will be calculated.

3.2.3 Input to Subroutine TRANS (Transient Driver)

The first line of input contains the following information:

DT = Time increment, sec.

NP = Number of points to be calculated.

IPRINT = Print skip increment.

The second line of input is the case number:

ICASE = Case number: 1, 2, 3, 4, or ? (to have an input menu displayed, input ?).

The remaining lines of input are determined by case number:

1. For ICASE = 1:

The first line of input contains the following power and velocity information:

HPAV = Horsepower available (if HPAV = 0, the power check is skipped), hp.

V1 = Initial velocity, mph.

V2 = Maximum change in velocity, mph.

V3, V4 = Coefficients which are related to the rate of change in velocity. For a constant velocity, input V2, V3, and V4 as zero.

The second line of input is the values of the coefficients in the equation of the steering ratio:

E1 = Initial steering ratio.

E2 = Maximum change in the steering ratio.

E3, E4 = Coefficients which are related to the rate of change in the steering ratio. For a constant steering ratio, input E2, E3, and E4 as zero.

2. For ICASE = 2:

The first line of input is the same as the first line of input for ICASE = 1.

The last line of input is the values of the coefficients in the equation of the turning radius:

RI1 = Initial instantaneous radius of curvature, ft.

RI2 = Maximum change in this radius, ft.

RI3, RI4 = Coefficients which are related to the rate of change in this radius. For a constant radius, input RI2, RI3, and RI4 as zero.

3. For ICASE = 3:

The only line of input is:

HPAV = Horsepower available, hp.

VI = Initial velocity, mph.

For this case, the digitized time history is stored in the array EP in a data statement.

4. For ICASE = 4:

The first line of input is:

VX11 = Initial velocity of the outer track, mph.

VX12 = Maximum change in this velocity, mph.

VX13, VX14 = Coefficients which are related to the rate of change in this velocity. For a constant velocity, input VX12, VX13, and VX14 as zero.

The last line of input is:

VX21 = Initial velocity of the inner track, mph.

VX22 = Maximum change in this velocity, mph.

VX23, VX24 = Coefficients which are related to the rate of change in this velocity. For a constant velocity, input VX22, VX23, and VX24 as zero.

3.3 OUTPUT

The output produced by TVSTEER is presented in tabulated form in this user's guide (see Figures 3.6-3.15). Because all the output values are stored in arrays, a plot routine accessing these arrays could be added easily. Also, a postprocessor could be added to convert all the output quantities from non-SI to SI units.

The first part of the output contains the type of test and most of the input as well as the vehicle and soil model parameters.

The remainder of the output is a table containing the following variables (listed as they appear in the table):

PT = Point number.

T = Time (not tabulated for steady-state), sec.

P = Offset, P/L

E = Steering ratio.

RØ = Radius of the trajectory (turning radius) of the center of gravity of the vehicle, ft.

V = Velocity of the vehicle, mph.

VX1 = Longitudinal component of velocity of the outer track, mph.

VX2 = Longitudinal component of velocity of the inner track, mph.

VS1 = Longitudinal component of slip velocity of the outer track, mph.

VS2 = Longitudinal component of slip velocity of the inner track, mph.

W = Yaw angle (not tabulated for steady-state), deg.

WD = Yaw rate, deg/sec.

FCX[1] = Forward acceleration, g's.

FCY[1] = Lateral acceleration, g's.

PTE = Power required from the engine, hp.

PTS = Total power required by the sprockets, hp.

DXT = Abscissa of trajectory (not tabulated for steady-state), ft.

DYT = Ordinate of trajectory (not tabulated for steady-state), ft.

The following variables are available but are not included in the tabulated output.

PT1 = Power required by the sprocket of the outer track, hp.

PT2 = Power required by the sprocket of the inner track, hp.

VX = Longitudinal component of velocity of the vehicle, mph.

VY = Lateral component of velocity of the vehicle, mph.

---

[1] There two quantities are also used in chapter 3 as the longitudinal and lateral components of inertial forces, respectively.

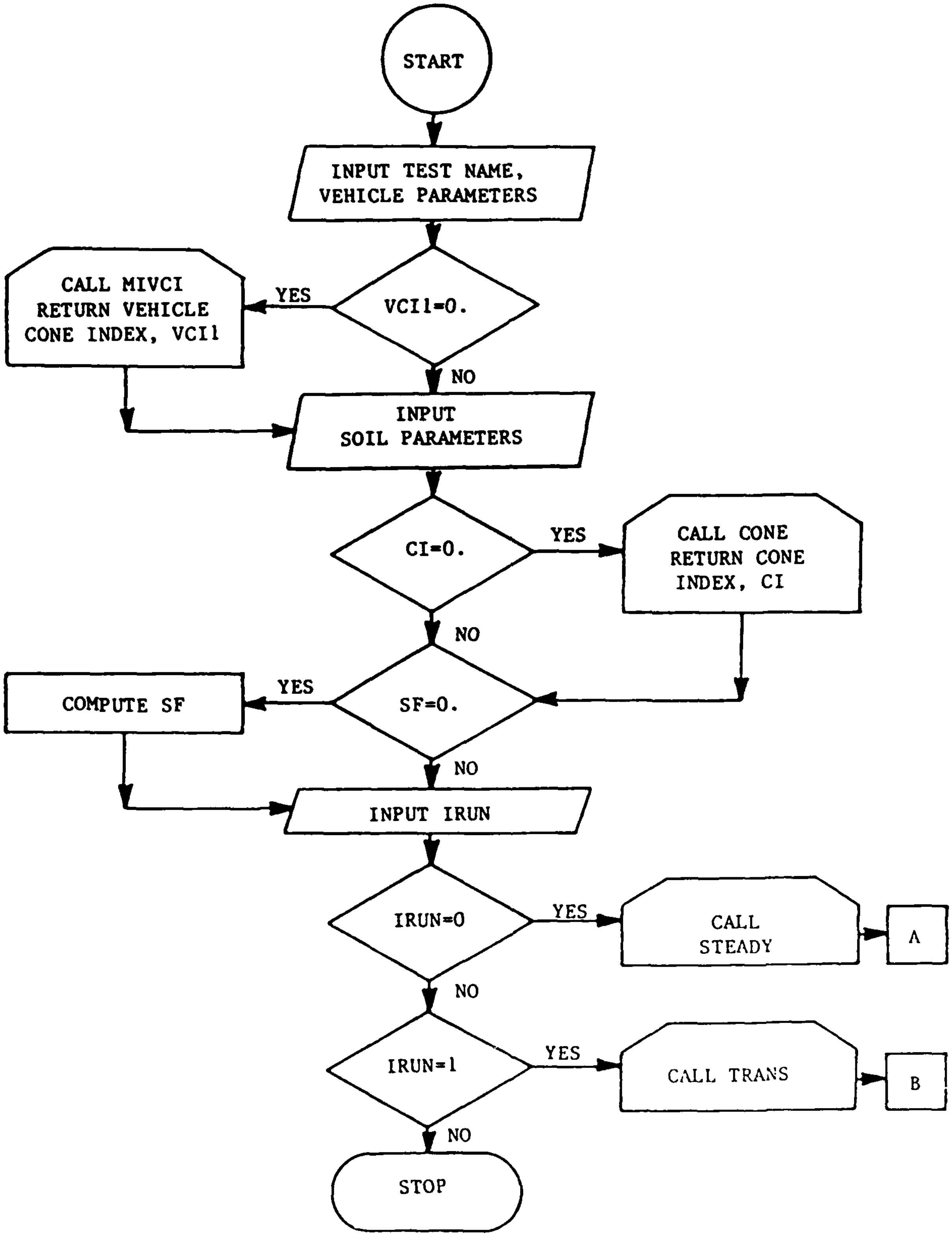


Figure 3.1. Flowchart for TVSTEER, main program.

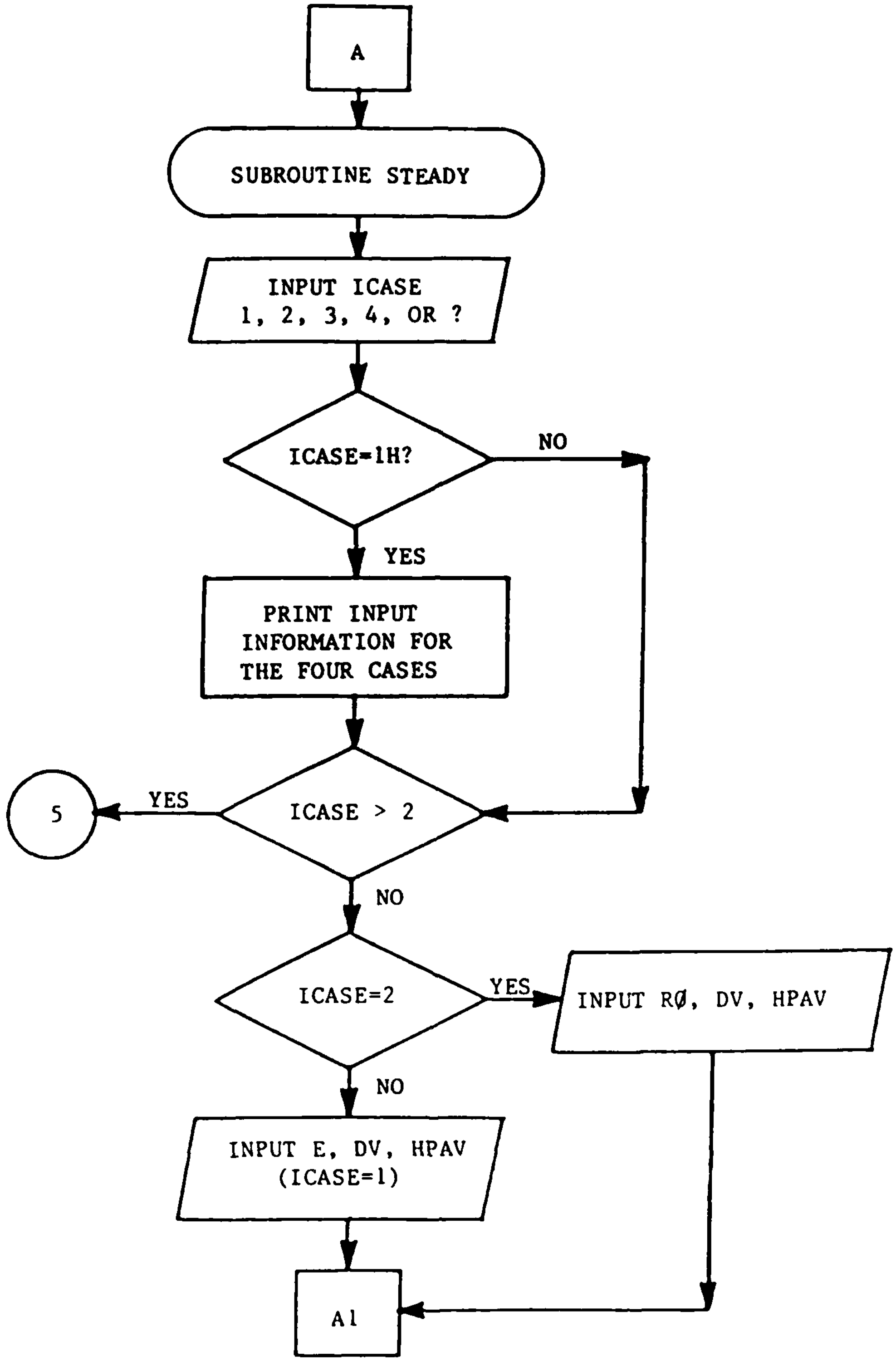


Figure 3.2. Flowchart for subroutine STEADY (Sheet 1 of 4).

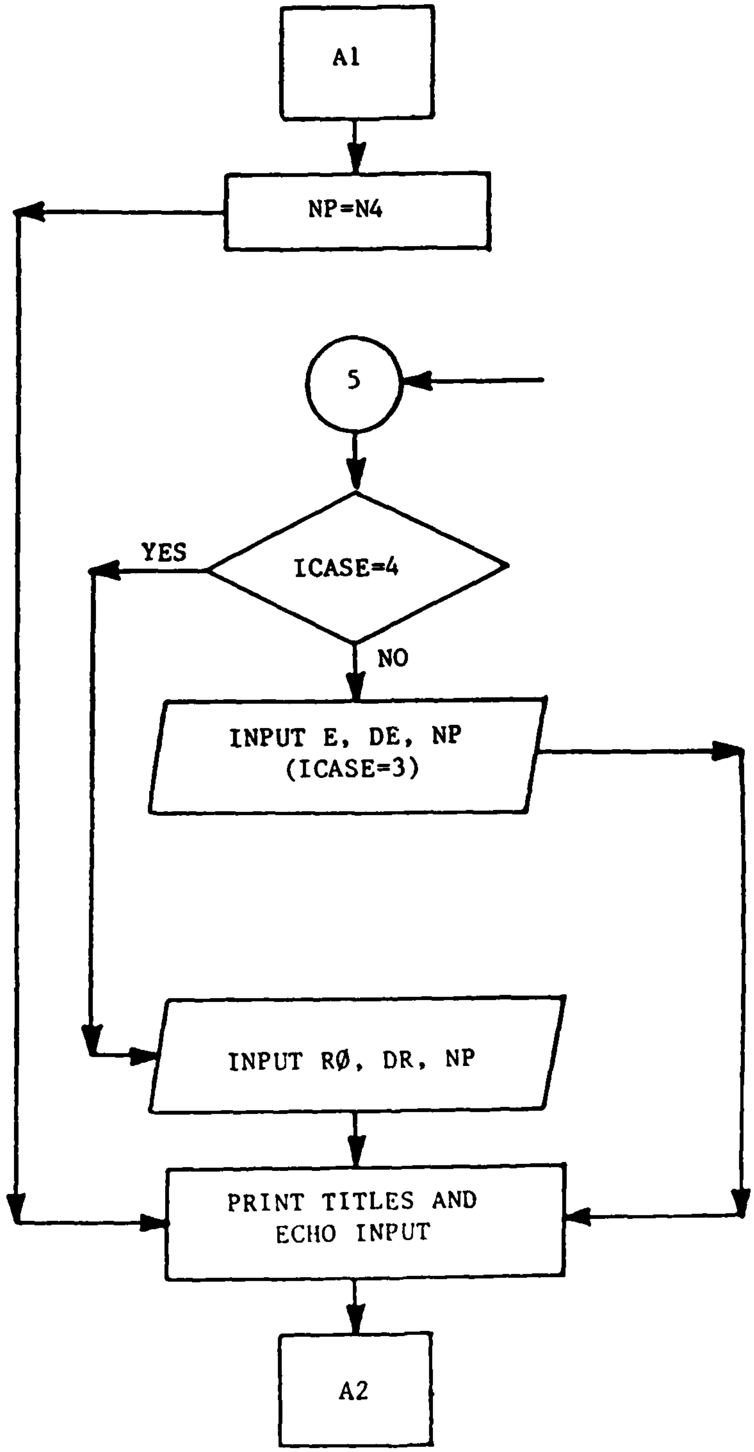


Figure 3.2. (Sheet 2 of 4).

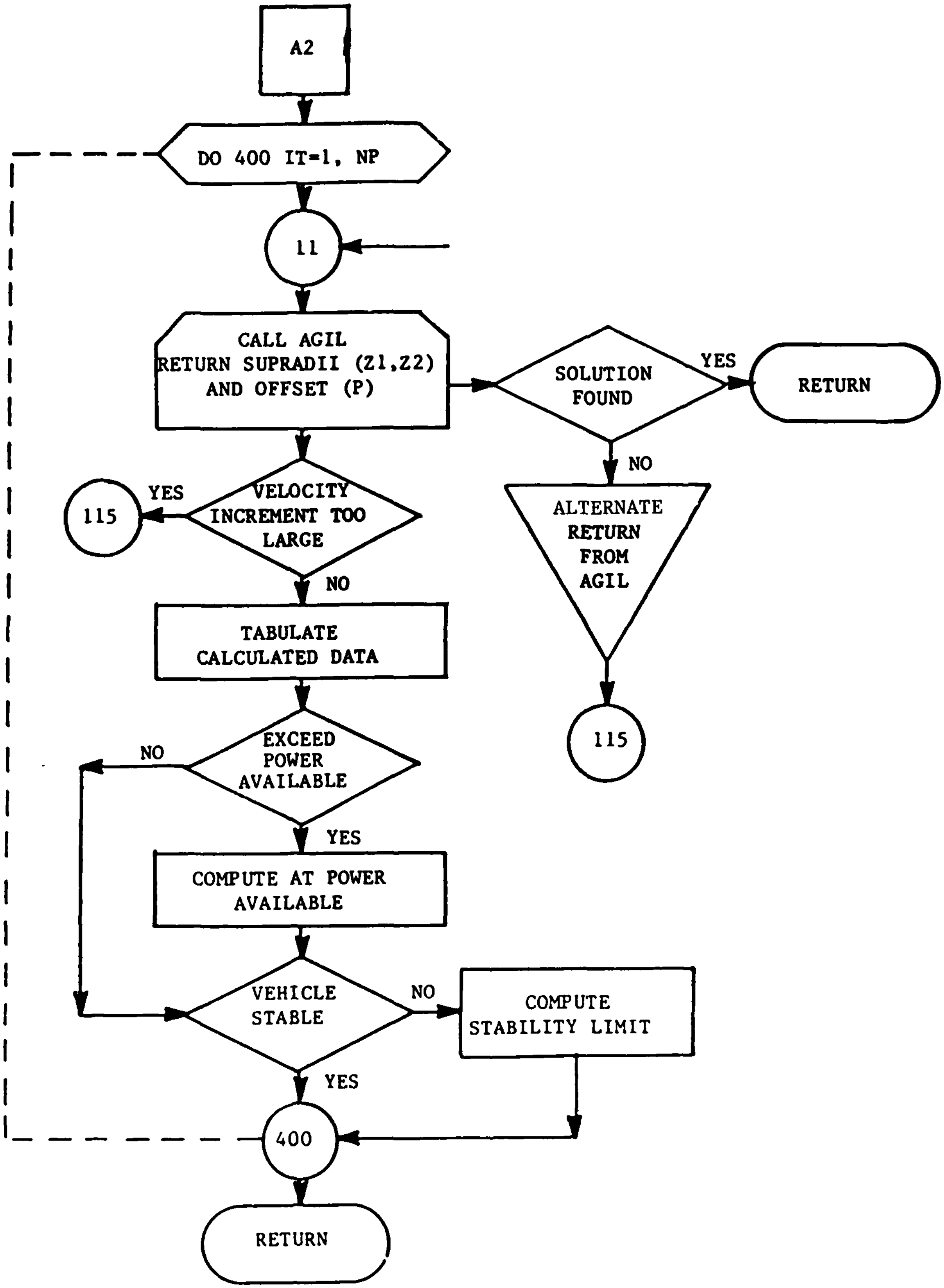


Figure 3.2. (Sheet 3 of 4).

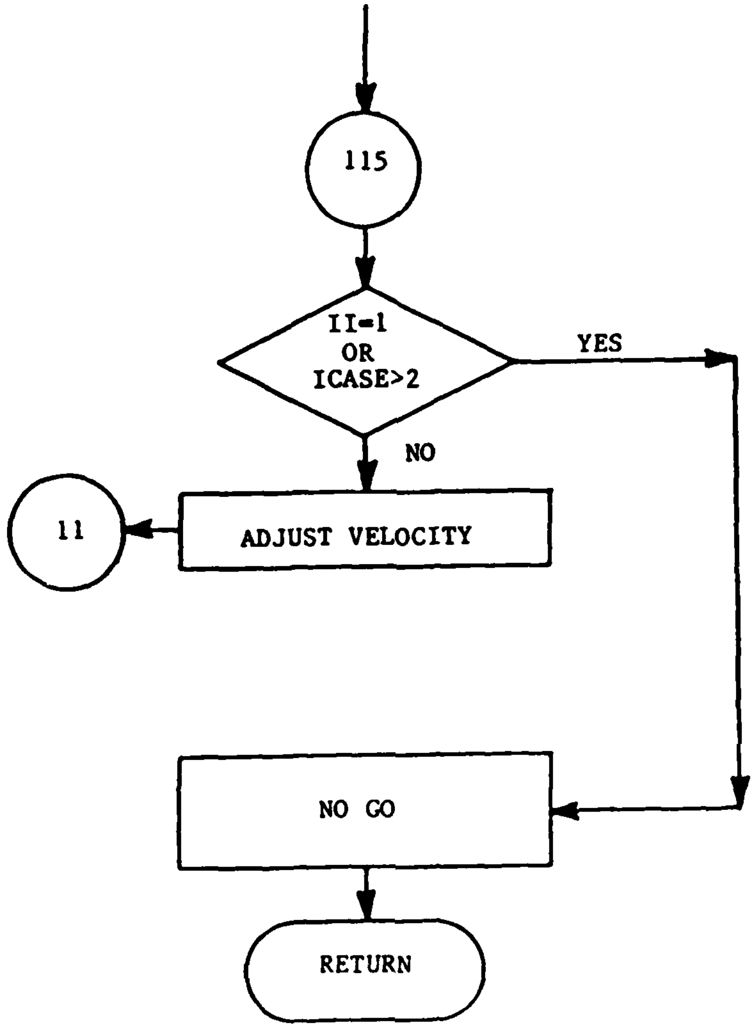


Figure 3.2. (Sheet 4 of 4).

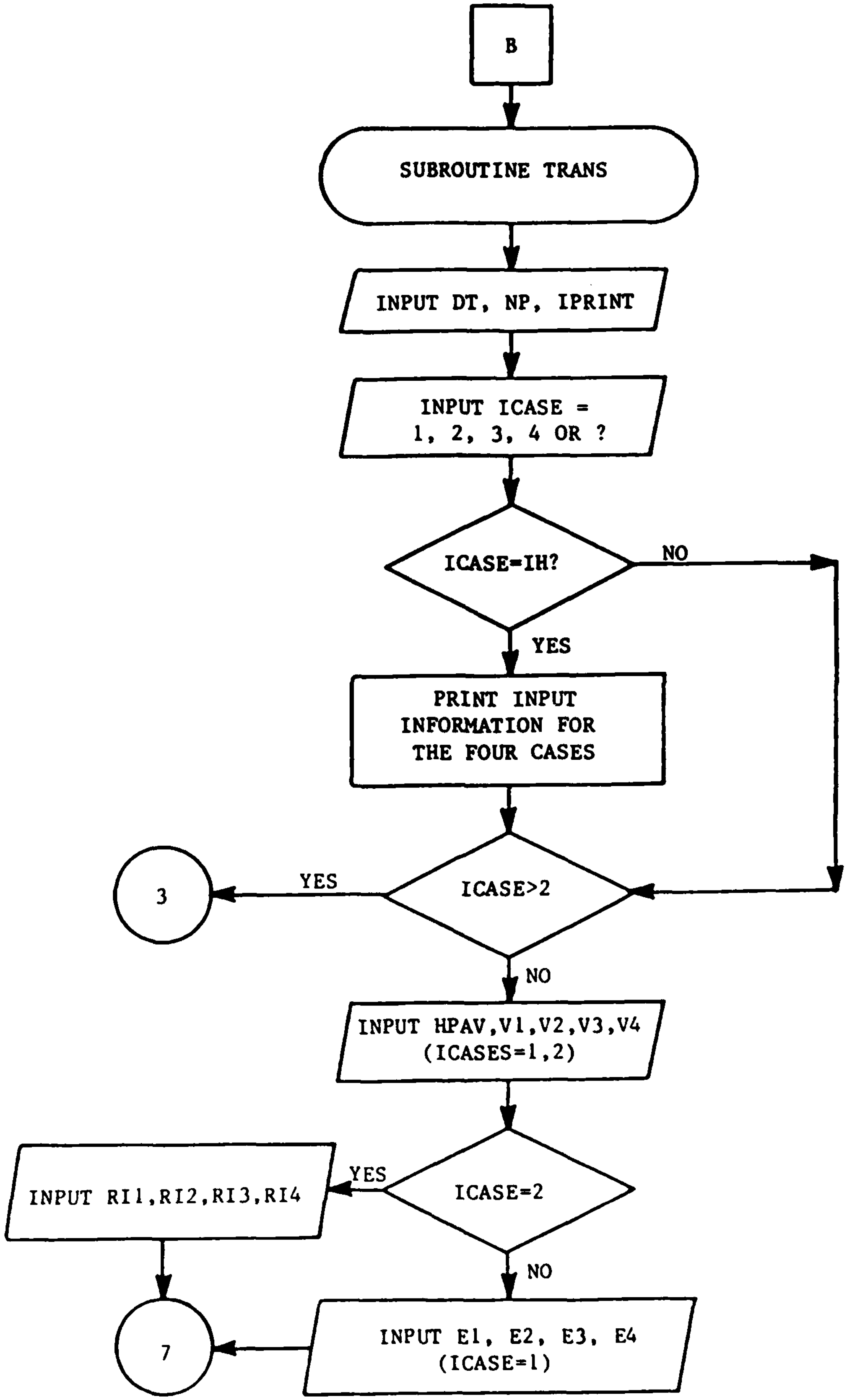


Figure 3.3. Flowchart for subroutine TRANS (Sheet 1 of 3).

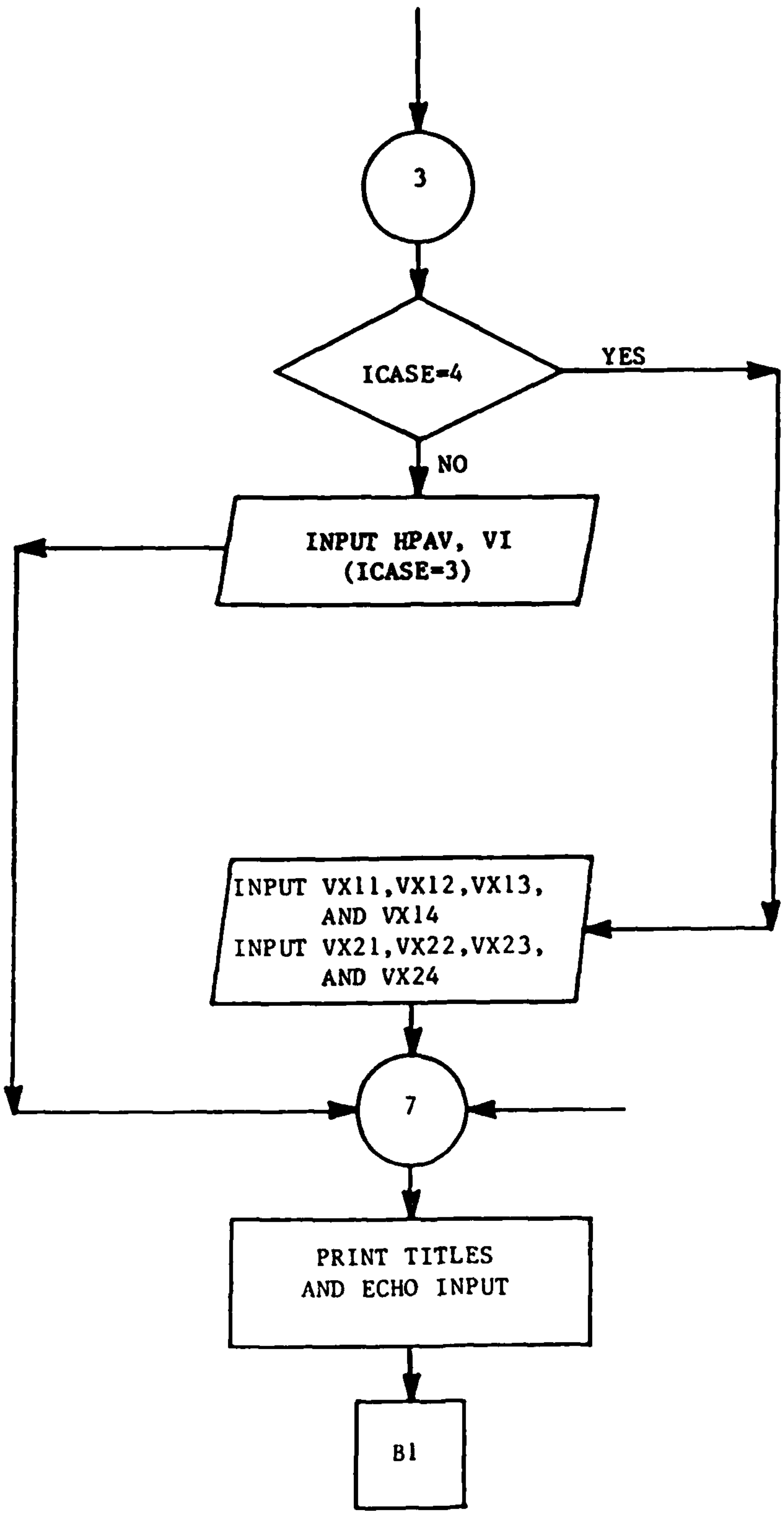


Figure 3.3. (Sheet 2 of 3).

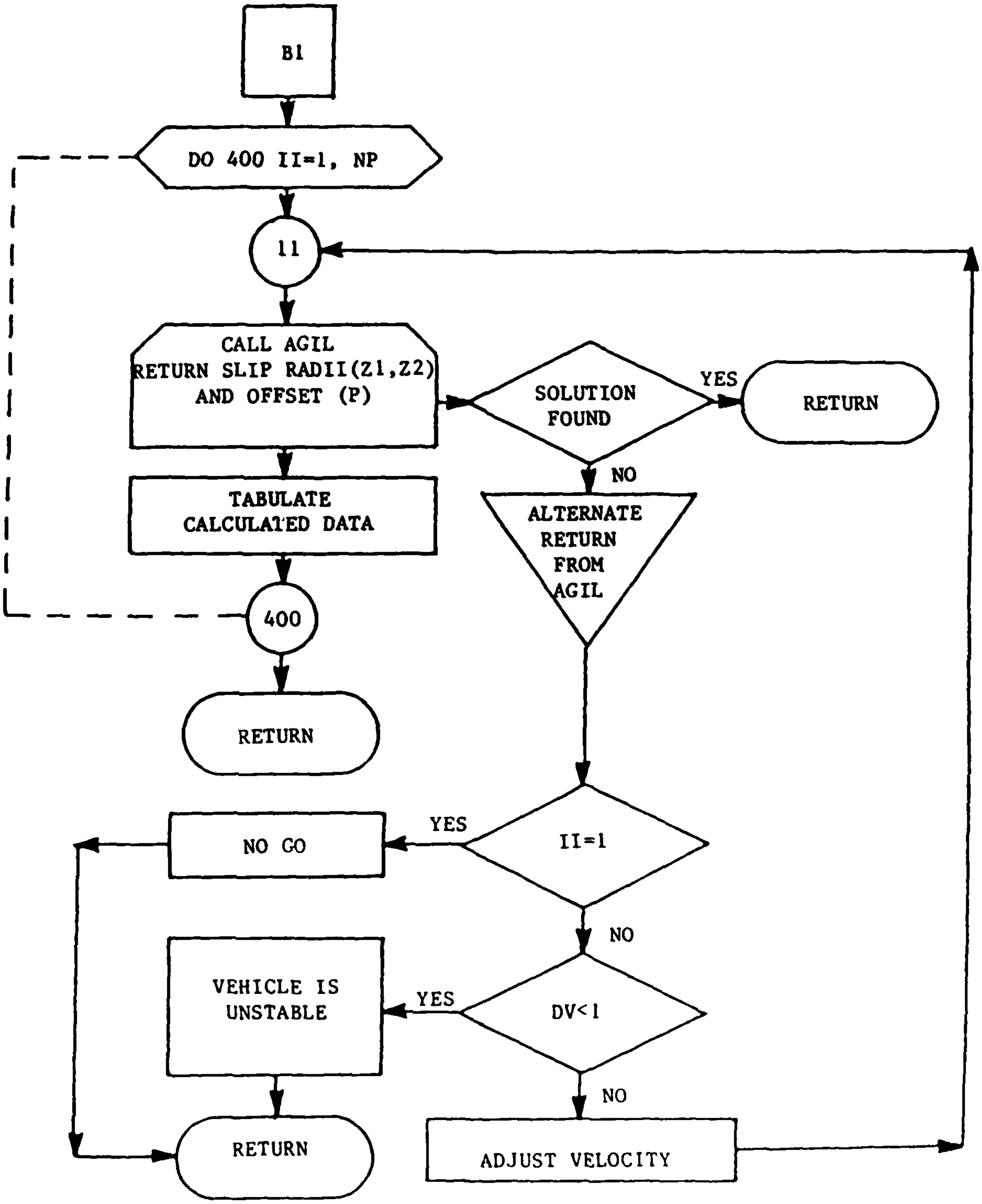


Figure 3.3. (Sheet 3 of 3).

```
 FSN
INPUT TEST NO. (UP TO 40 CHARACTERS) = SAMPLE RUN FOR USER'S GUIDE

TO HAVE CODE COMPUTE VCI1, INPUT VCI1=0.
INPUT WT,L,H,D,B,SL,CX,THETAD,THETAA,IZ,VCI1 = 18000.,105.,35.7,15.,90.,0.,0.,0.,30.,0.,0.


FOR TRNT, 0 = MANUAL, 1 = AUTOMATIC
INPUT SH,NB,TSL,HP,TRNT = 1.4,5,9.6,300.,1

TO HAVE CODE COMPUTE CONE INDEX, INPUT CI=0.
TC HAVE CODE COMPUTE ROLLING RESISTANCE, INPUT SF=0.
INPUT CI,A,SM,SN,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI = 0.,4.,0.,0.,1.,4.,0.18,25.,50.,0.,0.,0.

TO SIMULATE STANDARD WES CONE, INPUT CL=1.48,DI=0.79
FOR TYPICAL GAMA,Z, INPUT GAMA=0.07,Z=6.
INPUT CL,DI,GAMA,Z = 1.48,0.79,0.07,6.

INPUT RUNTYPE:
      FOR STEADY-STATE RUN, INPUT 0
      FOR TRANSIENT RUN, INPUT 1
INPUT YOUR CHOICE = 0

INPUT CASE:  1,2,3,4, OR ? = ?
CASE SELECTIONS:
                             CASE [1]..........VARY V (VELOCITY) ; INPUT E (STEERING RATIO)
                             CASE [2]..........VARY V (VELOCITY) ; INPUT RO (TURNING RADIUS)
                             CASE [3]....VARY E (STEERING RATIO) ; FIXED V (VELOCITY)
                             CASE [4]...VARY RO (TURNING RADIUS) ; FIXED V (VELOCITY)
INPUT YOUR CHOICE: = 1

INPUT E,DV,HPAV = 1.4,1.,1000.
```

Figure 3.4. Sample input for subroutine STEADY.

```
 FRN
INPUT TEST NO. (UP TO 40 CHARACTERS) = SAMPLE RUN FOR USER'S GUIDE

TO HAVE CODE COMPUTE VCI1, INPUT VCI1=0.
INPUT WT,L,H,D,B,SL,CX,THETAD,THETAA,IZ,VCI1 = 18000.,105.,35.7,15.,90.,0.,0.,0.,30.,92000.,20.9

TO HAVE CODE COMPUTE CONE INDEX, INPUT CI=0.
TO HAVE CODE COMPUTE ROLLING RESISTANCE, INPUT SF=0.
INPUT CI,A,SM,SN,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI = 181.,4.,0.,0.,1.,4.,0.18,25.,50.,0.,0.,0.

INPUT RUNTYPE:
      FOR STEADY-STATE RUN, INPUT 0
      FOR TRANSIENT RUN, INPUT 1
INPUT YOUR CHOICE = 1

MAXIMUM POINTS NP SET TO  100
INPUT DT,NP,IPRINT = 0.2,40,1

INPUT CASE:  1,2,3,4, OR ? = ?

CASE SELECTIONS:
                             CASE [1].........INPUT V,E (VELOCITY,STEERING RATIO)
                             CASE [2]........INPUT V,RI (VELOCITY,TURNING RADIUS)
                             CASE [3]...INPUT E,VI (STEERING RATIO,INITIAL VELOCITY) ; VARY V (VELOCITY)
                             CASE [4]...........INPUT VX1,VX2 (TRACK VELOCITIES)
INPUT YOUR CHOICE: = 1

INPUT HPAV,V1,V2,V3,V4 = 1000.,5.,-15.,1.,2.
INPUT E1,E2,E3,E4 = 1.1,-0.4,1.,2.
```

Figure 3.5. Sample input for subroutine TRANS.

STEADY-STATE TURNING MOTION

CASE (1)..........VARY V (VELOCITY) ; INPUT E (STEERING RATIO)

DV = 1.0(MPH) HPAV = 1000.0(HP) TEST NO. : SAMPLE RUN FOR USER'S GUIDE 01/29/86

WT(IN)	L(IN)	H(IN)	D(IN)	B(IN)	SL(IN)	CX(IN)	THETAD(DEG)	THETAA(DEG)	IZ(IN LB/SEC**2)	VC11
18000.0	105.0	35.7	15.0	90.0	0.	0.	0.	30.0	0.	20.9

CI	A(PSI)	SM(PSI)	C(PSI)	SN(1/PSI)	SXI	CD(PSI)	CLAMDA(SEC/IN)	PHI(DEG)	G(PSI/IN)	SF	ETA(DEG)	CHI(DEG)
181.0	4.0	0.	4.0	0.	1	4.0	0.190	25.0	50.0	0.059	0.	0.

PT	P/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP
1	-0.00	1.40	29.03	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	-0.00	1.40	29.50	1.0	1.2	0.8	0.05	-0.03	2.8	-0.00	0.00	10.8	8.5
3	0.00	1.40	29.69	2.0	2.3	1.7	0.09	-0.07	5.7	0.00	0.01	23.0	18.1
4	0.00	1.40	29.76	3.0	3.5	2.5	0.14	-0.11	8.5	0.00	0.02	36.2	28.4
5	0.01	1.40	29.76	4.0	4.7	3.3	0.18	-0.15	11.3	0.00	0.04	49.8	38.9
6	0.01	1.40	29.73	5.0	5.9	4.2	0.22	-0.19	14.1	0.00	0.06	63.6	49.7
7	0.02	1.40	29.69	6.0	7.0	5.0	0.27	-0.23	17.0	0.00	0.08	77.6	60.6
8	0.03	1.40	29.64	7.0	8.2	5.8	0.30	-0.26	19.8	0.00	0.11	91.7	71.6
9	0.04	1.40	29.59	8.0	9.4	6.7	0.34	-0.30	22.7	0.00	0.14	105.9	82.7
10	0.05	1.40	29.54	9.0	10.5	7.5	0.38	-0.34	25.6	0.00	0.18	120.2	93.9
11	0.06	1.40	29.49	10.0	11.7	8.3	0.41	-0.38	28.5	0.00	0.23	134.6	105.2
12	0.08	1.40	29.44	11.0	12.8	9.2	0.44	-0.42	31.4	0.01	0.27	149.1	116.7
13	0.09	1.40	29.37	12.0	14.0	10.0	0.47	-0.46	34.3	0.01	0.33	163.9	128.6
14	0.11	1.40	29.30	13.0	15.2	10.8	0.50	-0.50	37.3	0.01	0.39	178.9	140.9
15	0.12	1.40	29.22	14.0	16.3	11.7	0.53	-0.54	40.3	0.02	0.45	194.4	153.5
16	0.14	1.40	29.11	15.0	17.5	12.5	0.55	-0.58	43.3	0.02	0.52	210.4	166.9
17	0.16	1.40	28.99	16.0	18.6	13.3	0.57	-0.61	46.4	0.03	0.59	227.1	181.2
18	0.18	1.40	28.82	17.0	19.8	14.1	0.59	-0.64	49.6	0.04	0.67	244.7	196.6
19	0.21	1.40	28.62	18.0	20.9	14.9	0.61	-0.66	52.9	0.05	0.75	263.6	213.4
20	0.23	1.40	28.37	19.0	22.1	15.8	0.62	-0.67	56.3	0.06	0.85	284.0	232.2
21	0.26	1.40	28.05	20.0	23.2	16.6	0.63	-0.66	59.9	0.08	0.95	306.8	253.6
22	0.29	1.40	27.64	21.0	24.4	17.4	0.64	-0.63	63.8	0.10	1.06	332.9	278.9
23	0.32	1.40	27.06	22.0	25.6	18.3	0.66	-0.56	68.3	0.13	1.19	365.0	310.7
24	0.36	1.40	26.36	23.0	26.8	19.1	0.68	-0.43	73.3	0.16	1.33	405.0	351.0
25	0.40	1.40	25.42	24.0	28.0	20.0	0.70	-0.22	79.3	0.21	1.50	456.7	404.0
26	0.45	1.40	24.99	25.0	29.2	20.9	0.75	-0.09	84.1	0.26	1.65	512.6	461.5
27	0.53	1.40	24.35	26.0	30.5	21.8	0.98	0.27	89.7	0.35	1.82	620.1	569.6
28	0.57	1.40	24.17	26.1	30.8	22.0	1.20	0.50	90.8	0.39	1.95	672.2	619.6

STABILITY LIMIT ON F

PT	P/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP
27	0.50	1.40	24.56	25.7	30.1	21.5	0.91	0.16	87.9	0.32	1.77	585.4	534.7

PROCESSOR TIME (CPU-MIN) = 6.22281E-02

Figure 3.6. Sample run for steady-state motion, Case 1; soil model with linear shear failure envelope; zero track tension.

STEADY-STATE TURNING MOTION
CASE (2)..........VARY V (VELOCITY) ; INPUT RO (TURNING RADIUS)

DV = 1.0(MPH) HPAV = 1000.0(HP) TEST NO. = SAMPLE RUN FOR USER'S GUIDE 01/29/86

WT(IN)	L(IN)	H(IN)	D(IN)	B(IN)	SL(IN)	CX(IN)	THETAD(DEG)	THETAA(DEG)	IZ(IN LB/SEC**2)	VCII
18000.0	105.0	35.7	15.0	90.0	0.	0.	0.	30.0	0.	29.9

CI	A(PSI)	SH(PSI)	C(PSI)	SN(1/PSI)	SKI	CD(PSI)	CLAMDA(SEC/IN)	PHI(DEG)	G(PSI/IN)	SF	ETA(DEG)	CHI(DEG)
181.0	4.0	0.	4.0	0.	1	4.0	0.180	25.0	50.0	0.059	0.	0.

PT	P/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP
1	-0.00	1.40	29.00	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	-0.00	1.41	29.00	1.0	1.2	0.8	0.05	-0.04	2.9	-0.00	0.00	10.9	8.6
3	0.00	1.41	29.00	2.0	2.4	1.7	0.10	-0.07	5.8	0.00	0.01	23.5	18.5
4	0.00	1.41	29.00	3.0	3.5	2.5	0.14	-0.11	8.7	0.00	0.02	37.0	29.0
5	0.01	1.41	29.00	4.0	4.7	3.3	0.19	-0.15	11.6	0.00	0.04	50.9	39.8
6	0.02	1.41	29.00	5.0	5.9	4.2	0.23	-0.19	14.5	0.00	0.06	65.0	50.7
7	0.02	1.41	29.00	6.0	7.0	5.0	0.27	-0.23	17.4	0.00	0.08	79.2	61.8
8	0.03	1.41	29.00	7.0	8.2	5.8	0.31	-0.27	20.3	0.00	0.11	93.5	72.9
9	0.04	1.41	29.00	8.0	9.4	6.7	0.35	-0.31	23.2	0.00	0.15	107.7	84.0
10	0.05	1.41	29.00	9.0	10.5	7.5	0.38	-0.35	26.1	0.00	0.19	122.1	95.2
11	0.06	1.41	29.00	10.0	11.7	8.3	0.42	-0.39	29.0	0.00	0.23	136.4	106.6
12	0.08	1.41	29.00	11.0	12.9	9.1	0.45	-0.43	31.9	0.01	0.28	151.0	118.1
13	0.09	1.41	29.00	12.0	14.0	10.0	0.48	-0.47	34.8	0.01	0.33	165.6	129.9
14	0.11	1.40	29.00	13.0	15.2	10.8	0.51	-0.51	37.7	0.01	0.39	180.5	142.0
15	0.12	1.40	29.00	14.0	16.3	11.6	0.53	-0.54	40.6	0.02	0.45	195.6	154.5
16	0.14	1.40	29.00	15.0	17.5	12.5	0.55	-0.58	43.5	0.02	0.52	211.1	167.5
17	0.16	1.40	29.00	16.0	18.6	13.3	0.57	-0.61	46.4	0.03	0.59	227.0	181.1
18	0.18	1.40	29.00	17.0	19.8	14.1	0.59	-0.63	49.3	0.04	0.66	243.4	195.5
19	0.20	1.39	29.00	18.0	20.9	15.0	0.60	-0.65	52.2	0.05	0.74	260.4	210.8
20	0.23	1.39	29.00	19.0	22.0	15.8	0.61	-0.66	55.1	0.06	0.83	278.2	227.2
21	0.25	1.39	29.00	20.0	23.1	16.7	0.62	-0.66	58.0	0.07	0.92	297.1	245.0
22	0.28	1.38	29.00	21.0	24.3	17.6	0.62	-0.64	60.9	0.08	1.01	317.0	264.4
23	0.30	1.37	29.00	22.0	25.4	18.5	0.62	-0.60	63.7	0.10	1.11	338.6	285.8
24	0.33	1.37	29.00	23.0	26.5	19.4	0.62	-0.53	66.6	0.12	1.21	362.0	309.7
25	0.36	1.36	29.00	24.0	27.6	20.3	0.62	-0.44	69.5	0.14	1.32	388.0	336.6
26	0.39	1.35	29.00	25.0	28.7	21.3	0.61	-0.32	72.4	0.17	1.43	416.5	366.4
27	0.41	1.34	29.00	26.0	29.8	22.2	0.60	-0.20	75.3	0.19	1.55	445.6	397.5
28	0.45	1.33	29.00	27.0	30.9	23.2	0.63	-0.10	78.2	0.23	1.66	489.2	441.5
29	0.48	1.33	29.00	27.5	31.5	23.6	0.69	-0.02	79.7	0.25	1.72	520.4	474.0
30	0.50	1.33	29.00	27.7	31.7	23.9	0.72	0.01	80.4	0.27	1.75	537.6	491.4
31	0.50	1.33	29.00	27.8	31.8	23.9	0.72	0.01	80.6	0.27	1.76	540.1	494.1
32	0.50	1.33	29.00	27.9	31.9	24.0	0.71	0.01	80.8	0.27	1.77	541.5	495.7
33	0.50	1.33	29.00	27.9	31.9	24.0	0.70	0.02	81.0	0.27	1.78	542.7	497.3
34	0.50	1.33	29.00	28.0	32.0	24.1	0.70	0.03	81.1	0.27	1.79	544.5	499.3
35	0.50	1.33	29.00	28.1	32.1	24.2	0.70	0.05	81.3	0.27	1.79	547.0	502.1
36	0.51	1.33	29.00	28.1	32.1	24.2	0.70	0.07	81.5	0.28	1.80	550.5	505.7
37	0.51	1.32	29.00	28.2	32.2	24.3	0.71	0.10	81.7	0.28	1.81	554.7	510.0
38	0.51	1.32	29.00	28.2	32.3	24.4	0.72	0.12	81.9	0.28	1.82	559.6	515.0
39	0.52	1.32	29.00	28.3	32.4	24.5	0.73	0.15	82.0	0.29	1.82	565.3	520.7
40	0.52	1.32	29.00	28.4	32.4	24.5	0.75	0.18	82.2	0.29	1.83	571.9	527.3

MAXIMUM POINTS NP SET TO 40

STABILITY LIMIT ON P

34	0.50	1.33	29.00	28.0	32.0	24.0	0.70	0.02	81.0	0.27	1.78	543.2	497.9

PROCESSOR TIME (CPU-MIN) = 1.32814E-01

Figure 3.7. Sample run for steady-state motion, Case 2; soil model with linear shear failure envelope; zero track tension.

STEADY-STATE TURNING MOTION
CASE (3)....VARY E (STEERING RATIO) ; FIXED V (VELOCITY)

DE = 0.02 NP = 40   TEST NO. = SAMPLE RUN FOR USER'S GUIDE   02/04/86

WT(IN)	L(IN)	H(IN)	D(IN)	B(IN)	SL(IN)	SX(IN)	THETAD(DEG)	THETAA(DEG)	IZ(IN LB/SEC**2)	VCI1
18000.0	105.0	35.7	15.0	90.0	0.	0.	0.	30.0	0.	20.9

CI	A(PSI)	SM(PSI)	C(PSI)	SN(1/PSI)	SXI	CD(PSI)	CLAMDA(SEC/IN)	PHI(DEG)	G(PSI/IN)	SF	ETA(DEG)	CHI(DEG)
181.0	4.0	0.	4.0	0.	1	4.0	0.180	25.0	50.0	0.059	0.	0.

PT	F/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP
1	0.00	1.01	982.81	5.7	5.7	5.7	0.01	-0.01	0.5	0.00	0.00	18.1	16.9
2	0.00	1.03	332.65	5.7	5.8	5.6	0.02	-0.02	1.4	0.00	0.01	20.6	18.8
3	0.00	1.05	202.33	5.7	5.8	5.6	0.04	-0.03	2.4	0.00	0.01	23.2	20.7
4	0.00	1.07	146.33	5.7	5.9	5.5	0.05	-0.04	3.3	0.00	0.01	26.0	22.7
5	0.01	1.09	115.13	5.7	6.0	5.5	0.07	-0.05	4.2	0.00	0.02	28.9	24.8
6	0.01	1.11	95.22	5.7	6.0	5.4	0.08	-0.06	5.0	0.00	0.02	31.8	26.9
7	0.01	1.13	81.40	5.7	6.1	5.4	0.10	-0.08	5.9	0.00	0.03	34.8	29.1
8	0.01	1.15	71.25	5.7	6.1	5.3	0.11	-0.09	6.7	0.00	0.03	37.7	31.3
9	0.01	1.17	63.46	5.7	6.2	5.3	0.12	-0.10	7.5	0.00	0.03	40.7	33.5
10	0.01	1.19	57.31	5.7	6.2	5.2	0.14	-0.11	8.4	0.00	0.04	43.7	35.6
11	0.01	1.21	52.32	5.7	6.3	5.2	0.15	-0.12	9.2	0.00	0.04	46.7	37.8
12	0.01	1.23	48.19	5.7	6.3	5.1	0.16	-0.13	9.9	0.00	0.05	49.6	40.0
13	0.01	1.25	44.72	5.7	6.4	5.1	0.17	-0.14	10.7	0.00	0.05	52.6	42.1
14	0.01	1.27	41.76	5.7	6.4	5.0	0.18	-0.15	11.5	0.00	0.05	55.5	44.2
15	0.02	1.29	39.20	5.7	6.4	5.0	0.20	-0.16	12.2	0.00	0.06	58.3	46.3
16	0.02	1.31	36.97	5.7	6.5	4.9	0.21	-0.17	13.0	0.00	0.06	61.1	48.4
17	0.02	1.33	35.02	5.7	6.5	4.9	0.22	-0.18	13.7	0.00	0.06	63.9	50.4
18	0.02	1.35	33.28	5.7	6.6	4.9	0.23	-0.19	14.4	0.00	0.07	66.7	52.4
19	0.02	1.37	31.73	5.7	6.6	4.8	0.24	-0.20	15.1	0.00	0.07	69.4	54.4
20	0.02	1.39	30.34	5.7	6.7	4.8	0.25	-0.21	15.8	0.00	0.07	72.1	56.4
21	0.02	1.41	29.09	5.7	6.7	4.7	0.26	-0.22	16.5	0.00	0.07	74.7	58.3
22	0.02	1.43	27.95	5.7	6.7	4.7	0.27	-0.23	17.1	0.00	0.08	77.3	60.2
23	0.02	1.45	26.91	5.7	6.8	4.7	0.28	-0.24	17.8	0.00	0.08	79.9	62.1
24	0.02	1.47	25.97	5.7	6.8	4.6	0.29	-0.24	18.4	0.00	0.08	82.4	63.9
25	0.02	1.49	25.09	5.7	6.8	4.6	0.30	-0.25	19.1	0.00	0.09	84.9	65.8
26	0.02	1.51	24.29	5.7	6.9	4.6	0.30	-0.26	19.7	0.00	0.09	87.4	67.5
27	0.02	1.53	23.55	5.7	6.9	4.5	0.31	-0.27	20.3	0.00	0.09	89.8	69.3
28	0.03	1.55	22.86	5.7	7.0	4.5	0.32	-0.28	21.0	0.00	0.09	92.2	71.1
29	0.03	1.57	22.22	5.7	7.0	4.5	0.33	-0.28	21.6	0.00	0.10	94.5	72.8
30	0.03	1.59	21.63	5.7	7.0	4.4	0.34	-0.29	22.1	0.00	0.10	96.8	74.5
31	0.03	1.61	21.07	5.7	7.1	4.4	0.35	-0.30	22.7	0.00	0.10	99.1	76.1
32	0.03	1.63	20.55	5.7	7.1	4.4	0.36	-0.31	23.3	0.00	0.11	101.3	77.8
33	0.03	1.65	20.06	5.7	7.1	4.3	0.36	-0.31	23.9	0.00	0.11	103.5	79.4
34	0.03	1.67	19.50	5.7	7.2	4.3	0.37	-0.32	24.4	0.00	0.11	105.7	81.0
35	0.03	1.69	19.16	5.7	7.2	4.3	0.38	-0.33	25.0	0.00	0.11	107.9	82.5
36	0.03	1.71	18.76	5.7	7.2	4.2	0.39	-0.33	25.5	0.00	0.12	110.0	84.1
37	0.03	1.73	18.37	5.7	7.3	4.2	0.39	-0.34	26.1	0.00	0.12	112.0	85.6
38	0.03	1.75	18.00	5.7	7.3	4.2	0.40	-0.35	26.6	0.00	0.12	114.1	87.1
39	0.03	1.77	17.66	5.7	7.3	4.1	0.41	-0.35	27.1	0.00	0.12	116.1	88.6
40	0.03	1.79	17.33	5.7	7.3	4.1	0.41	-0.36	27.6	0.00	0.13	118.1	90.1

PROCESSOR TIME (CPU-MIN) = 3.55539E-02

Figure 3.8. Sample run for steady-state motion, Case 3; soil model with linear shear failure envelope; zero track tension.

STEADY-STATE TURNING MOTION
CASE [4]...VARY RO (TURNING RADIUS) ; FIXED V (VELOCITY)

DR = 24.8(FT) NP = 40 TEST NO. = SAMPLE RUN FOR USER'S GUIDE 02/04/86

WT(IN)	L(IN)	H(IN)	D(IN)	B(IN)	SL(IN)	CX(IN)	THETAD(DEG)	THETAA(DEG)	IZ(IN LB/SEC**2)	VCI1
18000.0	105.0	35.7	15.0	90.0	0.	0.	0.	30.0	0.	20.9

CI	A(PSI)	SM(PSI)	C(PSI)	SN(1/PSI)	SXI	CD(PSI)	CLAMDA(SEC/IN)	PHI(DEG)	G(PSI/IN)	SF	ETA(DEG)	CHI(DEG)
181.0	4.0	0.	4.0	0.	1	4.0	0.180	25.0	50.0	0.059	0.	0.

PT	P/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP
1	0.00	1.01	983.00	5.7	5.7	5.7	0.01	-0.01	0.5	0.00	0.00	18.1	16.9
2	0.00	1.01	958.20	5.7	5.7	5.7	0.01	-0.01	0.5	0.00	0.00	18.1	17.0
3	0.00	1.01	933.40	5.7	5.7	5.7	0.01	-0.01	0.5	0.00	0.00	18.2	17.0
4	0.00	1.01	908.60	5.7	5.7	5.7	0.01	-0.01	0.5	0.00	0.00	18.2	17.0
5	0.00	1.01	883.80	5.7	5.7	5.7	0.01	-0.01	0.5	0.00	0.00	18.2	17.0
6	0.00	1.01	859.00	5.7	5.7	5.7	0.01	-0.01	0.6	0.00	0.00	18.3	17.1
7	0.00	1.01	834.20	5.7	5.7	5.7	0.01	-0.01	0.6	0.00	0.00	18.3	17.1
8	0.00	1.01	809.40	5.7	5.7	5.7	0.01	-0.01	0.6	0.00	0.00	18.4	17.1
9	0.00	1.01	784.60	5.7	5.7	5.7	0.01	-0.01	0.6	0.00	0.00	18.4	17.2
10	0.00	1.01	759.80	5.7	5.7	5.7	0.01	-0.01	0.6	0.00	0.00	18.5	17.2
11	0.00	1.01	735.00	5.7	5.7	5.7	0.01	-0.01	0.7	0.00	0.00	18.5	17.2
12	0.00	1.01	710.20	5.7	5.7	5.7	0.01	-0.01	0.7	0.00	0.00	18.6	17.3
13	0.00	1.01	685.40	5.7	5.7	5.7	0.01	-0.01	0.7	0.00	0.00	18.6	17.3
14	0.00	1.01	660.60	5.7	5.7	5.7	0.01	-0.01	0.7	0.00	0.00	18.7	17.4
15	0.00	1.02	635.80	5.7	5.7	5.7	0.01	-0.01	0.8	0.00	0.00	18.8	17.4
16	0.00	1.02	611.00	5.7	5.7	5.7	0.01	-0.01	0.8	0.00	0.00	18.9	17.5
17	0.00	1.02	586.20	5.7	5.7	5.7	0.01	-0.01	0.8	0.00	0.00	18.9	17.6
18	0.00	1.02	561.40	5.7	5.8	5.7	0.01	-0.01	0.9	0.00	0.00	19.0	17.6
19	0.00	1.02	536.60	5.7	5.8	5.6	0.01	-0.01	0.9	0.00	0.00	19.1	17.7
20	0.00	1.02	511.80	5.7	5.8	5.6	0.01	-0.01	0.9	0.00	0.00	19.2	17.8
21	0.00	1.02	487.00	5.7	5.8	5.6	0.02	-0.01	1.0	0.00	0.00	19.4	17.9
22	0.00	1.02	462.20	5.7	5.8	5.6	0.02	-0.01	1.0	0.00	0.00	19.5	18.0
23	0.00	1.02	437.40	5.7	5.8	5.6	0.02	-0.01	1.1	0.00	0.00	19.7	18.1
24	0.00	1.02	412.60	5.7	5.8	5.6	0.02	-0.01	1.2	0.00	0.01	19.8	18.2
25	0.00	1.03	387.80	5.7	5.8	5.6	0.02	-0.01	1.2	0.00	0.01	20.0	16.4
26	0.00	1.03	363.00	5.7	5.8	5.6	0.02	-0.02	1.3	0.00	0.01	20.3	18.5
27	0.00	1.03	338.20	5.7	5.8	5.6	0.02	-0.02	1.4	0.00	0.01	20.5	18.7
28	0.00	1.03	313.40	5.7	5.8	5.6	0.02	-0.02	1.5	0.00	0.01	20.8	18.9
29	0.00	1.03	288.60	5.7	5.8	5.6	0.03	-0.02	1.7	0.00	0.01	21.2	19.2
30	0.00	1.04	263.80	5.7	5.8	5.6	0.03	-0.02	1.8	0.00	0.01	21.6	19.5
31	0.00	1.04	239.00	5.7	5.8	5.6	0.03	-0.02	2.0	0.00	0.01	22.2	19.9
32	0.00	1.05	214.20	5.7	5.8	5.6	0.04	-0.03	2.2	0.00	0.01	22.9	20.4
33	0.00	1.05	189.40	5.7	5.9	5.6	0.04	-0.03	2.5	0.00	0.01	23.7	21.1
34	0.00	1.06	164.60	5.7	5.9	5.5	0.05	-0.04	2.9	0.00	0.01	24.9	21.9
35	0.01	1.07	139.80	5.7	5.9	5.5	0.06	-0.04	3.4	0.00	0.02	26.5	23.1
36	0.01	1.09	115.00	5.7	6.0	5.5	0.07	-0.05	4.2	0.00	0.02	28.9	24.8
37	0.01	1.12	90.20	5.7	6.0	5.4	0.09	-0.07	5.3	0.00	0.02	32.8	27.6
38	0.01	1.16	65.40	5.7	6.1	5.3	0.12	-0.10	7.3	0.00	0.03	39.9	32.9
39	0.01	1.28	40.60	5.7	6.4	5.0	0.19	-0.16	11.9	0.00	0.05	56.7	45.1
40	0.04	1.90	15.80	5.7	7.5	4.0	0.45	-0.39	30.3	0.00	0.14	128.4	97.6

PROCESSOR TIME (CPU-MIN) = 3.47982E-02

Figure 3.9. Sample run for steady-state motion, Case 4; soil model with linear shear failure envelope; zero track tension.

TRANSIENT TURNING MOTION
CASE (1)........INPUT V,E (VELOCITY,STEERING RATIO)

DT = 0.2(SEC) NP = 40 TEST NO. = SAMPLE RUN FOR USER'S GUIDE 01/29/96

HPAV = 1000.0(HP) DRIVER COEFFICIENTS FOR VELOCITY : 5.00,-15.00, 1.00, 2.00
STEERING RATIO: 1.10, -0.40, 1.00, 2.00

WT(IN)	L(IN)	H(IN)	D(IN)	R(IN)	SL(IN)	CX(IN)	THETAD(DEG)	THETAA(DEG)	IZ(IN LB/SEC**2)	VCI1
18000.0	105.0	35.7	15.0	90.0	0.	0.	0.	30.0	92000.0	20.9

CI	A(PSI)	SM(PSI)	C(PSI)	SN(1/PSI)	SXI	CD(PSI)	CLAMDA(SEC/IN)	PHI(DEG)	G(PSI/IN)	SF	ETA(DEG)	CHI(DEG)
181.0	4.0	0.	4.0	0.	1	4.0	0.180	25.0	50.0	0.059	0.	0.

PT	T SEC	P/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	W DEG	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP	DXT FT	DYT FT
1	0.20	-0.01	1.12	85.94	5.7	6.1	5.4	0.13	-0.05	0.5	5.3	0.16	0.03	80.9	73.0	1.6	0.0
2	0.40	-0.03	1.16	66.46	7.2	7.9	6.8	0.27	-0.05	1.9	8.7	0.35	0.05	182.1	166.2	3.5	0.1
3	0.60	-0.02	1.21	55.50	9.1	10.1	8.4	0.44	-0.07	4.2	13.8	0.41	0.10	271.0	245.7	5.9	0.2
4	0.80	0.00	1.26	47.24	10.8	12.3	9.8	0.62	-0.11	7.6	20.0	0.41	0.17	338.2	303.5	8.8	0.5
5	1.00	0.03	1.30	41.62	12.5	14.4	11.1	0.75	-0.18	12.2	26.7	0.37	0.25	381.5	338.4	12.1	1.1
6	1.20	0.06	1.34	37.56	13.8	16.2	12.1	0.85	-0.26	18.2	33.2	0.32	0.34	404.9	354.8	15.8	2.1
7	1.40	0.09	1.37	34.43	15.0	17.7	12.9	0.89	-0.34	25.5	39.3	0.28	0.43	414.2	358.8	19.8	3.6
8	1.60	0.12	1.39	32.07	16.0	18.9	13.6	0.91	-0.43	33.9	44.8	0.24	0.52	414.6	355.7	23.8	5.8
9	1.80	0.15	1.41	30.26	16.8	19.9	14.1	0.90	-0.50	43.3	49.5	0.21	0.61	410.6	349.4	27.6	8.7
10	2.00	0.18	1.43	28.82	17.4	20.7	14.4	0.89	-0.56	53.6	53.6	0.19	0.69	405.0	342.5	31.1	12.3
11	2.20	0.20	1.44	27.67	17.9	21.3	14.7	0.87	-0.60	64.7	57.1	0.17	0.77	399.3	336.2	33.9	16.6
12	2.40	0.22	1.46	26.75	18.3	21.8	15.0	0.85	-0.63	76.4	60.0	0.16	0.83	394.3	331.0	36.0	21.4
13	2.60	0.24	1.46	26.01	18.7	22.2	15.2	0.83	-0.65	88.6	62.4	0.15	0.89	390.2	327.1	37.1	26.7
14	2.80	0.25	1.47	25.41	18.9	22.6	15.3	0.82	-0.66	101.3	64.4	0.14	0.93	387.3	324.5	37.0	32.2
15	3.00	0.26	1.48	24.92	19.1	22.8	15.4	0.81	-0.66	114.4	66.1	0.14	0.97	385.3	322.8	35.9	37.6
16	3.20	0.27	1.48	24.52	19.3	23.0	15.5	0.80	-0.66	127.8	67.6	0.14	1.01	384.1	321.9	33.3	42.6
17	3.40	0.28	1.49	24.19	19.4	23.2	15.6	0.79	-0.65	141.4	68.7	0.14	1.04	383.4	321.6	29.7	47.0
18	3.60	0.29	1.49	23.91	19.5	23.3	15.7	0.78	-0.65	155.2	69.7	0.14	1.06	383.1	321.6	25.2	50.5
19	3.80	0.29	1.49	23.68	19.6	23.4	15.7	0.78	-0.64	169.3	70.5	0.14	1.08	383.1	321.9	20.0	52.7
20	4.00	0.30	1.49	23.49	19.7	23.5	15.8	0.78	-0.63	183.4	71.2	0.14	1.10	383.3	322.3	14.3	53.7
21	4.20	0.30	1.49	23.33	19.8	23.6	15.8	0.77	-0.62	197.7	71.8	0.14	1.11	383.5	322.7	8.6	53.3
22	4.40	0.30	1.49	23.20	19.8	23.7	15.8	0.77	-0.62	212.1	72.2	0.14	1.12	383.7	323.1	3.2	51.4
23	4.60	0.31	1.50	23.09	19.8	23.7	15.9	0.77	-0.61	226.6	72.6	0.14	1.13	384.0	323.5	-1.7	48.3
24	4.80	0.31	1.50	23.00	19.9	23.8	15.9	0.77	-0.61	241.2	72.9	0.14	1.14	384.2	323.9	-5.6	44.0
25	5.00	0.31	1.50	22.93	19.9	23.8	15.9	0.76	-0.60	255.8	73.2	0.14	1.14	384.5	324.2	-9.3	38.9
26	5.20	0.31	1.50	22.87	19.9	23.9	15.9	0.76	-0.60	270.4	73.4	0.14	1.15	384.7	324.5	-9.6	33.3
27	5.40	0.31	1.50	22.83	19.9	23.8	15.9	0.76	-0.60	285.1	73.5	0.14	1.15	384.8	124.8	-9.5	27.5
28	5.60	0.31	1.50	22.79	19.9	23.8	15.9	0.76	-0.59	299.8	73.7	0.14	1.16	385.0	325.0	-7.9	21.9
29	5.80	0.32	1.50	22.76	20.0	23.9	15.9	0.76	-0.59	314.6	73.8	0.14	1.16	385.1	325.2	-5.0	16.9
30	6.00	0.32	1.50	22.73	20.0	23.9	15.9	0.76	-0.59	329.4	73.9	0.14	1.16	385.2	325.3	-0.9	12.9
31	6.20	0.32	1.50	22.71	20.0	23.9	15.9	0.76	-0.59	344.1	74.0	0.14	1.16	385.3	325.4	4.2	9.9
32	6.40	0.32	1.50	22.70	20.0	23.9	15.9	0.76	-0.59	358.9	74.0	0.14	1.17	385.4	325.5	9.8	8.4
33	6.60	0.32	1.50	22.68	20.0	23.9	15.9	0.76	-0.59	373.8	74.1	0.14	1.17	385.5	325.6	15.6	8.4
34	6.80	0.32	1.50	22.67	20.0	23.9	15.9	0.76	-0.59	388.6	74.1	0.15	1.17	385.5	325.7	21.7	9.9
35	7.00	0.32	1.50	22.66	20.0	23.9	15.9	0.76	-0.59	403.4	74.1	0.15	1.17	385.6	325.8	26.3	12.6
36	7.20	0.32	1.50	22.65	20.0	23.9	15.9	0.76	-0.59	418.2	74.2	0.15	1.17	385.6	325.8	30.5	15.2
37	7.40	0.32	1.50	22.65	20.0	23.9	15.9	0.76	-0.59	433.1	74.2	0.15	1.17	385.6	325.8	33.5	21.7
38	7.60	0.32	1.50	22.64	20.0	23.9	15.9	0.76	-0.58	447.9	74.2	0.15	1.17	385.6	325.9	35.1	27.2
39	7.80	0.32	1.50	22.64	20.0	23.9	15.9	0.76	-0.58	462.8	74.2	0.15	1.17	385.7	325.9	35.2	33.1
40	8.00	0.32	1.50	22.64	20.0	23.9	15.9	0.76	-0.58	477.6	74.2	0.15	1.17	385.7	325.9	33.9	38.7

PROCESSOR TIME (CPU-MIN) = 4.45849E-02

Figure 3.10. Sample run for transient motion, Case 1; soil model with linear shear failure envelope; zero track tension.

TRANSIENT TURNING MOTION
CASE [2]........INPUT V,RI (VELOCITY,TURNING RADIUS)
NOTE: THIS CASE COULD BE MODIFIED TO INPUT TRAJECTORY INSTEAD OF RI

DT = 0.2(SEC)   NP = 40   TEST NO. = SAMPLE RUN FOR USER'S GUIDE   01/29/86

HPAV = 1000.0(HP)   DRIVER COEFFICIENTS FOR VELOCITY : 5.0, -25.0, 1.0, 2.0
TURNING RADIUS: 50.0, 0. , 0. , 0.

WT(IN)	L(IN)	H(IN)	D(IN)	B(IN)	SL(IN)	CX(IN)	THETAD(DEG)	THETAA(DEG)	IZ(IN LB/SEC**2)	VCI1
18000.0	105.0	35.7	15.0	90.0	0.	0.	0.	30.0	72000.0	20.9

CI	A(PSI)	SM(PSI)	C(PSI)	SN(1/PSI)	SXI	CD(PSI)	CLAMDA(SEC/IN)	PHI(DEG)	G(PSI/IN)	SF	ETA(DEG)	CHI(DEG)
181.0	4.0	0.	4.0	0.	1	4.0	0.180	25.0	50.0	0.059	0.	0.

PT	T SEC	P/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	W DEG	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP	DXT FT	DYT FT
1	0.20	-0.02	1.23	47.03	6.2	6.9	5.6	0.30	-0.09	1.0	10.4	0.27	0.06	143.7	127.6	1.6	0.0
2	0.40	-0.03	1.24	48.51	8.7	10.0	8.1	0.60	-0.03	3.5	14.7	0.58	0.11	349.0	318.7	3.8	0.1
3	0.60	-0.01	1.25	52.03	11.8	13.6	10.9	0.93	-0.02	7.0	19.8	0.69	0.18	539.0	493.5	6.8	0.4
4	0.80	0.01	1.25	51.34	14.7	16.9	13.6	1.10	-0.03	11.4	24.8	0.68	0.28	667.2	610.3	10.6	1.1
5	1.00	0.05	1.24	53.14	17.4	19.9	16.0	1.15	-0.08	16.9	29.3	0.62	0.38	730.1	666.2	15.2	2.2
6	1.20	0.09	1.23	52.89	19.7	22.3	18.1	1.10	-0.12	23.1	33.2	0.54	0.48	739.9	673.0	20.3	4.1
7	1.40	0.13	1.22	52.36	21.7	24.3	19.9	1.02	-0.19	30.1	36.5	0.46	0.59	715.8	648.6	25.8	6.7
8	1.60	0.16	1.22	52.19	23.3	26.0	21.3	0.93	-0.25	37.6	39.2	0.39	0.69	674.1	608.2	31.3	10.3
9	1.80	0.19	1.22	51.81	24.6	27.3	22.5	0.84	-0.30	45.7	41.4	0.33	0.77	625.1	561.7	36.7	14.8
10	2.00	0.22	1.21	51.48	25.7	28.4	23.4	0.76	-0.35	54.2	43.2	0.27	0.85	576.1	515.6	41.6	20.3
11	2.20	0.24	1.21	51.22	26.6	29.2	24.2	0.70	-0.38	62.9	44.6	0.23	0.91	530.9	473.3	45.8	26.7
12	2.40	0.26	1.21	50.99	27.2	29.9	24.8	0.64	-0.41	72.0	45.8	0.20	0.96	491.2	436.3	49.1	33.9
13	2.60	0.27	1.21	50.80	27.8	30.4	25.2	0.60	-0.43	81.2	46.7	0.17	1.01	457.2	404.8	51.2	41.6
14	2.80	0.28	1.20	50.63	28.2	30.9	25.6	0.56	-0.44	90.6	47.4	0.15	1.04	428.9	378.6	52.2	49.7
15	3.00	0.29	1.20	50.50	28.6	31.2	25.9	0.53	-0.45	100.2	48.0	0.13	1.07	405.6	357.1	51.8	58.0
16	3.20	0.30	1.20	50.40	28.8	31.5	26.2	0.51	-0.45	109.8	48.5	0.12	1.10	386.6	339.6	50.0	66.2
17	3.40	0.31	1.20	50.32	29.1	31.7	26.4	0.49	-0.46	119.6	48.9	0.11	1.12	371.2	325.4	46.8	74.1
18	3.60	0.31	1.20	50.25	29.2	31.9	26.6	0.48	-0.46	129.4	49.2	0.10	1.13	358.8	314.0	42.3	81.3
19	3.80	0.32	1.20	50.20	29.4	32.0	26.7	0.46	-0.46	139.2	49.4	0.10	1.15	348.9	304.9	36.7	87.8
20	4.00	0.32	1.20	50.16	29.5	32.1	26.8	0.46	-0.47	149.1	49.6	0.09	1.16	340.9	297.6	30.0	93.2
21	4.20	0.32	1.20	50.13	29.6	32.2	26.9	0.45	-0.47	159.1	49.8	0.09	1.16	334.5	291.7	22.4	97.3
22	4.40	0.32	1.20	50.11	29.7	32.3	26.9	0.44	-0.47	169.0	49.9	0.08	1.17	329.3	287.0	14.2	100.1
23	4.60	0.33	1.20	50.09	29.7	32.4	27.0	0.44	-0.47	179.0	50.0	0.08	1.18	325.2	283.2	5.6	101.5
24	4.80	0.33	1.20	50.07	29.8	32.4	27.0	0.43	-0.47	189.0	50.1	0.08	1.18	321.9	280.2	-3.7	101.4
25	5.00	0.33	1.20	50.06	29.8	32.4	27.1	0.43	-0.47	199.0	50.1	0.08	1.18	319.2	277.7	-11.6	99.7
26	5.20	0.33	1.20	50.04	29.9	32.5	27.1	0.43	-0.47	209.1	50.2	0.08	1.19	317.0	275.7	-19.8	96.6
27	5.40	0.33	1.20	50.04	29.9	32.5	27.1	0.43	-0.47	219.1	50.2	0.07	1.19	315.3	274.1	-27.2	92.1
28	5.60	0.33	1.20	50.03	29.9	32.5	27.1	0.42	-0.47	229.1	50.3	0.07	1.19	313.9	272.8	-33.8	86.3
29	5.80	0.33	1.20	50.02	29.9	32.5	27.2	0.42	-0.47	239.2	50.3	0.07	1.19	312.7	271.8	-39.3	79.5
30	6.00	0.33	1.20	50.02	29.9	32.6	27.2	0.42	-0.47	249.3	50.3	0.07	1.19	311.8	271.0	-43.5	71.9
31	6.20	0.33	1.20	50.02	29.9	32.6	27.2	0.42	-0.47	259.3	50.3	0.07	1.20	311.1	270.3	-46.4	63.5
32	6.40	0.33	1.20	50.01	30.0	32.6	27.2	0.42	-0.47	269.4	50.3	0.07	1.20	310.4	269.7	-47.7	55.0
33	6.60	0.33	1.20	50.01	30.0	32.6	27.2	0.42	-0.47	279.5	50.4	0.07	1.20	309.9	269.3	-47.5	46.2
34	6.80	0.33	1.20	50.01	30.0	32.6	27.2	0.42	-0.47	289.5	50.4	0.07	1.20	309.5	268.9	-45.8	37.6
35	7.00	0.33	1.20	50.01	30.0	32.6	27.2	0.42	-0.47	299.6	50.4	0.07	1.20	309.2	268.6	-42.5	29.5
36	7.20	0.33	1.20	50.01	30.0	32.6	27.2	0.42	-0.47	309.7	50.4	0.07	1.20	308.9	268.3	-38.0	22.0
37	7.40	0.33	1.20	50.00	30.0	32.6	27.2	0.42	-0.47	319.8	50.4	0.07	1.20	308.7	268.1	-32.1	15.5
38	7.60	0.33	1.20	50.00	30.0	32.6	27.2	0.42	-0.47	329.9	50.4	0.07	1.20	308.5	268.0	-25.3	10.0
39	7.80	0.33	1.20	50.00	30.0	32.6	27.2	0.42	-0.47	339.9	50.4	0.07	1.20	308.4	267.8	-17.5	5.9
40	8.00	0.33	1.20	50.00	30.0	32.6	27.2	0.42	-0.47	350.0	50.4	0.07	1.20	308.3	267.7	-9.2	3.2

PROCESSOR TIME (CPU-MIN) = 5.03479E-02

Figure 3.11. Sample run for transient motion, Case 2; soil model with linear failure envelope; zero track tension.

TRANSIENT TURNING MOTION

CASE (3)...INPUT E,VI (STEERING RATIO,INITIAL VELOCITY) ; VARY V (VELOCITY)

DT = 0.2(SEC) NP = 40 TEST NO. = SAMPLE RUN FOR USER'S GUIDE 01/29/86

HPAV = 335.0 VI = 25.0

WT(IN)	L(IN)	H(IN)	D(IN)	B(IN)	SL(IN)	CX(IN)	THETAD(DEG)	THETAA(DEG)	I2(IN LB/SEC**2)	VCI1
18000.0	105.0	35.7	15.0	90.0	0.	0.	0.	30.0	92000.0	20.9

CI	A(PSI)	SM(PSI)	C(PSI)	SN(1/PSI)	SXI	CD(PSI)	CLAMDA(SEC/IN)	PHI(DEG)	G(PSI/IN)	SF	ETA(DEG)	CHI(DEG)
181.0	4.0	0.	4.0	0.	1	4.0	0.180	25.0	50.0	0.059	0.	0.

PT	T SEC	P/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	W DEG	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP	DXT FT	DYT FT
1	0.20	0.09	1.10	124.30	25.6	26.9	24.4	0.44	-0.29	1.9	19.2	0.13	0.35	-331.6	296.3	7.4	0.1
2	0.40	0.11	1.10	107.07	26.2	27.5	25.0	0.37	-0.24	6.0	21.1	0.14	0.43	333.8	300.4	15.0	0.6
3	0.60	0.12	1.10	104.57	26.7	28.0	25.5	0.37	-0.25	10.2	21.7	0.13	0.45	332.9	299.3	22.7	1.6
4	0.80	0.12	1.10	104.08	27.2	28.6	26.0	0.36	-0.26	14.6	22.1	0.12	0.47	321.1	288.0	30.4	3.3
5	1.00	0.13	1.10	103.76	27.7	29.1	26.4	0.37	-0.26	19.1	22.6	0.12	0.49	327.4	293.7	38.1	5.5
6	1.20	0.13	1.10	103.62	28.2	29.6	26.9	0.37	-0.27	23.7	23.0	0.12	0.51	333.7	299.4	45.8	8.4
7	1.40	0.14	1.10	103.50	28.7	30.1	27.4	0.37	-0.28	28.3	23.4	0.12	0.53	334.3	299.8	53.3	12.0
8	1.60	0.15	1.10	103.35	29.2	30.6	27.8	0.37	-0.28	33.0	23.8	0.11	0.55	331.4	296.8	60.7	16.2
9	1.80	0.15	1.10	103.16	29.6	31.0	28.2	0.37	-0.29	37.8	24.2	0.11	0.57	333.6	298.7	67.7	21.1
10	2.00	0.16	1.10	103.03	30.0	31.5	28.6	0.36	-0.30	42.7	24.6	0.10	0.58	321.7	287.3	74.5	26.7
11	2.20	0.01	1.00	682.53	30.7	30.7	30.7	0.00	-0.00	45.2	0.0	0.16	0.09	333.5	316.8	80.9	32.8
12	2.40	-0.03	1.00	97048.85	31.4	31.4	31.4	0.00	-0.00	45.2	0.0	0.15	0.00	334.8	318.1	87.4	39.2
13	2.60	-0.03	1.00	99948.93	32.0	32.0	32.0	0.00	-0.00	45.2	0.0	0.15	0.00	333.9	317.2	93.9	45.8
14	2.80	-0.02	1.00	99753.48	32.6	32.6	32.6	0.00	-0.00	45.2	0.0	0.14	0.00	322.1	306.0	100.6	52.6
15	3.00	-0.02	1.00	99596.16	33.2	33.2	33.2	0.00	-0.00	45.2	0.0	0.14	0.00	328.0	311.6	107.4	59.4
16	3.20	-0.02	1.00	99596.15	33.8	33.8	33.8	0.00	-0.00	45.2	0.0	0.14	0.00	333.9	317.2	114.3	66.4
17	3.40	- .02	1.00	99554.84	34.4	34.4	34.4	0.00	-0.00	45.2	0.0	0.13	0.00	333.1	316.4	121.4	73.5
18	3.60	-0.02	1.00	99469.63	35.0	35.0	35.0	0.00	-0.00	45.2	0.0	0.13	0.00	333.0	316.4	128.5	80.7
19	3.80	-0.02	1.00	99399.93	35.5	35.5	35.5	0.00	-0.00	45.2	0.0	0.13.	0.00	333.6	316.9	135.8	88.0
20	4.00	-0.02	1.00	99342.77	36.1	36.1	36.1	0.00	-0.00	45.2	0.0	0.12	0.00	334.8	318.0	143.2	95.5
21	4.20	0.19	-1.10	-133.75	36.3	34.5	38.0	-0.54	0.50	42.5	-27.1	0.06	-0.66	329.2	286.6	150.8	102.9
22	4.40	0.24	-1.10	-106.07	36.5	34.7	38.2	-0.38	0.37	36.8	-30.5	0.07	-0.84	333.6	296.5	158.9	109.8
23	4.60	0.26	-1.10	-100.40	36.7	35.0	38.5	-0.36	0.35	30.6	-31.3	0.07	-0.90	332.6	296.6	167.7	115.9
24	4.80	0.26	-1.10	-98.95	36.9	35.2	38.7	-0.36	0.34	24.3	-31.6	0.07	-0.92	320.6	285.5	177.2	121.1
25	5.00	0.27	-1.10	-98.43	37.1	35.3	38.9	-0.36	0.34	18.0	-31.8	0.07	-0.93	323.0	287.8	187.2	125.2
26	5.20	0.27	-1.10	-98.18	37.3	35.5	39.1	-0.36	0.33	11.6	-32.1	0.07	-0.95	325.2	290.0	197.7	128.2
27	5.40	0.27	-1.10	-97.99	37.5	35.7	39.3	-0.36	0.33	5.1	-32.3	0.07	-0.96	327.5	292.2	208.5	130.1
28	5.60	0.28	-1.10	-97.82	37.7	35.9	39.5	-0.36	0.33	-1.3	-32.5	0.07	-0.97	329.8	294.5	219.5	130.7
29	5.80	0.28	-1.10	-97.64	37.9	36.1	39.7	-0.36	0.33	-7.9	-32.8	0.07	-0.98	332.1	296.7	230.6	130.1
30	6.00	0.28	-1.10	-97.46	38.1	36.3	39.9	-0.35	0.33	-14.4	-33.0	0.07	-1.00	334.5	299.0	241.6	128.2
31	6.20	0.09	-1.00	-444.89	38.6	38.6	38.6	-0.00	0.00	-17.7	-0.0	0.11	-0.22	328.9	312.5	252.4	125.3
32	6.40	-0.02	-1.00	-90635.89	39.1	39.1	39.1	-0.00	0.00	-17.8	-0.0	0.11	-0.00	333.7	317.0	263.3	121.9
33	6.60	-0.02	-1.00	-98951.54	39.6	39.6	39.6	-0.00	0.00	-17.8	-0.0	0.11	-0.00	331.4	314.6	274.3	118.4
34	6.80	-0.02	-1.00	-98894.87	40.0	40.0	40.0	-0.00	0.00	-17.8	-0.0	0.10	-0.00	329.9	313.4	285.4	114.8
35	7.00	-0.02	-1.00	-98862.67	40.5	40.5	40.5	-0.00	0.00	-17.8	-0.0	0.10	-0.00	333.7	317.0	296.6	111.2
36	7.20	-0.02	-1.00	-98845.71	40.9	40.9	40.9	-0.00	0.00	-17.8	-0.0	0.10	-0.00	332.8	316.2	308.0	107.6
37	7.40	-0.02	-1.00	-98805.53	41.4	41.4	41.4	-0.00	0.00	-17.8	-0.0	0.10	-0.00	332.6	315.9	319.5	103.9
38	7.60	-0.02	-1.00	-98772.46	41.8	41.8	41.8	-0.00	0.00	-17.8	-0.0	0.10	-0.00	332.8	315.2	331.1	100.2
39	7.80	-0.02	-1.00	-98702.28	42.2	42.2	42.2	-0.00	0.00	-17.8	-0.0	0.09	-0.00	319.8	303.7	342.8	96.4
40	8.00	-0.02	-1.00	-98612.46	42.6	42.6	42.6	-0.00	0.00	-17.8	-0.0	0.09	-0.00	322.8	[illegible]	354.7	92.6

PROCESSOR TIME (CPU-MIN) = 3.76020E-01

Figure 3.12. Sample run for transient motion, Case 3; soil model with linear shear failure envelope; zero track tension.

TRANSIENT TURNING MOTION

CASE (4)............INPUT VX1,VX2 (TRACK VELOCITIES)

DT = 0.2(SEC)   NP = 40   TEST NO. = SAMPLE RUN FOR USER'S GUIDE   01/29/86

VI = 25.0(MPH)   DRIVER COEFFICIENTS FOR OUTER TRACK: 25.0, 0., 0., 0.
INNER TRACK: 25.0, 12.5, 1.0, 2.0

WT(IN)	L(IN)	H(IN)	D(IN)	B(IN)	SL(IN)	CX(IN)	THETAD(DEG)	THETAA(DEG)	IZ(IN LB/SEC**2)	VCI
18000.0	105.0	35.7	15.0	90.0	0.	0.	0.	30.0	92000.0	20.9

CI	A(PSI)	SN(PSI)	C(PSI)	SN(1/PSI)	SXI	CD(PSI)	CLAMDA(SEC/IN)	PHI(DEG)	G(PSI/IN)	SF	ETA(DEG)	CHI(DEG)
181.0	4.0	0.	4.0	0.	1	4.0	0.180	25.0	50.0	0.059	0.	0.

PT	T SEC	P/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	W DEG	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP	DXT FT	DYT FT
1	0.20	0.04	1.02	447.09	24.7	25.0	24.4	0.07	-0.08	0.5	4.9	-0.07	0.09	6.2	2.6	7.3	0.0
2	0.40	0.09	1.08	148.01	24.1	25.0	23.1	0.20	-0.32	2.5	15.2	-0.13	0.26	-30.8	-41.9	14.4	0.2
3	0.60	0.15	1.16	81.50	23.5	25.0	21.6	0.31	-0.60	6.8	27.7	-0.14	0.45	8.0	-15.8	21.4	0.7
4	0.80	0.20	1.24	54.71	22.8	25.0	20.1	0.41	-0.85	13.6	40.4	-0.13	0.64	74.7	38.2	28.1	1.8
5	1.00	0.24	1.33	40.77	22.2	25.0	18.8	0.50	-1.02	22.9	52.6	-0.09	0.81	147.8	100.8	34.4	3.6
6	1.20	0.28	1.42	32.45	21.6	25.0	17.6	0.59	-1.08	34.5	63.9	-0.04	0.97	220.9	165.6	40.2	6.3
7	1.40	0.31	1.50	26.99	21.1	25.0	16.6	0.68	-1.05	48.4	74.2	0.02	1.11	290.5	229.4	45.3	10.0
8	1.60	0.34	1.58	23.25	20.7	25.0	15.8	0.79	-0.92	64.1	83.5	0.08	1.23	355.5	290.0	49.2	14.6
9	1.80	0.37	1.65	20.51	20.3	25.0	15.2	0.92	-0.72	81.6	91.6	0.14	1.34	417.7	349.0	51.8	20.0
10	2.00	0.39	1.71	18.50	19.9	25.0	14.6	1.07	-0.50	100.6	98.4	0.21	1.42	476.6	405.5	52.7	25.7
11	2.20	0.40	1.76	17.00	19.6	25.0	14.2	1.21	-0.30	120.9	103.9	0.27	1.49	528.8	456.0	51.8	31.4
12	2.40	0.41	1.80	15.87	19.4	25.0	13.9	1.33	-0.15	142.1	108.0	0.33	1.55	574.2	500.4	49.1	36.4
13	2.60	0.42	1.84	15.15	19.2	25.0	13.6	1.45	-0.07	163.9	110.6	0.37	1.59	609.9	535.2	44.9	40.0
14	2.80	0.43	1.87	14.69	19.1	25.0	13.4	1.55	-0.02	186.2	112.5	0.41	1.61	636.3	560.4	39.7	41.9
15	3.00	0.44	1.89	14.34	19.0	25.0	13.2	1.66	0.03	208.9	113.9	0.43	1.62	657.8	580.7	34.3	41.7
16	3.20	0.44	1.91	14.08	18.9	25.0	13.1	1.75	0.08	231.7	114.9	0.45	1.63	675.8	597.5	29.3	39.5
17	3.40	0.45	1.93	13.87	18.8	25.0	13.0	1.83	0.12	254.8	115.7	0.47	1.64	690.8	611.5	25.6	35.5
18	3.60	0.45	1.94	13.70	18.7	25.0	12.9	1.90	0.15	278.0	116.3	0.48	1.64	703.2	623.0	23.7	30.5
19	3.80	0.45	1.95	13.57	18.7	25.0	12.8	1.95	0.17	301.3	116.7	0.49	1.64	713.3	632.4	23.9	25.1
20	4.00	0.45	1.96	13.46	18.6	25.0	12.7	2.00	0.19	324.7	117.1	0.50	1.65	721.4	639.9	26.2	20.3
21	4.20	0.46	1.97	13.38	18.6	25.0	12.7	2.04	0.21	348.1	117.4	0.51	1.65	727.9	645.9	30.3	16.8
22	4.40	0.46	1.97	13.32	18.5	25.0	12.7	2.07	0.22	371.6	117.6	0.51	1.65	733.2	650.7	35.3	15.1
23	4.60	0.46	1.98	13.26	18.5	25.0	12.6	2.09	0.23	395.2	117.8	0.52	1.65	737.3	654.6	40.6	15.6
24	4.80	0.46	1.98	13.22	18.5	25.0	12.6	2.11	0.24	418.7	117.9	0.52	1.65	740.7	657.6	45.3	18.2
25	5.00	0.46	1.99	13.19	18.5	25.0	12.6	2.13	0.25	442.3	118.1	0.52	1.65	743.4	660.1	48.5	22.4
26	5.20	0.46	1.99	13.16	18.5	25.0	12.6	2.14	0.25	465.9	118.1	0.53	1.65	745.5	662.1	49.8	27.6
27	5.40	0.46	1.99	13.14	18.5	25.0	12.6	2.15	0.26	489.6	118.2	0.53	1.65	747.2	663.6	48.9	32.8
28	5.60	0.46	1.99	13.13	18.5	25.0	12.5	2.16	0.26	513.2	118.3	0.53	1.65	748.6	664.9	46.0	37.3
29	5.80	0.46	1.99	13.11	18.4	25.0	12.5	2.16	0.26	536.9	118.3	0.53	1.65	749.8	666.0	41.6	40.1
30	6.00	0.46	1.99	13.10	18.4	25.0	12.5	2.17	0.27	560.6	118.4	0.53	1.65	750.7	666.8	36.3	41.0
31	6.20	0.46	2.00	13.09	18.4	25.0	12.5	2.17	0.27	584.3	118.4	0.53	1.65	751.5	667.5	31.2	39.7
32	6.40	0.46	2.00	13.08	18.4	25.0	12.5	2.18	0.27	607.9	118.5	0.53	1.65	752.1	668.1	27.0	36.5
33	6.60	0.46	2.00	13.08	18.4	25.0	12.5	2.18	0.27	631.6	118.5	0.53	1.65	752.6	668.5	24.5	31.8
34	6.80	0.46	2.00	13.07	18.4	25.0	12.5	2.18	0.27	655.3	118.5	0.53	1.65	753.0	668.9	24.1	26.5
35	7.00	0.46	2.00	13.07	18.4	25.0	12.5	2.18	0.27	679.0	118.5	0.53	1.65	753.3	669.2	25.8	21.5
36	7.20	0.46	2.00	13.06	18.4	25.0	12.5	2.19	0.27	702.7	118.5	0.53	1.65	753.6	669.4	29.4	17.6
37	7.40	0.46	2.00	13.06	18.4	25.0	12.5	2.19	0.27	726.4	118.5	0.53	1.65	753.8	669.6	34.2	15.5
38	7.60	0.46	2.00	13.06	18.4	25.0	12.5	2.19	0.28	750.1	118.5	0.54	1.65	754.0	669.8	39.5	15.5
39	7.80	0.46	2.00	13.06	18.4	25.0	12.5	2.19	0.28	773.9	118.5	0.54	1.65	754.1	669.9	44.3	17.7
40	8.00	0.46	2.00	13.06	18.4	25.0	12.5	2.19	0.28	797.6	118.6	0.54	1.65	754.2	670.0	47.9	21.5

PROCESSOR TIME (CPU-MIN) = 4.79193E-02

Figure 3.13. Sample run for transient motion, Case 4; soil model with linear shear failure envelope; zero track tension.

STEADY-STATE TURNING MOTION
CASE (1).........VARY V (VELOCITY) ; INPUT E (STEERING RATIO)

DV = 1.0(MPH) HPAV = 1000.0(HP) TEST NO. = SAMPLE RUN FOR USER'S GUIDE 01/29/86

WT(IN)	L(IN)	H(IN)	D(IN)	B(IN)	SL(IN)	CX(IN)	THETAD(DEG)	THETAA(DEG)	IZ(IN LB/SEC**2)	VC(1
18000.0	105.0	35.7	15.0	90.0	26.2	0.	30.0	30.0	0.	20.7

CI	A(PSI)	SM(PSI)	C(PSI)	SN(1/PSI)	SXI	CD(PSI)	CLAMDA(SEC/IN)	PHI(DEG)	G(PSI/IN)	SF	ETA(DEG)	CHI(DEG)
181.0	4.0	0.	4.0	0.	1	4.0	0.180	25.0	50.0	0.059	0.	0.

PT	P/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP
1	-0.01	1.40	28.96	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	-0.01	1.40	28.23	1.0	1.2	0.8	0.04	-0.03	3.0	-0.00	0.00	10.4	8.2
3	-0.01	1.40	28.44	2.0	2.3	1.7	0.08	-0.06	5.9	-0.00	0.01	22.3	17.6
4	-0.01	1.40	28.52	3.0	3.5	2.5	0.12	-0.10	8.8	-0.00	0.02	35.1	27.5
5	-0.01	1.40	28.55	4.0	4.7	3.3	0.16	-0.13	11.8	-0.00	0.04	48.3	37.8
6	-0.00	1.40	28.55	5.0	5.9	4.2	0.19	-0.16	14.7	-0.00	0.06	61.7	48.3
7	0.00	1.40	28.53	6.0	7.0	5.0	0.23	-0.20	17.7	0.00	0.08	75.3	58.9
8	0.01	1.40	28.52	7.0	8.2	5.8	0.27	-0.23	20.6	0.00	0.11	89.0	69.6
9	0.02	1.40	28.50	8.0	9.4	6.7	0.30	-0.27	23.6	0.00	0.15	102.8	80.3
10	0.03	1.40	28.49	9.0	10.5	7.5	0.33	-0.30	26.5	0.00	0.19	116.7	91.2
11	0.04	1.40	28.48	10.0	11.7	8.3	0.36	-0.34	29.5	0.00	0.23	130.7	102.2
12	0.05	1.40	28.47	11.0	12.8	9.2	0.39	-0.38	32.5	0.00	0.28	144.9	113.5
13	0.07	1.40	28.46	12.0	14.0	10.0	0.42	-0.42	35.4	0.01	0.34	159.3	125.0
14	0.08	1.40	28.44	13.0	15.2	10.8	0.45	-0.45	38.4	0.01	0.40	174.1	137.0
15	0.10	1.40	28.42	14.0	16.3	11.7	0.48	-0.49	41.4	0.01	0.46	189.4	149.5
16	0.12	1.40	28.39	15.0	17.5	12.5	0.50	-0.53	44.4	0.02	0.53	205.2	162.7
17	0.14	1.40	28.34	16.0	18.6	13.3	0.52	-0.56	47.5	0.03	0.60	221.7	176.7
18	0.16	1.40	28.25	17.0	19.8	14.1	0.54	-0.60	50.6	0.03	0.68	239.1	191.6
19	0.18	1.40	28.13	18.0	20.9	15.0	0.56	-0.62	53.8	0.04	0.77	258.0	208.6
20	0.21	1.40	27.96	19.0	22.1	15.8	0.58	-0.63	57.1	0.06	0.86	278.5	227.2
21	0.24	1.40	27.73	20.0	23.2	16.6	0.60	-0.63	60.6	0.07	0.96	301.2	248.6
22	0.27	1.40	27.39	21.0	24.4	17.4	0.62	-0.61	64.4	0.09	1.07	327.4	273.9
23	0.31	1.40	26.95	22.0	25.6	18.3	0.65	-0.55	68.6	0.12	1.19	359.4	305.4
24	0.36	1.40	26.17	23.0	26.8	19.1	0.66	-0.40	73.8	0.16	1.34	402.0	348.5
25	0.39	1.40	25.24	24.0	28.0	20.0	0.66	-0.21	79.9	0.21	1.51	449.9	398.5
26	0.44	1.40	25.00	25.0	29.2	20.9	0.75	-0.09	84.0	0.26	1.65	519.1	459.2
27	0.48	1.40	24.83	25.5	29.8	21.3	0.84	0.02	86.3	0.30	1.72	557.3	506.3
28	0.55	1.40	23.88	26.0	30.6	21.9	1.03	0.46	91.5	0.38	1.85	648.3	594.2
29	0.61	1.40	23.57	26.1	30.9	22.1	1.38	0.84	92.9	0.43	1.88	726.8	673.1

STABILITY LIMIT ON P

28	0.50	1.40	24.57	25.6	30.0	21.5	0.89	0.14	97.2	0.32	1.76	582.3	531.6

PROCESSOR TIME (CPU-MIN) = 2.17331E-01

Figure 3.14. Sample run for steady-state motion, Case 1; soil model with linear shear failure envelope; zero track tension.

STEADY-STATE TURNING MOTION
CASE (1).........VARY V (VELOCITY) ; INPUT E (STEERING RATIO)

DV = 2.0(MPH) HPAV = 300.0(HP) TEST NO. = SAMPLE RUN FOR USER'S GUIDE 01/2[illegible]/86

WT(LB)	L(IN)	H(IN)	D(IN)	B(IN)	SL(IN)	CX(IN)	THETAD(DEG)	THETAA(DEG)	IZ(IN LB/SEC**2)	VCI1
18000.0	105.0	35.7	15.0	90.0	0.	0.	0.	30.0	0.	20.9

CI	A(PSI)	SH(PSI)	C(PSI)	SN(1/PSI)	SX?	CD(PSI)	CLAMDA(SEC/IN)	PHI(DEG)	G(PSI/IN)	SF	ETA(DEG)	CHI(DEG)
96.0	5.4	3.6	0.	0.2300	0	2.2	10.000	0.	125.0	0.140	0.	[illegible]

	PT	P/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	WD DEG/SEC	FCX G	FCY G	PTE HP	PTS HP
	1	-0.00	1.20	53.50	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	2	0.00	1.20	53.44	2.0	2.2	1.8	0.05	-0.03	3.1	0.00	0.01	26.1	22.2
	3	0.01	1.20	53.47	4.0	4.4	3.7	0.11	-0.06	6.3	0.00	0.02	52.3	44.4
	4	0.01	1.20	53.52	6.0	6.6	5.5	0.16	-0.09	9.4	0.00	0.04	78.6	66.7
	5	0.02	1.20	53.58	8.0	8.8	7.3	0.22	-0.13	12.5	0.00	0.08	104.7	[illegible]
	6	0.03	1.20	53.65	10.0	11.0	9.1	0.27	-0.16	15.7	0.00	0.12	131.5	111.6
	7	0.05	1.20	53.71	12.0	13.2	11.0	0.33	-0.19	18.8	0.00	0.18	158.3	134.4
	8	0.07	1.20	53.73	14.0	15.4	12.8	0.39	-0.22	21.9	0.00	0.24	185.4	157.5
	9	0.09	1.20	53.72	16.0	17.6	14.6	0.45	-0.25	25.0	0.00	0.32	213.1	181.2
	10	0.11	1.20	53.65	18.0	19.8	16.5	0.50	-0.27	28.2	0.01	0.40	241.4	205.7
	11	0.14	1.20	53.54	20.0	22.0	18.3	0.56	-0.30	31.4	0.01	0.50	270.7	231.2
	12	0.17	1.20	53.30	22.0	24.2	20.1	0.62	-0.31	34.7	0.02	0.61	301.2	258.1
POWER LIMIT														
	12	0.17	1.20	53.31	21.9	24.1	20.1	0.62	-0.31	34.6	0.02	0.60	300.0	257.1
	13	0.20	1.20	52.91	24.0	26.4	22.0	0.67	-0.32	38.1	0.02	0.73	333.4	[illegible]
	14	0.24	1.20	52.42	26.0	28.6	23.8	0.72	-0.32	41.7	0.03	0.96	367.8	318.9
	15	0.28	1.20	51.64	28.0	30.8	25.6	0.77	-0.29	45.6	0.05	1.01	406.2	355.0
	16	0.33	1.20	50.58	30.0	33.0	27.5	0.79	-0.25	49.8	0.07	1.19	448.5	396.3
	17	0.39	1.20	49.17	32.0	35.2	29.3	0.82	-0.16	54.7	0.10	1.39	502.7	[illegible]
	18	0.45	1.20	47.86	34.0	37.3	31.1	0.79	-0.10	59.7	0.13	1.61	562.0	512.9
	19	0.49	1.20	47.90	34.5	37.9	31.6	0.86	-0.06	60.5	0.15	1.65	589.0	540.0
	20	0.49	1.20	47.80	34.6	38.0	31.7	0.87	-0.04	60.8	0.15	1.66	594.2	545.3
	21	0.50	1.20	47.67	34.6	38.1	31.7	0.88	-0.02	61.0	0.15	1.67	597.[illegible]	548.8
	22	0.50	1.20	47.52	34.6	38.1	31.7	0.88	-0.01	61.2	0.15	1.68	599.8	551.3
STABILITY LIMIT ON DV														
	22	0.50	1.20	47.52	34.6	38.1	31.7	0.88	-0.01	61.2	0.15	1.68	599.8	551.3

PROCESSOR TIME (CPU-MIN) = 1.60637E-01

Figure 3.15. Sample run for steady-state motion, Case 1; soil model with nonlinear shear failure envelope; zero track tension.

REFERENCES

1. Baladi, G. Y., and Rohani, B.; "A Mathematical Model of Terrain-Vehicle Interaction for Predicting the Steering Performance of Track-Laying Vehicles"; Proceedings of Sixth International Conference of the International Society for Terrain-Vehicle Systems; 1978; Vienna, Austria.

2. Baladi, G. Y. and Rohani, B.; "Analysis of Steerability of Tracked Vehicles; Theoretical Predictions Versus Field Measurements"; Miscellaneous Paper SL-81-3; 1981; US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

3. Rohani, B. and Baladi, G. Y.; "Steerability Analysis of Tracked Vehicles on Soft Soil; Theoretical Predictions Versus Field Measurements;" Technical Report GL-82-4; 1982; US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

4. Bekker, M. B.; The Theory of Land Locomotion; 1963; The University of Michigan Press, Ann Arbor, Mich.

5. Hayashi, I.; "Practical Analysis of Tracked Vehicle Steering Depending on Longitudinal Track Slippage"; Proceedings, International Society for Terrain-Vehicle Systems Conference; 1975, Vol 2, p 493.

6. Kitano, M. and Jyorzaki, H.; "A Theoretical Analysis of Steerability of Tracked Vehicles;" Journal of Terramechanics, International Society for Terrain-Vehicle Systems; 1976, Vol 13, No. 4, pp 241-258.

7. Kitano, M. and Kuma, M.; "An Analysis of Horizontal Plane Motion of Tracked Vehicles"; Journal of Terramechanics, International Society for Terrain-Vehicle Systems; 1977, Vol 14, No. 4, pp 221-225.

8. Baladi, G. Y. and Rohani, B.; "A Terrain-Vehicle Interaction Model for Analysis of Steering Performance of Track-Laying Vehicles"; Technical Report GS-79-6; 1979; US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

9. Kondner, R. L.; "Hyperbolic Stress-Strain Response: Cohesive Soils"; Journal, Soil Mechanics and Foundation Division, American Society of Civil Engineers; 1963, Vol 89, No. SM1, pp 115-143.

10. Rula, A. A. and Nuttall, C. J., Jr.; "An Analysis of Ground Mobility Models (ANAMOB)"; Technical Report M-71-4; 1971; U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

11. Rohani, B. and Baladi, G. Y.; "Correlation of Mobility Cone Index With Fundamental Engineering Properties of Soil"; Miscellaneous Paper SL-84-4; 1981; US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

APPENDIX A: PROGRAM LISTING

```
C
C     **************************************************************
C     *                                                            *
C     *      TVSTEER IS A MODEL USED FOR PREDICTING STEERING       *
C     *    PERFORMANCE OF HIGH-MOBILITY/AGILITY TRACKED VEHICLES   *
C     *   IN STEADY-STATE TURNING MOTION AND/OR TRANSIENT MOTION.  *
C     *                                                            *
C     **************************************************************
C
C                          INPUT FOR TVSTEER
C     --------------------------------------------------------------
C
C     TESTN -- TEST TITLE (40 CHARACTERS MAX)
C     IRUN  -- RUNTYPE (0 = STEADY-STATE, 1 = TRANSIENT)
C
C         VEHICLE PARAMETERS
C         ----------------------------------------------------------
C
C     WT     -- VEHICLE WEIGHT (LB)
C     L      -- CONTACT LENGTH OF TRACK (IN)
C     H      -- HEIGHT OF THE CENTER OF GRAVITY (IN)
C     D      -- TRACK WIDTH (IN)
C     B      -- TRACK TREAD, DISTANCE BETWEEN CENTER LINES (IN)
C     SL     -- DISTANCE BETWEEN CENTERS OF ADJACENT WHEELS (IN)
C     CX     -- ABSCISSA FOR CENTER OF GRAVITY (IN)
C     THETAD -- DEPARTURE ANGLE OF TRACK ENVELOPE (DEG)
C     THETAA -- APPROACH ANGLE OF TRACK ENVELOPE (DEG)
C     IZ     -- MASS MOMENT OF INERTIA (IN LB/SEC**2),
C                NOT APPLICABLE FOR STEADY STATE
C     VCI1   -- ONE PASS VEHICLE CONE INDEX
C                TO HAVE CODE COMPUTE VCI1,
C                THE FOLLOWING INPUT IS REQUIRED BY SUBROUTINE MIVCI
C
C                GH   -- GROUSER HEIGHT (IN)
C                NB   -- TOTAL NUMBER OF BOGIES ON TRACK
C                TSL  -- TRACK SHOE LENGTH (IN)
C                HP   -- HORSEPOWER
C                TRNT -- TRANSMISSION TYPE (0=MANUAL, 1=AUTOMATIC)
C
C          SOIL MODEL PARAMETERS
C          ---------------------------------------------------------
C
C     CI     -- WES CONE INDEX
C                 TO HAVE CODE COMPUTE CI,
C                 THE FOLLOWING INPUT IS REQUIRED BY SUBROUTINE CONE
C
C                 CL   -- CONE LENGTH (IN)
C                 DI   -- CONE DIAMETER (IN)
C                 GAMA -- DENSITY (PSI/IN)
C                 Z    -- DEPTH (IN)
C
```

```
C     A      -- SHEAR STRENGTH OF SOIL (PSI)
C     SM     -- MATERIAL CONSTANT IN FAILURE ENVELOPE (PSI)
C     SN     -- MATERIAL CONSTANT IN FAILURE ENVELOPE (1/PSI)
C     SXI    -- TYPE OF SOIL MODEL (0 = NONLINEAR, 1 = LINEAR)
C     CD     -- ADDED COHESIVE STRENGTH DUE TO DYNAMIC LOADING (PSI)
C     CLAMDA -- MATERIAL CONSTANT RELATED TO RATE EFFECT (SEC/IN)
C     PHI    -- ANGLE OF INTERNAL FRICTION (DEG)
C     G      -- SHEAR MODULUS (PSI/IN)
C     SF     -- ROLLING RESISTANCE (MAY BE COMPUTED BY CODE)
C     ETA    -- ANGLE OF SLOPING TERRAIN (DEG)
C     CHI    -- DIRECTIONAL ANGLE ON SLOPING TERRAIN (DEG)
C     C      -- COHESION (PSI), C = A-SM
C
C     ----------------------------------------------------------------
C                           INPUT FOR STEADY
C     ----------------------------------------------------------------
C
C     ICASE  -- TYPE OF RUN
C     E      -- STEERING RATIO
C     DV     -- VELOCITY INCREMENT (MPH)
C     HPAV   -- AVAILABLE HORSEPOWER
C     RO     -- TURNING RADIUS (FT)
C     DE     -- STEERING RATIO INCREMENT
C     NP     -- NUMBER OF POINTS
C     DR     -- TURNING RADIUS INCREMENT (FT)
C
C     ----------------------------------------------------------------
C                           INPUT FOR TRANS
C     ----------------------------------------------------------------
C
C     DT     -- TIME INCREMENT (SEC)
C     NP     -- NUMBER OF POINTS
C     IPRINT -- PRINT SKIP INCREMENT
C     ICASE  -- TYPE OF RUN
C     HPAV   -- AVAILABLE HORSEPOWER
C     VI     -- INITAIL VELOCITY (MPH)
C     EP     -- ARRAY CONTAINING STEERING RATIO TIME HISTORY
C
C                   DRIVER COEFFICIENTS
C     V1-V4, E1-E4, RI1-RI4, VX11-VX14, VX21-VX24
C
C     ================================================================
C                                OUTPUT
C     ----------------------------------------------------------------
C
C     PT  -- POINT NUMBER
C     T   -- TIME (SEC), NOT APPLICABLE FOR STEADY-STATE
C     P/L -- OFFSET
C     E   -- STEERING RATIO
C     RO  -- RADIUS OF TRAJECTORY AT CENTER OF GRAVITY (FT)
C     VEL -- VEHICLE VELOCITY (MPH)
C     VX1 -- OUTER TRACK VELOCITY (MPH)
C     VX2 -- INNER TRACK VELOCITY (MPH)
C     VS1 -- OUTER TRACK SLIP VELOCITY (MPH)
C     VS2 -- INNER TRACK SLIP VELOCITY (MPH)
C     W   -- YAW ANGLE (DEG), NOT APPLICABLE FOR STEADY-STATE
```

```
C     WD  -- YAW RATE (DEG/SEC)
C     FCX -- LONGITUDINAL ACCELERATION (G)
C     FCY -- LATERAL ACCELERATION (G)
C     PTE -- POWER REQUIRED FROM ENGINE (HP)
C     PTS -- POWER REQUIRED AT SPROCKET (HP)
C     DXT -- ABSCISSA OF TRAJECTORY (FT),
C              NOT APPLICABLE FOR STEADY-STATE
C     DYT -- ORDINATE OF TRAJECTORY (FT),
C              NOT APPLICABLE FOR STEADY-STATE
C     PT1 -- POWER REQUIRED BY SPROCKET OF OUTER TRACK (HP)
C     PT2 -- POWER REQUIRED BY SPROCKET OF INNER TRACK (HP)
C              PT1 AND PT2 ARE NOT TABULATED
C     VX  -- LONGITUDINAL COMPONENT OF VEHICLE VELOCITY (MPH)
C     VY  -- LATERAL COMPONENT OF VEHICLE VELOCITY (MPH)
C              VX AND VY ARE NOT TABULATED
C
C     =============================================================
C
      PARAMETER ( N2 = 100 )
      REAL L,IZ
      CHARACTER TESTN*40,DATE*8
      DATA GRAV,DRAD,VMP / 386.4, 0.017453293, 0.056818182 /
      DATA MPR,RDEG / O040075040021, 57.29578 /
C
      COMMON /ARRAYS/ TP(N2),VXP(N2),VYP(N2),FCXP(N2),FCYP(N2),
     &                VSX1P(N2),VSX2P(N2),ROP(N2),PTEP(N2),PTSP(N2),
     &                DXTP(N2),DYTP(N2),WDP(N2),WP(N2),VX1P(N2),
     &                VX2P(N2),EP(N2),VP(N2),PP(N2),PT1P(N2),PT2P(N2)
      COMMON /INOUT / E,VX1,VX2,V,RIOL,LOGRE,LVX
      COMMON /IN    / DTIM1,DTIM2,WPRV,WDPRV,VXPRV,VYPRV,TESTN,DATE
      COMMON /VPARAM/ WT,L,H,D,B,SL,CX,THETAA,THETAD,IZ,VCI1
      COMMON /SPARAM/ CI,A,SM,SN,C,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI
      COMMON /OUT   / FCX,FCY,VSX1,VSX2,PTE,PTS,WD,W,VX,VY,
     &                P,Z1,Z2,IDIR,VXD,VYD,PT1,PT2
      COMMON /MISC  / GRAV,DRAD,VMP,RDEG
C
C     =============================================================
C              THESE ARE CALLS TO SYSTEM DEPENDENT SUBROUTINES
C
      CALL FPARAM(3,MPR)
      CALL FPARAM(1,132)
      CALL PTIME(PTI)
      CALL DATIM(DATE,TIM)
C
C                             END SYSTEM DEPENDENT CALLS
C     =============================================================
C
      PRINT *, 'INPUT TEST NO. (UP TO 40 CHARACTERS)'
      READ 240, TESTN
      PRINT *,
      PRINT *, 'TO HAVE CODE COMPUTE VCI1, INPUT VCI1=0.'
      PRINT *, 'INPUT WT,L,H,D,B,SL,CX,THETAD,THETAA,IZ,VCI1'
      READ *, WT,L,H,D,B,SL,CX,THETAD,THETAA,IZ,VCI1
      PRINT *,
      IF (VCI1 .LE. 0.) CALL MIVCI
C
```

```
      PRINT *, 'TO HAVE CODE COMPUTE CONE INDEX, INPUT CI=0.'
      PRINT *, 'TO HAVE CODE COMPUTE ROLLING RESISTANCE, INPUT SF=0.'
      PRINT *, 'INPUT CI,A,SM,SN,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI'
      READ *, CI,A,SM,SN,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI
C
      C = A - SM
      IF (SXI .LT. 1.) C = 0.
C
      IF (CI .LE. 0.) CALL CONE
      IF (SF .LE. 0.) SF = .045 + (2.3075/(CI-VCI1+6.5))
C
      PRINT *,
      PRINT *, 'INPUT RUNTYPE :  '
      PRINT *, '       FOR STEADY-STATE RUN, INPUT 0'
      PRINT *, '       FOR TRANSIENT RUN, INPUT 1'
      PRINT *, 'INPUT YOUR CHOICE'
      READ *, IRUN
      IF (IRUN .EQ. 0) CALL STEADY
      IF (IRUN .EQ. 1) CALL TRANS
C
C                SYSTEM DEPENDENT ROUTINE TO GET PROCESSOR TIME
C
      CALL PTIME(PTU)
      PTU = (PTU-PTI)*60
      PRINT 250, PTU
      PRINT 246
C
      STOP
C     ===============================================================
C
  240 FORMAT(A40)
  246 FORMAT(1H1)
  250 FORMAT(/,' PROCESSOR TIME (CPU-MIN) = ',1PE13.5)
C
      END
C
C     ***************************************************************
C     *                                                             *
C     *    THIS SUBROUTINE IS FOR STEADY-STATE TURNING MOTION.      *
C     *                                                             *
C     ***************************************************************
C
      SUBROUTINE STEADY
C
      PARAMETER ( N2 = 100,N4 = 40 )
      REAL L
      LOGICAL LOGRE,LSTB,LVX
C
      CHARACTER TESTN*40,DATE*8
      CHARACTER LAB2*5,INPUT,VFMT*3,LFMT*64(4)
      DATA VFMT /3H(V)/
C
      COMMON /ARRAYS / TP(N2),VXP(N2),VYP(N2),FCXP(N2),FCYP(N2),
     &                 VSX1P(N2),VSX2P(N2),ROP(N2),PTEP(N2),PTSP(N2),
     &                 DXTP(N2),DYTP(N2),WDP(N2),WP(N2),VX1P(N2),
     &                 VX2P(N2),EP(N2),VP(N2),FP(N2),PT1P(N2),PT2P(N2)
```

```
      COMMON /INOUT / E,VX1,VX2,V,RIOL,LOGRE,LVX
      COMMON /IN    / DTIM1,DTIM2,WPRV,WDPRV,VXPRV,VYPRV,TESTN,DATE
      COMMON /VPARAM/ WT,L,H,D,B,SL,CX,THETAA,THETAD,IZ,VCI1
      COMMON /SPARAM/ CI,A,SM,SN,C,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI
      COMMON /OUT   / FCX,FCY,VSX1,VSX2,PTE,PTS,WD,W,VX,VY,
     &                P,Z1,Z2,IDIR,VXD,VYD,PT1,PT2
      COMMON /MISC  / GRAV,DRAD,VMP,RDEG
C
      PRINT *,
      PRINT *, 'INPUT CASE:  1,2,3,4, OR ? '
      READ *, INPUT
      IF (INPUT .EQ. 1H?) GO TO 900
      DECODE(INPUT,VFMT) ICASE
      IF (ICASE.GE.1 .AND. ICASE.LE.4) GO TO 915
  900 PRINT 910
      PRINT 245, LFMT
      PRINT 916
      READ *, ICASE
  910 FORMAT(' CASE SELECTIONS:')
      DATA LFMT /
     &                          64H CASE [1]..........VARY V (VELOCITY) ;
     & INPUT E (STEERING RATIO) ,
     &                          64H CASE [2]..........VARY V (VELOCITY) ;
     & INPUT RO (TURNING RADIUS),
     &                          64H CASE [3]....VARY E (STEERING RATIO) ;
     & FIXED V (VELOCITY)       ,
     &                          64H CASE [4]...VARY RO (TURNING RADIUS) ;
     & FIXED V (VELOCITY)       /
  916 FORMAT(' INPUT YOUR CHOICE:  ')
  915 PRINT *,
C
      IF (ICASE .GT. 2) GO TO 5
      IF (ICASE .EQ. 2) GO TO 4
C
      PRINT *, 'INPUT E,DV,HPAV '
      READ *, E,DV,HPAV
      LOGRE = .FALSE.
      GO TO 75
C
    4 CONTINUE
      LOGRE =  .TRUE.
      PRINT *, 'INPUT RO,DV,HPAV '
      READ *, RO,DV,HPAV
      RI = RO
      RIOL = 12.*RI/L
C
   75 CONTINUE
      V = 0.
      NP = N4
      IHP = 0
      IF (HPAV .LE. 0.) IHP = 1
      GO TO 7
C
    5 CONTINUE
      DV = 0.
      IHP = 1
```

```
      IF (ICASE .EQ. 4) GO TO 6
      PRINT 165, N2
      PRINT *, 'INPUT V,E,DE,NP'
      READ *, V,E,DE,NP
      LOGRE = .FALSE.
      DR = 0.
      GO TO 7
C
    6 CONTINUE
      PRINT 165, N4
      PRINT *, 'INPUT V,RO,DR,NP'
      READ *, V,RO,DR,NP
      LOGRE = .TRUE.
      DE = 0.
      RI = RO
      RIOL = 12.*RI/L
C
    7 CONTINUE
      PRINT 246
      PRINT 250
      PRINT 245, LFMT(ICASE)
      PRINT 207
      IF (ICASE.EQ.1 .OR. ICASE.EQ.2)
     &                     PRINT 202, DV,HPAV,TESTN,DATE
      IF (ICASE .EQ. 3) PRINT 203, DE,NP,TESTN,DATE
      IF (ICASE .EQ. 4) PRINT 204, DR,NP,TESTN,DATE
      PRINT 170
      PRINT 180, WT,L,H,D,B,SL,CX,THETAD,THETAA,IZ,VCI1
      PRINT *,
      PRINT 190
      PRINT 200, CI,A,SM,C,SN,IFIX(SXI),CD,
     &                               CLAMDA,PHI,G,SF,ETA,CHI
      PRINT 207
      PRINT 205
      PRINT 209
C
      LSTB = .FALSE.
      V = V*17.6
      DV = DV*17.6
      DR = 12.*DR/L
      DTIM1 = 0.
      WDPRV = 0.
      VXPRV = 0.
      VYPRV = 0.
      LVX = .FALSE.
C
C     ------------------------------------------------------------
C     STEADY-STATE CALCULATIONS
C     ------------------------------------------------------------
C
      DO 400 II = 1,NP
C
   11 CALL AGIL($115)
C
      IF(II.EQ.1 .OR. ICASE.GT.2) GO TO 390
      IF((P-PP(II-1)) .GT. 0.1) GO TO 115
```

```
C
  390 CONTINUE
      PP(II) = P
      Z1P = Z1
      Z2P = Z2
      VP(II) = V*VMP
      ROP(II) = RIOL*L/12.
      EP(II) = E
      IF (E .LT. 1.) EP(II) = -1./E
      V = V+DV
      VSX1P(II) = VSX1*VMP
      VSX2P(II) = VSX2*VMP
      VX2P(II) = VX2*VMP
      VX1P(II) = VX1*VMP
      WDP(II) = WD*RDEG
      PTEP(II) = PTE
      PTSP(II) = PTS
      PT1P(II) = PT1
      PT2P(II) = PT2
      FCXP(II) = FCX
      FCYP(II) = FCY
      PRINT 14, II,PP(II),EP(II),ROP(II),VP(II),VX1P(II),VX2P(II),
     &           VSX1P(II), VSX2P(II),WDP(II),FCXP(II),FCYP(II),
     &           PTEP(II),PTSP(II)
C
  392 CONTINUE
      IF (ICASE .GT. 2) GO TO 160
      IF(P.GT.0.555 .AND. LSTB) GO TO 404
C
C     CALCULATES MAXIMUM POWER
C
      IF(IHP) 393,393,396
  393 IF(PTEP(II)-HPAV) 396,394,394
C
  394 PFC = (PTEP(II)-HPAV) / (PTEP(II)-PTEP(II-1))
      IHP = 1
      ROPF = ROP(II) - (ROP(II)-ROP(II-1))*PFC
      VPF = VP(II) - (VP(II)-VP(II-1))*PFC
      VX1F = VX1P(II) - (VX1P(II)-VX1P(II-1))*PFC
      VX2F = VX2P(II) - (VX2P(II)-VX2P(II-1))*PFC
      VSX1F = VSX1P(II) - (VSX1P(II)-VSX1P(II-1))*PFC
      VSX2F = VSX2P(II) - (VSX2P(II)-VSX2P(II-1))*PFC
      PTEF = PTEP(II) - (PTEP(II)-PTEP(II-1))*PFC
      PTSF = PTSP(II) - (PTSP(II)-PTSP(II-1))*PFC
      FCXF = FCXP(II) - (FCXP(II)-FCXP(II-1))*PFC
      FCYF = FCYP(II) - (FCYP(II)-FCYP(II-1))*PFC
      PF = PP(II) - (PP(II)-PP(II-1))*PFC
      EF = EP(II) - (EP(II)-EP(II-1))*PFC
      WDF = WDP(II) - (WDP(II)-WDP(II-1))*PFC
      PRINT *, 'POWER LIMIT'
      PRINT 14, II,PF,EF,ROPF,VPF,VX1F,VX2F,VSX1F,VSX2F,
     &           WDF,FCXF,FCYF,PTEF,PTSF
      PRINT *,
C
  396 CONTINUE
      IF(LSTB) GO TO 400
```

```
      IF(II .EQ. 1) GO TO 400
      IF(P-.5) 397,462,460
  397 IF((VSX2P(II)-VSX2P(II-1))/DV/VMP-1.) 398,398,464
  398 IF((VSX1P(II)-VSX1P(II-1))/DV/VMP-1.) 400,400,466
C
  160 CONTINUE
      E = E+DE
      RIOL = RIOL - DR
C
  400 CONTINUE
C     ---------------------------------------------------------------
C
      IF (ICASE.GT.2) GO TO 480
      PRINT 165, N4
      IF (.NOT. LSTB) GO TO 480
C
  404 PRINT 207
      PRINT *, ' STABILITY LIMIT ON',LAB2
      PRINT *,
      PRINT 14, N3,PS,ES,ROPS,VPS,VX1S,VX2S,VSX1S,
     &         VSX2S,WDS,FCXS,FCYS,PTES,PTSS
      GO TO 99
C
  460 N3 = II
      PDC = (PP(N3)-.5) / (PP(N3)-PP(N3-1))
      IF(P .GT. 0.555) LSTB = .TRUE.
      GO TO 463
C
  462 N3 = II
      PDC = 0.
  463 LAB2 = ' P  '
      GO TO 468
C
  464 N3 = II-1
      PDC = 0.
      LAB2 = ' VS2'
      GO TO 468
C
  466 N3 = II-1
      PDC = 0.
      LAB2 = ' VS1'
      GO TO 468
C
  467 N3 = II - 1
      LSTB = .TRUE.
      PDC = 0.
      LAB2 = ' DV '
C
  468 CONTINUE
      ROPS = ROP(N3) - (ROP(N3)-ROP(N3-1))*PDC
      VPS = VP(N3) - (VP(N3)-VP(N3-1))*PDC
      VSX1S = VSX1P(N3) - (VSX1P(N3)-VSX1P(N3-1))*PDC
      VSX2S = VSX2P(N3) - (VSX2P(N3)-VSX2P(N3-1))*PDC
      VX1S = VX1P(N3) - (VX1P(N3)-VX1P(N3-1))*PDC
      VX2S = VX2P(N3) - (VX2P(N3)-VX2P(N3-1))*PDC
      PTES = PTEP(N3) - (PTEP(N3)-PTEP(N3-1))*PDC
```

```
      PTSS = PTSP(N3) - (PTSP(N3)-PTSP(N3-1))*PDC
      FCXS = FCXP(N3) - (FCXP(N3)-FCXP(N3-1))*PDC
      FCYS = FCYP(N3) - (FCYP(N3)-FCYP(N3-1))*PDC
      PS = PP(N3) - (PP(N3)-PP(N3-1))*PDC
      ES = EP(N3) - (EP(N3)-EP(N3-1))*PDC
      WDS = WDP(N3) - (WDP(N3)-WDP(N3-1))*PDC
      IF(LSTB) GO TO 404
      LSTB = .TRUE.
      GO TO 400
C
  115 IF(II.EQ.1 .OR. ICASE.GT.2) GO TO 119
      IF(DV .LT. 1.) GO TO 467
      DV = DV/2.
      V = V - DV
      P = PP(II-1)
      Z1 = Z1P
      Z2 = Z2P
      GO TO 11
C
  119 PRINT *, 'THE VEHICLE WILL NOT GO IN THIS PARTICULAR SOIL.'
      GO TO 99
C
  480 PRINT 207
C
   99 RETURN
C     ==============================================================
C
   14 FORMAT(13X,I3,1X,F6.2,F7.2,F10.2,1X,F5.1,2X,F5.1,1X,F5.1,2F7.2,
     &          F7.1,2F7.2,2F7.1)
  165 FORMAT(' MAXIMUM POINTS NP SET TO',I5)
  170 FORMAT(2X,'WT(IN)',3X,'L(IN)',3X,'H(IN)',2X,'D(IN)',4X,
     &          'B(IN)',3X,'SL(IN)',1X,'CX(IN)',4X,'THETAD(DEG)',3X,
     &          'THETAA(DEG)',1X,'IZ(IN LB/SEC**2)',3X,'VCI1')
  180 FORMAT(1X,F8.1,2X,F5.1,2(3X,F4.1),4X,F5.1,5X,F4.1,2X,F5.1,
     &               7X,F5.1,10X,F5.1,7X,F8.1,8X,F4.1)
  190 FORMAT(4X,'CI',5X,'A(PSI)',1X,'SM(PSI)',1X,'C(PSI)',1X,
     &          'SN(1/PSI)',2X,'SXI',3X,'CD(PSI)',1X
     &          'CLAMDA(SEC/IN)',4X,'PHI(DEG)',2X,'G(PSI/IN)',2X,
     &          'SF',4X,'ETA(DEG)',1X,'CHI(DEG)')
  200 FORMAT(2X,F5.1,1X,2(3X,F5.1),3X,F4.1,3X,F6.4,5X,I1,5X,F5.1,
     &       6X,F6.3,10X,F4.1,6X,F5.1,3X,F5.3,4X,F4.1,4X,F5.1)
  202 FORMAT(2X,'DV = ',F6.1,'(MPH)',1X,'HPAV = ',F6.1,'(HP)',
     &       3X,'TEST NO. = ',A40,3X,A8,3X,//)
  203 FORMAT(2X,'DE = ',F6.2,1X,'NP = ',I3,
     &       6X,'TEST NO. = ',A40,3X,A8,3X,//)
  204 FORMAT(2X,'DR = ',F6.1,'(FT)',1X,'NP = ',I3,
     &       6X,'TEST NO. = ',A40,3X,A8,3X,//)
  205 FORMAT(14X,'PT',4X,'P/L',4X,'E',6X,'RO',7X,'VEL',4X,'VX1',
     &       3X,'VX2',3X,'VS1',4X,'VS2',4X,'WD',5X,'FCX',
     &       4X,'FCY',4X,'PTE',4X,'PTS')
  207 FORMAT(/,1X,119(1H=),//)
  209 FORMAT(34X,'FT',7X,'MPH',4X,2('MPH',3X),'MPH',4X,'MPH',2X,
     &       'DEG/SEC',3X,'G',6X,'G',1X,2(5X,'HP'),//)
  245 FORMAT(28X,A64)
  246 FORMAT(1H1)
  250 FORMAT(46X,'STEADY-STATE TURNING MOTION')
```

```
C
      END
C
C     ************************************************************
C     *                                                          *
C     *         THIS SUBROUTINE IS FOR TRANSIENT MOTION.         *
C     *                                                          *
C     ************************************************************
C
      SUBROUTINE TRANS
C
      PARAMETER ( N2 = 100 )
      REAL L,IZ
      LOGICAL LOGRE,LVX,LSTB,LOGV
C
      CHARACTER TESTN*40,DATE*8
      CHARACTER INPUT,VFMT*3,LFMT*76(4)
      DATA VFMT /3H(V)/
C
      COMMON /ARRAYS/ TP(N2),VXP(N2),VYP(N2),FCXP(N2),FCYP(N2),
     &                VSX1P(N2),VSX2P(N2),ROP(N2),PTEP(N2),PTSP(N2),
     &                DXTP(N2),DYTP(N2),WDP(N2),WP(N2),VX1P(N2),
     &                VX2P(N2),EP(N2),VP(N2),PP(N2),PT1P(N2),PT2P(N2)
      COMMON /INOUT / E,VX1,VX2,V,RIOL,LOGRE,LVX
      COMMON /IN    / DTIM1,DTIM2,WPRV,WDPRV,VXPRV,VYPRV,TESTN,DATE
      COMMON /VPARAM/ WT,L,H,D,B,SL,CX,THETAA,THETAD,IZ,VCI1
      COMMON /SPARAM/ CI,A,SM,SN,C,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI
      COMMON /OUT   / FCX,FCY,VSX1,VSX2,PTE,PTS,WD,W,VX,VY,
     &                P,Z1,Z2,IDIR,VXD,VYD,PT1,PT2
      COMMON /MISC  / GRAV,DRAD,VMP,RDEG
C
C     ============================================================
C        THE DIGITIZED TIME HISTORY (FOR CASE 3) AND THE FUNCTION
C            (FOR CASES 1,2, AND 4) USED FOR SAMPLE PROBLEMS
C
      DATA EP /10*1.1,10*1.0,10*-1.1,70*1./
C
      EXPS(X) = EXP(AMAX1(X,-88.))
      FT(T,X1,X2,X3,X4) =
     &          X1 + X2*(EXPS(-X3*T) + X3*T*EXPS(-X4*T) - 1.)
C
C
C      NOTE:  TO DRIVE THE MODEL, THE ABOVE MAY BE REPLACED BY ANY
C             DIGITIZED TIME HISTORY AND/OR ANY FUNCTION
C     ============================================================
C
      PRINT *,
      PRINT 165, N2
      PRINT *, 'INPUT DT,NP,IPRINT'
      READ *, DT,NP,IPRINT
C
      PRINT *,
      PRINT *, 'INPUT CASE:  1,2,3,4, OR ? '
      READ *, INPUT
      IF (INPUT .EQ. 1H?) GO TO 900
      IF (INPUT .EQ. 1H1) ICASE = 1
```

```
      IF (INPUT .EQ. 1H2) ICASE = 2
      IF (INPUT .EQ. 1H3) ICASE = 3
      IF (INPUT .EQ. 1H4) ICASE = 4
      IF (ICASE.GE.1 .AND. ICASE.LE.4) GO TO 915
  900 PRINT 910
      PRINT 245, LFMT
      PRINT 916
      READ *, ICASE
  910 FORMAT(/' CASE SELECTIONS:')
      DATA LFMT /
     & 54H CASE [1].........INPUT V,E (VELOCITY,STEERING RATIO) ,
     & 54H CASE [2]........INPUT V,RI (VELOCITY,TURNING RADIUS) ,
     &     76H CASE [3]...INPUT E,VI (STEERING RATIO,INITIAL VELOCITY) ,
     & VARY V (VELOCITY) ,
     & 54H CASE [4]...........INPUT VX1,VX2 (TRACK VELOCITIES)  /
  916 FORMAT( 'INPUT YOUR CHOICE:  ')
  915 PRINT *,
C
      LOGRE = .FALSE.
      LVX = .FALSE.
      IF (ICASE .GT. 2) GO TO 3
C
      PRINT *, 'INPUT HPAV,V1,V2,V3,V4'
      READ *, HPAV,V1,V2,V3,V4
      VI = V1
      IF (ICASE .EQ. 2) GO TO 2
      PRINT *, 'INPUT E1,E2,E3,E4'
      READ *, E1,E2,E3,E4
      GO TO 7
C
C     NOTE:  CASE 2 COULD BE MODIFIED TO INPUT TRAJECTORY
C                              INSTEAD OF RI
C
    2 PRINT *, 'INPUT RI1,RI2,RI3,RI4'
      READ *, RI1,RI2,RI3,RI4
      LOGRE = .TRUE.
      GO TO 7
C
    3 IF (ICASE .EQ .4) GO TO 4
      PRINT *, 'INPUT HPAV,VI'
      READ *, HPAV,VI
      GO TO 7
C
    4 LVX = .TRUE.
      PRINT *, 'INPUT VX11,VX12,VX13,VX14'
      READ *, VX11,VX12,VX13,VX14
      PRINT *, 'INPUT VX21,VX22,VX23,VX24'
      READ *, VX21,VX22,VX23,VX24
      VI = AMAX1(VX11,VX21)
C
    7 PRINT 246
      PRINT 250
      PRINT 245, LFMT(ICASE)
      IF (ICASE .EQ. 2) PRINT 225
      PRINT 207
      PRINT 203, DT,NP,TESTN,DATE
```

```
      IF (ICASE .EQ. 1) PRINT 210, HPAV,V1,V2,V3,V4,E1,E2,E3,E4
      IF (ICASE .EQ. 2) PRINT 220, HPAV,V1,V2,V3,V4,RI1,RI2,RI3,RI4
      IF (ICASE .EQ. 3) PRINT 230, HPAV,VI
      IF (ICASE .EQ. 4) PRINT 240, VI,VX11,VX12,VX13,VX14,
     &                  VX21,VX22,VX23,VX24
      PRINT *,
      PRINT 170
      PRINT 180, WT,L,H,D,B,SL,CX,THETAD,THETAA,IZ,VCI1
      PRINT *,
      PRINT 190
      PRINT 200, CI,A,SM,C,SN,IFIX(SXI),CD,
     &                           CLAMDA,PHI,G,SF,ETA,CHI
      PRINT 207
      PRINT 205
      PRINT 209
C
C     SET UP INITIAL CONDITIONS
C
      T = DT
      VX = VI*17.6
      VY = 0.
      WD = 0.
      DXTPS = 0.
      DYTPS = 0.
      THETA = 0.
      LOGV = .FALSE.
      DTIM1 = 1./DT
      DTIM2 = DT/2.
      DTO12 = DTIM2/12.
      DXTPRV = VX
      DYTPRV = VY
      THDPRV = 0.
      WPRV = 0.
      WDPRV = WD
      VXPRV = VX
      VYPRV = VY
C
C     ------------------------------------------------------------
C     TRANSIENT CALCULATIONS
C     ------------------------------------------------------------
C
      DO 400 II = 1,NP
C
      LSTB = .FALSE.
      DA = 8.8
      DV = 8.8
      GO TO (10,20,30,40) ,ICASE
C
   10 CONTINUE
      E = FT(T,E1,E2,E3,E4)
      V = FT(T,V1,V2,V3,V4)*17.6
      IF(LOGV) V = AMIN1(VP(II-1)*17.6 + 2.*DA*DT , V)
      GO TO 11
C
   20 CONTINUE
      RIOL = FT(T,RI1,RI2,RI3,RI4)*12./L
```

```
      V = FT(T,V1,V2,V3,V4)*17.6
      IF(LOGV) V = AMIN1(VP(II-1)*17.6 + 2.*DA*DT , V)
      GO TO 11
C
   30 CONTINUE
      V = SQRT(VXPRV**2+VYPRV**2) + DA*DT
      E = EP(II)
      IF(.NOT.LOGV) GO TO 11
      EI = E
      IF(VPREV .GE. VI) GO TO 48
      IF(ABS(EP(II-1)-1.) .LE. 0.05) GO TO 47
      IF(VPREV .LT. VI) E = EP(II-1) - .05*IDIR
      GO TO 49
   47 E = 1. + (EI-1.)/ABS(EI-1.)*.000001
   49 CONTINUE
      IF(RIOL*(E/EI-1.)) 11,48,46
   46 E = EI
   48 LOGV = .FALSE.
      GO TO 11
C
   40 CONTINUE
      VX1 = FT(T,VX11,VX12,VX13,VX14)*17.6
      VX2 = FT(T,VX21,VX22,VX23,VX24)*17.6
      E = VX1/VX2
C
   11 CALL AGIL($115)
C
      Z1P = Z1
      Z2P = Z2
      PP(II) = P
      IF(LVX) V = SQRT(VX**2 + VY**2)
      VP(II) = V*VMP
      VPREV = V
      IF(LVX .OR. HPAV.LE.0.) GO TO 160
      RATIO = ABS(PTE/HPAV)
      IF(RATIO .GT. 1.0) GO TO 154
      IF(RATIO .GE. 0.95) GO TO 160
      IF(ICASE.NE.3) GO TO 156
      IF(LSTB) GO TO 160
C
      V = V+DA*DT
      GO TO 11
C
  154 CONTINUE
      V = V-DA*DT
      DA = AMAX1(DA/1.2,.05)
      IF(V.LE.VI .AND. ICASE.EQ.3) LOGV = .TRUE.
      IF(ICASE .LT. 3) LOGV = .TRUE.
      GO TO 11
C
  156 LOGV = .FALSE.
  160 CONTINUE
      WDP(II) = WD*RDEG
      ALPHD = (VX*VYD-VY*VXD) / V**2
      THED = WD - ALPHD
      ROP(II) = V/THED/12.
```

```
      THETA = THETA + (THED+THDPRV)*DTIM2
      DXT = V*COS(THETA)
      DYT = V*SIN(THETA)
      DXTPS = DXTPS + (DXTPRV+DXT)*DTO12
      DYTPS = DYTPS + (DYTPRV+DYT)*DTO12
      DXTP(II) = DXTPS
      DYTP(II) = DYTPS
      DXTPRV = DXT
      DYTPRV = DYT
      THDPRV = THED
      WDPRV = WD
      VXPRV = VX
      VYPRV = VY
      WPRV = W
      WP(II) = W*RDEG
      TP(II) = T
      EP(II) = E
      IF (E .LT. 1.) EP(II) = -1./E
      FCXP(II) = FCX
      FCYP(II) = FCY
      VX1P(II) = VX1*VMP
      VX2P(II) = VX2*VMP
      VSX1P(II) = VSX1*VMP
      VSX2P(II) = VSX2*VMP
      VXP(II) = VX*VMP
      VYP(II) = VY*VMP
      PTEP(II) = PTE
      PTSP(II) = PTS
      PT1P(II) = PT1
      PT2P(II) = PT2
      T = T + DT
      IF (MOD(II,IPRINT).NE.0) GO TO 400
      PRINT 14, II,TP(II),PP(II),
     &          EP(II),ROP(II),VP(II),VX1P(II),VX2P(II),
     &          VSX1P(II),VSX2P(II),WP(II),WDP(II), FCXP(II),
     &          FCYP(II), PTEP(II),PTSP(II),DXTP(II),DYTP(II)
C
  400 CONTINUE
C     ----------------------------------------------------------------
C
      PRINT 207
      GO TO 99
C
  115 IF (II .EQ. 1) GO TO 119
      V = V - DV
      IF(DV .LT. 1.) GO TO 116
      DV = DV/2.
      LSTB = .TRUE.
      P = PP(II-1)
      Z1 = Z1P
      Z2 = Z2P
      IF(.NOT.LVX) GO TO 11
      VX1 = VX1P(II-1)*17.6
      VX2 = VX2P(II-1)*17.6
      E = VX1/VX2
      GO TO 11
```

```
C
  116 PRINT 207
      PRINT *, 'VEHICLE GOES UNSTABLE AT THIS POINT',
     & ' (TOO VIOLENT MANEUVER ATTEMPTED)'
      PRINT *,
      II = II-1
      PRINT 14, II,TP(II),PP(II),
     &          EP(II),ROP(II),VP(II),VX1P(II),VX2P(II),
     &          VSX1P(II),VSX2P(II),WP(II),WDP(II), FCXP(II),
     &          FCYP(II), PTEP(II),PTSP(II),DXTP(II),DYTP(II)
      GO TO 99
C
  119 PRINT *, 'THE VEHICLE WILL NOT GO IN THIS PARTICULAR SOIL.'
C
   99 RETURN
C     ===============================================================
C
   14 FORMAT(1X,I3,F6.2,F7.2,F6.2,F10.2,3F6.1,2F7.2,F7.1,F6.1,
     &          2F6.2,2F7.1,2F8.1)
  165 FORMAT(' MAXIMUM POINTS NP SET TO',I5)
  170 FORMAT(2X,'WT(IN)',3X,'L(IN)',3X,'H(IN)',2X,'D(IN)',4X,
     &          'B(IN)',3X,'SL(IN)',1X,'CX(IN)',4X,'THETAD(DEG)',3X,
     &          'THETAA(DEG)',1X,'IZ(IN LB/SEC**2)',3X,'VCI1')
  180 FORMAT(1X,F8.1,2X,F5.1,2(3X,F4.1),4X,F5.1,5X,F4.1,2X,F5.1,
     &               7X,F5.1,10X,F5.1,7X,F8.1,8X,F4.1)
  190 FORMAT(4X,'CI',5X,'A(PSI)',1X,'SM(PSI)',1X,'C(PSI)',1X,
     &          'SN(1/PSI)',2X,'SXI',3X,'CD(PSI)',1X
     &          'CLAMDA(SEC/IN)',4X,'PHI(DEG)',2X,'G(PSI/IN)',2X,
     &          'SF',4X,'ETA(DEG)',1X,'CHI(DEG)')
  200 FORMAT(2X,F5.1,1X,2(3X,F5.1),3X,F4.1,3X,F6.4,5X,I1,5X,F5.1,
     &       6X,F6.3,10X,F4.1,6X,F5.1,3X,F5.3,4X,F4.1,4X,F5.1)
  203 FORMAT(2X,'DT = ',F4.1,'(SEC)',3X,'NP = ',I3,
     &       12X,'TEST NO. = ',A40,3X,A8,3X,//)
  205 FORMAT(2X,'PT',3X,'T',5X,'P/L',4X,'E',6X,'RO',7X,'VEL',3X,'VX1',
     &       3X,'VX2',3X,'VS1',4X,'VS2',5X,'W',5X,'WD',4X,'FCX',
     &       3X,'FCY',3X,'PTE',4X,'PTS',5X,'DXT',5X,'DYT')
  207 FORMAT(/,1X,119(1H=),//)
  209 FORMAT(6X,'SEC',18X,'FT',7X,3('MPH',3X),2('MPH',4X),'DEG',
     &       2X,'DEG/SEC',2X,'G',5X,'G',2(5X,'HP'),2(6X,'FT'),//)
  210 FORMAT(2X,'HPAV = ',F6.1,'(HP)',7X,'DRIVER COEFFICIENTS FOR',
     &       ' VELOCITY      :',F6.2,3(',',F6.2),/,50X,
     &       'STEERING RATIO:',F6.2,3(',',F6.2))
  220 FORMAT(2X,'HPAV = ',F6.1,'(HP)',7X,'DRIVER COEFFICIENTS FOR',
     &       ' VELOCITY      :',F8.1,3(',',F8.1),/,50X,
     &       'TURNING RADIUS:',F8.1,3(',',F8.1))
  225 FORMAT(25X,'NOTE:  THIS CASE COULD BE MODIFIED TO INPUT',
     &       ' TRAJECTORY INSTEAD OF RI')
  230 FORMAT(2X,'HPAV = ',F6.1,4X,'VI = ',F4.1)
  240 FORMAT(2X,'VI = ',F4.1,'(MPH)',3X,'DRIVER COEFFICIENTS FOR',
     &       ' OUTERTRACK:',F6.1,3(',',F6.1),/,43X,
     &       'INNER TRACK:',F6.1,3(',',F6.1))
  245 FORMAT(28X,A76)
  246 FORMAT(1H1)
  250 FORMAT(48X,'TRANSIENT TURNING MOTION')
C
      END
```

```
C
C     ************************************************************
C     *                                                          *
C     *    THIS SUBROUTINE CALCULATES THE SLIP RADII AND OFFSET.   *
C     *                (TECHNICAL REPORT GL-79-6)                *
C     *                                                          *
C     ************************************************************
C
      SUBROUTINE AGIL(*)
C
      PARAMETER ( N = 10 , N1 = N+1 )
      REAL L,JACK,IZ,IZB
      LOGICAL LOGRE,LVX
      CHARACTER TESTN*40,DATE*8
      SAVE
      DATA PTA,PTAD,PTAPM,IFIRST /0.95 , 0.95 , 0.75 , 0/
C
      DIMENSION T1(N1),T2(N1),Q1(N1),Q2(N1),DX(N1)
C
      COMMON /INOUT / E,VX1,VX2,V,RIOL,LOGRE,LVX
      COMMON /IN    / DTIM1,DTIM2,WPRV,WDPRV,VXPRV,VYPRV,TESTN,DATE
      COMMON /VPARAM/ WT,L,H,D,B,SL,CX,THETAA,THETAD,IZ,VCI1
      COMMON /SPARAM/ CI,A,SM,SN,C,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI
      COMMON /OUT   / FCX,FCY,VSX1,VSX2,PTE,PTS,WD,W,VX,VY,
     &                P,Z1,Z2,IDIR,VXD,VYD,PT1,PT2
      COMMON /MISC  / GRAV,DRAD,VMP,RDEG
C
C     ==============================================================
C
C                         FUNCTION FOR R (INPUT E)
C
      FR(Z1,Z2,E) = (E*(BOL-2.*Z2)+BOL+2.*Z1) / (E-1.)*.5
C
C                         FUNCTION FOR E (INPUT RO)
C
      FE(Z1,Z2,ROL) = (Z1+BOL/2.+ROL) / (Z2-BOL/2.+ROL)
C
C     --------------------------------------------------------------
C
C        FUNCTIONS FOR NORMAL STRESSES WITHOUT TRACK TENSION TERM
C
      FR1B(X) = CZ2 + CXCZT6*X - HOBFCY - HOBFCX*X
      FR2B(X) = CZ2 + CXCZT6*X + HOBFCY - HOBFCX*X
C
C     WHERE
C          HOBFCY = HOL/BOL*(-FCY-SZSC)
C          HOBFCX = 6*HOL*(FCX+SZCC)
C          CXCZT6 = 6*CXOL*COS(ETA)
C
C     --------------------------------------------------------------
C
C                    FUNCTIONS FOR TRACK TENSION TERMS
C
      FSO(X) = AL3PRX + (ALSAN1*X+AL1AN1)*DU1 + AN1*DU4
      FSI(X) = AL3PRX + (ALSA2P*X+AL1AN2)*DU1 + AN2A2P*DU2
     &                - (ALSAN2*X-AL1A2P)*DU3
```

```
C
C     ------------------------------------------------------------------
C
C                        EQUATIONS FOR TRACK TENSION
C
      FA(T1S) = AN1 - STETD*T1S
      GA(T2S) = DUM1*(AN2-STHETA*T2S) + DUM2*(AN2P+STETD*T2S)
      FA2(T1S) = (FA(T1S)-AA) / DT
      GA2(T2S) = (GA(T2S)-BB) / DT
C
C     ------------------------------------------------------------------
C
C                      FUNCTION FOR TOTAL SHEAR STRENGTH
C
      EXPS(X) = EXP(AMAX1(X,-88.))
      FSM(XCD,SIG) = (ABAR+SMBAR*EXPS(-SN*SIG))*(1.-SXI) +
     &                                 (CBAR+SIG*TPHI)*SXI + XCD
C
C     ------------------------------------------------------------------
C
C                            EQUATIONS OF MOTION
C
      FB(TS) = TS - SF - FCX - SZCC
      GB(QS) = QS + FCY + SZSC
      HB(QX,TD) = QX + BOL/2.*TD + SF*HOL*(FCY+SZSC) + IZB*WDD
      F2(TS) = (FB(TS)-AV) / DT
      G2(QS) = (GB(QS)-BV) / DT
      H2(QX,TD) = (HB(QX,TD)-CV) / DT
C
C     ==================================================================
C
      IF (IFIRST .NE. 0) GO TO 20
      IFIRST = 1
C
      DT = .0005
      CHI = CHI*DRAD
      DX(1) = 0.
      CONT = 1.E-5
      HPF = WT/6600.
      HPFE = 0.5/PTA
      EPREV = E
      P = 0.
      Z1 = .1
      Z2 = -.1
C
C     ------------------------------------------------------------------
C     VARIABLES RELATED TO VEHICLE PARAMETERS
C     ------------------------------------------------------------------
C
      ALSQOW = L*L/WT
      HOB = H/B
      DOL = D/L
      IZB = IZ/L/WT
      HOL = H/L
      HOLT6 = 6.*HOL
      BOL = B/L
```

```
      CXOL = CX/L
C
C     USED FOR TRACK TENSION ONLY (SL .NE. 0.)
C
      IF(SL) 69,73,69
   69 TETD1 = THETAD*DRAD
      THETA1 = THETAA*DRAD
      STETD = SIN(TETD1)
      STHETA = SIN(THETA1)
      AN2 = STHETA
      AN1 = STETD
      AN2P = -STETD
      SLOL = SL/L
      AL2 = SLOL*2.
      M = SLOL*N+.5
      M1 = M+1
      M2 = N1-M
      DX(2) = SLOL/M
      DO 70 I = 3,M1
   70 DX(I) = DX(2)
      DX(M+2) = (1.-AL2) / (N-2*M)
      DO 71 I = M+3,M2
   71 DX(I) = DX(M+2)
      DO 72 I = M2+1,N1
   72 DX(I) = DX(2)
      M1 = M1 + 1
      M2 = M2 + 1
      AL3 = 3. - AL2
      ALS = 2./SLOL**2
      AL1 = ((1.-SLOL)/SLOL)**2
      GO TO 75
C
C     USED ONLY FOR ZERO TRACK TENSION (SL .EQ. 0.)
C
   73 DXT = 1./N
      DO 74 I = 2,N1
   74 DX(I) = DXT
C
C     -----------------------------------------------------------
C     VARIABLES RELATED TO SOIL MODEL PARAMETERS
C     -----------------------------------------------------------
C
   75 CONTINUE
      PHI1 = PHI*DRAD
      TPHI = TAN(PHI1)
      CBAR = DOL*ALSQOW*C
      ABAR = DOL*ALSQOW*A
      SMBAR = DOL*ALSQOW*SM
      GBAR = DOL*G*ALSQOW*L
      CDBAR = DOL*CD*ALSQOW
      CLMDAB = CLAMDA*L
      DI = SF
      CZ = COS(ETA*DRAD)
      CZ2 = CZ/2.
      SZ = SIN(ETA*DRAD)
      CXCZT6 = CXOL*CZ*6.
```

```
C
C     ----------------------------------------------------------------
C     DETERMINE DIRECTION VEHICLE IS TURNING
C     ----------------------------------------------------------------
C
   20 CONTINUE
      IDIR = 1
      IF (LOGRE) GO TO 47
      IF(E-1.) 41,44,47
C
   41 IF(E) 42,43,43
   42 E = -1./E
      IF (E-1.) 43,44,47
C
   43 CONTINUE
      IDIR = -1
      GO TO 47
C
   44 CONTINUE
      IF(EPREV-1.) 45,46,46
C
   45 E = 0.9999
      IF (LVX) VX1 = VX2*E
      IDIR = -1
      GO TO 47
C
   46 E = 1.0001
      IF (LVX) VX2 = VX1/E
C
   47 CONTINUE
      EPREV = E
C
C     ----------------------------------------------------------------
C     ITERATE TO FIND SOLUTIONS
C     ----------------------------------------------------------------
C
      DO 100 IL = 1,36
C
      K = 1
    8 PSQ = P**2
      IF (LOGRE) GO TO 510
C
C     FOR CASES WHERE E IS INPUT
C
      ROL = FR(Z1,Z2,E)
      RIOL = SIGN(SQRT(PSQ+ROL**2),ROL)
      GO TO 520
C
C     FOR CASES WHERE RI IS INPUT (RI=RO FOR STEADY-STATE)
C
  510 CONTINUE
      RIOLSQ = RIOL*RIOL
      IF (PSQ .GE. RIOLSQ) RETURN 1
      ROL = SIGN(SQRT(RIOLSQ-PSQ),RIOL)
      E = FE(Z1,Z2,ROL)
C
```

```
  520 CONTINUE
      IF (LVX) GO TO 530
      WDL = V/RIOL
      VX2 = WDL*(BOL+Z1-Z2)/(E-1.)
      VX1 = VX2*E
      GO TO 540
C
  530 CONTINUE
      WDL = VX2*(E-1.) / (BOL+Z1-Z2)
C
  540 WDLO2 = WDL*.5
      WD = WDL/L
      VX = ROL*WDL
      VY = P*WDL
      WDD = (WD-WDPRV)*DTIM1
      VXD = (VX-VXPRV)*DTIM1
      VYD = (VY-VYPRV)*DTIM1
      FCY = (VX*WD-VYD)/GRAV
      FCX = (VY*WD+VXD)/GRAV
      W = WPRV + (WD+WDPRV)*DTIM2
      CC = COS(CHI+W)
      SC = SIN(CHI+W)
      SZSC = SZ*SC
      SZCC = SZ*CC
      HOBFCY = HOB*(-FCY-SZSC)
      HOBFCX = HOLT6*(FCX+SZCC)
      Z1SQ = Z1*Z1
      Z2SQ = Z2*Z2
      IF(V) 77,78,77
   77 TEM1 = WDLO2/VX1
      TEM2 = WDLO2/VX2
      GO TO 79
C
   78 TEM1 = 0.
      TEM2 = 0.
C
   79 CONTINUE
      VSX2 = Z2*WDL
      K2 = 4
C
C     USED FOR TRACK TENSION ONLY (SL .NE. 0.)
C
      IF(SL) 80,85,80
   80 IF(VSX2) 81,82,82
   81 AN2 = 0.
      DUM1 = 0.
      DUM2 = 1.
      GO TO 83
   82 AN2P = 0.
      DUM1 = 1.
      DUM2 = 0.
   83 CONTINUE
      K2 = 1
      IL2 = 1
   84 ALSAN1 = ALS*AN1
      AL1AN1 = AL1*AN1
```

```
      AL3PR = AL3*(AN2-AN2P-AN1)
      ALSA2P = ALS*AN2P
      AL1AN2 = AL1*AN2P + AN2
      AN2A2P = AN2+AN2P
      ALSAN2 = ALS*AN2
      AL1A2P = AL1*AN2 + AN2P
      DU1=1.
      DU2=0.
      DU3=0.
      DU4=0.
C
   85 CONTINUE
      X = -.5
      UP1 = .5 - P - CXOL
      UP1S = UP1**2
      UP1Z1S = SQRT(UP1S+Z1SQ)
      UP1Z2S = SQRT(UP1S+Z2SQ)
      ARG1 = AMAX1(UP1+UP1Z1S,1.E-20)
      ARG2 = AMAX1(UP1+UP1Z2S,1.E-20)
      D1BP = UP1*UP1Z1S + Z1SQ*ALOG(ARG1)
      D2BP = UP1*UP1Z2S + Z2SQ*ALOG(ARG2)
C
C     ------------------------------------------------------------
C     INTEGRATE ALONG TRACKS FOR COMPONENTS OF SHEAR STRESS
C     ------------------------------------------------------------
C
      DO 10 I = 1,N1
C
      X = X + DX(I)
      R1B = FR1B(X)
      R2B = FR2B(X)
C
C     USED FOR TRACK TENSION ONLY (SL .NE. 0.)
C
      IF(SL) 32,37,32
   32 IF(I-M1) 36,33,34
   33 DU1=0.
      DU2=1.
      DU4=1.
   34 IF(I-M2) 36,35,36
   35 DU2=0.
      DU3=1.
   36 CONTINUE
      AL3PRX = AL3PR*X
      R1B = R1B + FSO(X)
      R2B = R2B + FSI(X)
C
   37 CONTINUE
      XMP = X - P - CXOL
      XMPSQ = XMP**2
      RTZ1 = SQRT(XMPSQ+Z1SQ)
      RTZ2 = SQRT(XMPSQ+Z2SQ)
      SG1 = XMP/RTZ1
      CG1 = Z1/RTZ1
      SG2 = XMP/RTZ2
      CG2 = Z2/RTZ2
```

```
      DD1B = WD*RTZ1
      DD2B = WD*RTZ2
      ARG1 = AMAX1(XMP+RTZ1,1.E-20)
      ARG2 = AMAX1(XMP+RTZ2,1.E-20)
      D1B = DI + TEM1*(D1BP-XMP*RTZ1-Z1SQ*ALOG(ARG1))
      D2B = DI + TEM2*(D2BP-XMP*RTZ2-Z2SQ*ALOG(ARG2))
      GD1B = D1B*GBAR
      GD2B = D2B*GBAR
      CCD1 = CDBAR * (1.0-EXPS(-CLMDAB*ABS(DD1B)))
      CCD2 = CDBAR * (1.0-EXPS(-CLMDAB*ABS(DD2B)))
      TAU1 = FSM(CCD1,AMAX1(R1B,0.))
      TAU2 = FSM(CCD2,AMAX1(R2B,0.))
      TQ1 = GD1B*TAU1 / (TAU1+ABS(GD1B))
      TQ2 = GD2B*TAU2 / (TAU2+ABS(GD2B))
C
      T1(I) = TQ1*CG1
      T2(I) = TQ2*CG2
      Q1(I) = TQ1*SG1 + TQ2*SG2
      Q2(I) = Q1(I)*(X-CXOL)
C
   10 CONTINUE
C     --------------------------------------------------------------
C
      T1S = 0.
      T2S = 0.
      DO 21 I = 2,N1
      DX02 = DX(I)*.5
      T1S = T1S + (T1(I)+T1(I-1))*DX02
   21 T2S = T2S + (T2(I)+T2(I-1))*DX02
      T1S = T1S*IDIR
      T2S = T2S*IDIR
      GO TO (87,88,89,90) ,K2
C
C     USED FOR TRACK TENSION ONLY (SL .NE. 0.)
C
   87 AA = FA(T1S)
      BB = GA(T2S)
      IF(ABS(AA).LT.CONT .AND. ABS(BB).LT.CONT) GO TO 90
      K2 = 2
      AN2 = AN2 + DUM1*DT
      AN2P = AN2P + DUM2*DT
      GO TO 84
   88 FAX = FA2(T1S)
      GAX = GA2(T2S)
      AN2 = AN2 - DUM1*DT
      AN2P = AN2P - DUM2*DT
      AN1 = AN1 + DT
      K2 = 3
      GO TO 84
   89 FAY = FA2(T1S)
      GAY = GA2(T2S)
      AN1 = AN1 - DT
      RJAC2 = FAX*GAY - FAY*GAX
      IF(ABS(RJAC2) .LT. 1.E-37) RETURN 1
      DELTTT = (-AA*GAY+BB*FAY) / RJAC2
      DELTT3 = (-BB*FAX+AA*GAX) / RJAC2
```

```
      AN2 = AN2 + DUM1*DELTTT
      AN2P = AN2P + DUM2*DELTTT
      AN1 = AN1 + DELTT3
      IL2 = IL2 + 1
      K2 = 1
      IF (IL2 .LT. 36) GO TO 84
      RETURN 1
C
   90 CONTINUE
      QS = 0.
      QX = 0.
      DO 23 I = 2,N1
      DX02 = DX(I)*.5
      QS = QS + (Q1(I)+Q1(I-1))*DX02
   23 QX = QX + (Q2(I)+Q2(I-1))*DX02
      QS = QS*IDIR
      QX = QX*IDIR
      TS = T1S + T2S
      TD = T2S - T1S
      GO TO (30,40,50,60) ,K
C
   30 AV = FB(TS)
      BV = GB(QS)
      CV = HB(QX,TD)
      IF(ABS(AV).LT.CONT .AND. ABS(BV).LT.CONT
     &                    .AND. ABS(CV).LT.CONT) GO TO 120
      P = P+DT
      K = 2
      GO TO 8
C
   40 FX = F2(TS)
      GX = G2(QS)
      HX = H2(QX,TD)
      P = P - DT
      Z1 = Z1 + DT
      K = 3
      GO TO 8
C
   50 FY = F2(TS)
      GY = G2(QS)
      HY = H2(QX,TD)
      Z1 = Z1 - DT
      Z2 = Z2 + DT
      K = 4
      GO TO 8
C
   60 FZ = F2(TS)
      GZ = G2(QS)
      HZ = H2(QX,TD)
      Z2 = Z2 - DT
      A1F = GY*HZ - GZ*HY
      B1F = FY*HZ - FZ*HY
      C1F = FY*GZ - FZ*GY
      A2F = BV*HX - CV*GX
      B2F = AV*HX - CV*FX
      C2F = AV*GX - BV*FX
```

```
C                                                                       AGIL0449
      JACK = FX*A1F - GX*B1F + HX*C1F                                   AGIL0450
      IF(ABS(JACK).LT.1.E-37) RETURN 1                                  AGIL0451
C                                                                       AGIL0452
      P = P + (BV*B1F - AV*A1F - CV*C1F)/JACK                           AGIL0453
      Z1 = Z1 + (FZ*A2F - GZ*B2F + HZ*C2F)/JACK                         AGIL0454
      Z2 = Z2 + (GY*B2F - FY*A2F - HY*C2F)/JACK                         AGIL0455
C                                                                       AGIL0456
  100 CONTINUE                                                          AGIL0457
      RETURN 1                                                          AGIL0458
C     --------------------------------------------------------------   AGIL0459
C                                                                       AGIL0460
  120 CONTINUE                                                          AGIL0461
      PT1 = VX1*T1S*HPF                                                 AGIL0462
      PT2 = VX2*T2S*HPF                                                 AGIL0463
      PTS = PT1 + PT2                                                   AGIL0464
      IF(E-1.) 140,130,130                                              AGIL0465
C                                                                       AGIL0466
  130 PTE = HPFE*(PT1/E*(E+1.+(E-1.)/PTAPM)+                            AGIL0467
     *         PT2*(E+1.-PTAD*(E-1.)/PTAPM))                            AGIL0468
      GO TO 150                                                         AGIL0469
C                                                                       AGIL0470
  140 ONEOE = 1./E                                                      AGIL0471
      PTE = HPFE*(PT2*E*(ONEOE+1.+(ONEOE-1.)/PTAPM)+                    AGIL0472
     *         PT1*(ONEOE+1.-PTAD*(ONEOE-1.)/PTAPM))                    AGIL0473
C                                                                       AGIL0474
  150 CONTINUE                                                          AGIL0475
      VSX1 = Z1*WDL                                                     AGIL0476
C                                                                       AGIL0477
      RETURN                                                            AGIL0478
      END                                                               AGIL0479
C                                                                       MIVCI001
C     ***************************************************************  MIVCI002
C     *                                                             *  MIVCI003
C     *      THIS SUBROUTINE CALCULATES THE VEHICLE CONE INDEX      *  MIVCI004
C     *        FOR ONE-PASS TRAFFIC USING THE MOBILITY INDEX.       *  MIVCI005
C     *                 (TECHNICAL REPORT GL-79-6)                  *  MIVCI006
C     *                                                             *  MIVCI007
C     ***************************************************************  MIVCI008
C                                                                       MIVCI009
      SUBROUTINE MIVCI                                                  MIVCI010
C                                                                       MIVCI011
      REAL L                                                            MIVCI012
      COMMON /VPARAM/ WT,L,H,D,B,SL,CX,THETAA,THETAD,IZ,VCI1            MIVCI013
      COMMON /MISC  / GRAV,DRAD,VMP,RDEG                                MIVCI014
C                                                                       MIVCI015
      PRINT *,                                                          MIVCI016
      PRINT *, 'FOR TRNT, 0 = MANUAL, 1 = AUTOMATIC'                    MIVCI017
      PRINT *, 'INPUT GH,NB,TSL,HP,TRNT'                                MIVCI018
      READ *, GH,NB,TSL,HP,TRNT                                         MIVCI019
      PRINT *,                                                          MIVCI020
C                                                                       MIVCI021
      CPF = WT/(D*L)                                                    MIVCI022
C                                                                       MIVCI023
      WF = 1.0                                                          MIVCI024
      IF(WT.GE.50000.0 .AND. WT.LT.70000.0) WF = 1.2                    MIVCI025
```

```
      IF(WT.GE.70000.0 .AND. WT.LT.100000.0) WF = 1.4
      IF(WT .GE. 100000.0) WF = 1.8
C
      TRKF = D/100.
C
      GF = 1.0
      IF(GH .GT. 1.5) GF = 1.1
C
      BF = (WT/10.)/(NB*TSL*D)
      CF = 1.5*L/(NB-1)/TAN(THETAA*DRAD)/10.
      HPT = HP/(WT/2000.)
C
      EF = 1.0
      IF(HPT .LT. 10.) EF = 1.05
C
      TRNF = 1.05
      IF(TRNT .GT. 0.) TRNF = 1.0
C
      AMI = ((CPF*WF)/(TRKF*GF)+BF-CF) * EF * TRNF
C
C     ------------------------------------------------------------
C
      VCI1 = 7.0 + 0.2*AMI - 39.2/(AMI+5.6)
C
C     ------------------------------------------------------------
C
      RETURN
      END
C
C     ************************************************************
C     *                                                          *
C     *     THIS SUBROUTINE CALCULATES THE MOBILITY CONE INDEX.  *
C     *            TO SIMULATE THE STANDARD WES CONE INPUT       *
C     *               CL = 1.48 (IN) ; DI = 0.799 (IN)           *
C     *                (MISCELLANEOUS PAPER SL-81-4)             *
C     *                                                          *
C     ************************************************************
C
      SUBROUTINE CONE
C
      DOUBLE PRECISION TL,AG,AGM,AA,A1,A2,A3,A4,A5,A6,A12
      COMMON /SPARAM/ CI,A,SM,SN,C,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI
      COMMON /MISC  / GRAV,DRAD,VMP,RDEG
C
      PRINT *,
      PRINT *, 'TO SIMULATE STANDARD WES CONE, INPUT CL=1.48,DI=0.79'
      PRINT *, 'FOR TYPICAL GAMA,Z, INPUT GAMA=0.07,Z=6.'
      PRINT *, 'INPUT CL,DI,GAMA,Z'
      READ *, CL,DI,GAMA,Z
C
      TL = CL
      AG = 4*G
      AGM = GAMA
      TAL = DI/2./CL
      PHI1 = PHI*DRAD
      SPHI = SIN(PHI1)
```

```
      TPHI = TAN(PHI1)
      ELP = 4.*SPHI/(1.+SPHI)/3.
      ELP2 = 2. - ELP
      ELP3 = 3. - ELP
C
      IF(PHI) 30,20,30
C
   20 CONTINUE
C
C     ------------------------------------------------------------
C
      CI = 4.*C/3.*(1.+DLOG(AG/C)) +
     &                  2.*C*TL/DI + AGM*((Z+TL)-2.*TL/3.)
C
C     ------------------------------------------------------------
C
      RETURN
C
   30 CONTINUE
C
      A1 = AGM*TPHI
      AA = A1*(Z+TL) + C
      A12 = A1**2
      A2 = A12*TPHI*(DI/2.)**2
      A3 = 2.*TAL*(1.+SPHI)*AG**ELP
      A4 = 3.*(TAL+TPHI)/(3.-SPHI)
      A5 = AA**ELP3
      A6 = (AA+ELP2*A1*TL)*DMAX1(0.,(AA-TL*AGM*TPHI))**ELP2
C
C     ------------------------------------------------------------
C
      CI = -C/TPHI + A3/A2*A4*(A5-A6)/ELP2/ELP3
C
C     ------------------------------------------------------------
C
      RETURN
      END

*
```

APPENDIX B: GLOSSARY

B.1 MAIN PROGRAM

A = Material constant in failure envelope, psi.

B = Track tread (distance between center lines of tracks), in.

C = Static cohesive component of shear strength, psi.

CD = Added cohesive strength due to dynamic loading, psi.

CHI = Directional angle of the vehicle on sloping terrain, deg.

CI = WES cone index.

CLAMDA = Material constant related to rate effect, sec/in.

CONE = Subroutine to calculate CI.

CX = Abscissa of the center of gravity of the vehicle, in.

D = Track width, in.

DATE = Character variable for the current date.

DATIM = System subroutine for obtaining the current date and time.

DRAD = Factor for converting from degrees to radians.

ETA = Angle of sloping terrain, deg.

FPRAM = System subroutine for setting the reflexive read characters that are sent to a terminal for requesting input and the line length for formatted output directed to a terminal.

FXOPT = System subroutine for monitoring FORTRAN execution errors.

G = Shear modulus, psi/in.

GRAV = Acceleration due to gravity, in/sec^2.

H = Height of the center of gravity, in.

IRUN = Variable used to determine the type of run (steady-state or transient motion).

IZ = Mass moment of inertia of the vehicle about an axis passing through its center of gravity and parallel to the Z axis, in-lb/sec^2.

L = Length of track in contact with the ground, in.

MIVCI = Subroutine to calculate VCI1 (vehicle cone index for one pass).

MPR = Octal constant used by subroutine FPARAM.

N2 = Parameter variable for setting dimension of arrays.

PHI = Angle of internal friction, deg.

PTI = Processor time at start of calculation, hr.

PTIME = System subroutine for obtaining the central processor time.

PTU = Processor time used, min.

RDEG = Factor for converting from radians to degrees.

SF = Coefficient of rolling resistance.

SL = Distance between center lines of adjacent wheels, in.

SM = Material constant in failure envelope, psi.

SN = Material constant in failure envelope, 1/psi.

STEADY = Subroutine for steady-state turning motion.

SXI = Variable used to determine the type of soil model used.

TESIN = Test title of up to 40 characters.

THETAA = Approach angle of the track envelope, deg.

THETAD = Departure angle of the track envelope, deg.

TIM = Current time, used only for subroutine DATIM.

TRANS = Subroutine for transient motion.

VCI1 = Vehicle cone index for one pass.

VMP = Factor for converting from inches per second to miles per hour.

WT = Weight of the vehicle, lb.

B.2 SUBROUTINE STEADY

AGIL = Subroutine for solving the equations of motion.

DE = Steering ratio increment.

DR = Turning radius decrement, ft.

DTIM1 = Set to zero for steady-state turning motion.

DV = Velocity increment, mph (converted internally to in/sec.)

E = Steering ratio.

EF = E at the power limit.

EP = Array for storing E.

ES = E at the stability limit.

FCX = Forward acceleration, g's.

FCXF = FCX at the power limit, g's.

FCXP = Array for storing FCX.

FCXS = FCX at the stability limit, g's.

FCY = Lateral acceleration, g's.

FCYF = FCY at the power limit, g's.

FCYP = Array for storing FCY.

FCYS = FCY at the stability limit, g's.

HPAV = Horsepower available, hp.

ICASE = Case number: 1, 2, 3, 4 or ?

IHP = Flag used for power limit check.

II = Loop counter.

INPUT = Character variable for keyboard input.

L = Length of track in contact with the ground, in.

LAB2 = Character variable for type of stability limit.

LFMT = Character array for the case menu.

LOGRE = Switch variable; set false if E is input, true if RØ is input.

LSTB = Switch variable for stability check; set true when stability limit is reached.

LVX = Set false for steady-state turning motion.

N2 = Parameter variable for setting dimension of arrays.

N3 = Point number at the stability limit.

N4 = Maximum number of points which can be calculated for Cases 1 and 2.

NP = Number of points to be calculated.

P = Offset.

PDC = Factor for interpolation.

PF = P at the power limit.

PFC = Factor for interpolation.

PP = Array for storing P.

PS = P at the stability limit.

PT1 = Power required by the sprocket of the outer track, hp.

PT1P = Array for storing PT1.

PT2 = Power required by the sprocket of the inner track, hp.

PT2P = Array for storing PT2.

PTE = Power required from the engine, hp.

PTEF = PTE at the power limit, hp.

PTEP = Array for storing PTE.

PTES = PTE at the stability limit, hp.

PTS = Total power required by the sprockets, hp.

PTSF = PTS at the power limit, hp.

PTSP = Array for storing PTS.

PTSS = PTS at the stability limit, hp.

RØ = Radius of the trajectory (turning radius) of the center of gravity of the vehicle, ft (converted internally to in).

RØP = Array for storing RØ.

RØPF = RØ at the power limit, ft.

RØPS = RØ at the stability limit, ft.

RDEG = Factor for converting from radians to degrees.

RI = Instantaneous radius of curvature, in.

RIOL = RI/L.

V = Velocity of the vehicle, mph (converted internally to in/sec).

VFMT = Character variable containing format for input variables.

VMP = Factor for converting from in/sec to mph.

VP = Array for storing V.

VPF = V_p at the power limit, mph.

VPS = V_p at the stability limit, mph.

VSX1 = Longitudinal component of slip velocity of the outer track, in/sec.

VSX1F = VSX1 at the power limit, mph.

VSX1P = Array for storing VSX1.

VSX1S = VSX1 at the stability limit, mph.

VSX2 = Longitudinal component of slip velocity of the inner track, in/sec.

VSX2F = VSX2 at the power limit, mph.

VSX2P = Array for storing VSX2.

VSX2S = VSX2 at the stability limit, mph.

VX1 = Longitudinal component of velocity of the outer track, in/sec.

VX1F = VX1 at the power limit, mph.

VX1P = Array for storing VX1.

VX1S = VX1 at the stability limit, mph.

VX2 = Longitudinal component of velocity of the inner track, in/sec.

VX2F = VX2 at the power limit, mph.

VX2P = Array for storing VX2.

VX2S = VX2 at the stability limit, mph.

VXPRV, VYPRV = Set to zero for steady-state turning motion.

WD = Yaw rate, rad/sec.

WDF = WD at the power limit, deg/sec.

WDP = Array for storing WD.

WPPRV = Set to zero for steady-state turning motion.

WDS = WD at the stability limit, deg/sec.

Z1 = Slip radius of the outer track.

Z1P = Previous value of Z1.

Z2 = Slip radius of the inner track.

Z2P = Previous value of Z2.

B.3 SUBROUTINE TRANS

AGIL = Subroutine for solving the equations of motion.

ALPHD = Rate of change in the side-slip angle, rad/sec.

DA = Velocity increment for power control, in/sec.

DT = Time increment, sec.

DTIM1 = 1/DT.

DTIM2 = DT/2.

DT012 = DTIM1/12.

DV = Velocity increment for stability control, in/sec.

DXT = V * cos THETA.

DXTP = Array for storing DXTPS.

DXTPRV = Previous value of DXT.

DXTPS = Abscissa of trajectory, ft.

DYT = V * sin THETA.

DYTP = Array for storing DYTPS.

DYTPRV = Previous value of DYT.

DYTPS = Ordinate of trajectory, ft.

E = Steering ratio.

E1, E2, E3, E4 = Coefficients for calculating the steering ratio E.

EI = Current value of E.

EP = Array for storing E.

FCX = Forward acceleration, g's.

FCXP = Array for storing FCX.

FCY = Lateral acceleration, g's.

FCYP = Array for storing FCY.

FT = Driver function used for sample runs.

HPAV = Horsepower available, hp.

ICASE = Case number.

IDIR = Turn direction indicator (1 for left turn, -1 for right turn).

II = Loop counter.

INPUT = Character variable for keyboard input.

IPRINT = Print skip increment.

L = Length of track in contact with the ground, in.

LFMT = Character array for the case menu.

LOGRE = Switch variable (set true if RI is input).

LOGV = Switch variable for velocity check.

LSTB = Switch variable for stability check.

LVX = Switch variable (set true if track velocities are input).

NP = Number of points to be calculated.

N2 = Parameter variable for setting dimension of arrays.

P = Offset.

PP = Array for storing P.

PT1 = Power required by the sprocket of the outer track, hp.

PT1P = Array for storing PT1.

PT2 = Power required by the sprocket of the inner track, hp

PT2P = Array for storing PT2.

PTE = Power required from the engine, hp.

PTEP = Array for storing PTE.

PTS = Total power required by the sprockets, hp.

PTSP = Array for storing PTS.

RATIO = Ratio of power required to horsepower available.

RØP = Array for storing the radius of trajectory (turning radius) of the center of gravity of the vehicle.

RDEG = Factor for converting from radians to degrees.

RI1, RI2, RI3, RI4 = Coefficients for calculating the instantaneous radius of curvature (RI).

RIOL = RI/L

T = Time, sec.

THED = Rate of change in the directional angle, rad/sec.

THETA = Directional angle, rad.

THDPRV = Previous value of THED.

TP = Array for storing T.

V = Velocity of the vehicle, mph (converted internally to in/sec).

V1, V2, V3, V4 = Coefficients for calculating the velocity of the vehicle (V).

VFMT = Character variable containing format for input variables.

VI = Initial velocity of the vehicle, mph.

VMP = Factor for converting from in/sec to mph.

VP = Array for storing V.

VPREV = Previous value of V.

VSX1 = Longitudinal component of slip velocity of the outer track, in/sec.

VSX1P = Array for storing VSX1.

VSX2 = Longitudinal component of slip velocity of the inner track, in/sec.

VSX2P = Array for storing VSX2.

VX = Longitudinal component of velocity of the vehicle, in/sec.

VX1 = Longitudinal component of velocity of the outer track, in/sec.

VX11, VX12, VX13, VX14 = Coefficients for computing the longitudinal component of velocity of the outer track (VX1).

VX1P = Array for storing VX1.

VX2 = Longitudinal component of velocity of the inner track, in/sec.

VX21, VX22, VX23, VX24 = Coefficients for calculating the longitudinal component of velocity of the inner track (VX2).

VX2P = Array for storing VX2.

VXD = Derivative with respect to time of VX.

VXP = Array for storing VX.
VXPRV = Previous value of VX.
VY = Lateral component of velocity of the vehicle, in/sec.
VYD = Derivative with respect to time of VY.
VYP = Array for storing VY.
VYPRV = Previous value of VY.
W = Yaw angle, rad.
WD = Yaw rate, rad/sec.
WDP = Array for storing WD.
WDPRV = Previous value of WD.
WP = Array for storing W.
Z1 = Slip radius of the outer track.
Z1P = Previous value of Z1.
Z2 = Slip radius of the inner track.
Z2P = Previous value of Z2.

B.4 SUBROUTINE AGIL

D1B = Shearing deformation of soil under the outer track
D2B = Shearing deformation of soil under the inner track
E = Steering ratio.
FCX = Longitudinal component of inertial force.
FCY = Lateral component of inertial force.
P = Offset.
PT1 = Power required by the sprocket of the outer track.
PT2 = Power required by the sprocket of the inner track.
PTE = Power required from the engine.
PTS = Total power required by the sprockets.
Q1 = Lateral component of shear stress along the outer track.
Q2 = Lateral component of shear stress along the inner track.
R1B = Normal stress under the outer track.
R2B = Normal stress under the inner track.
RIOL = Instantaneous radius of curvature.
ROL = Ordinate of the instantaneous center of rotation of the vehicle.
SF = Coefficient of rolling resistance.

T1 = Longitudinal component of shear stress along the outer track.

T2 = Longitudinal component of shear stress along the inner track.

TAU1 = Maximum shear strength of soil under the outer track.

TAU2 = Maximum shear strength of soil under the inner track.

TQ1 = Shear stress under the outer track.

TQ2 = Shear stress under the inner track.

V = Velocity of the vehicle.

VSX1 = Longitudinal component of slip velocity of the outer track.

VSX2 = Longitudinal component of slip velocity of the inner track.

VX = Longitudinal component of velocity of the vehicle.

VX1 = Longitudinal component of velocity of the outer track.

VX2 = Longitudinal component of velocity of the inner track.

VXD = Time derivative of VX.

VY = Lateral component of velocity of the vehicle.

VYD = Time derivative of VY.

W = Yaw angle.

WD = Yaw rate.

Z1 = Slip radius of the outer track.

Z2 = Slip radius of the inner track.

B.5 SUBROUTINE MIVCI

AMI = Mobility index.

BF = Bogie factor.

CF = Clearance factor.

CPF = Contact pressure factor.

D = Track width, in.

DRAD = Factor for converting from degrees to radians.

EF = Engine factor.

GF = Grouser factor.

GH = Height of the grouser, in.

HP = Specified engine horsepower, hp.

HPT = Horsepower per ton.

L = Length of track in contact with the ground, in.

NB = Total number of bogies on track in contact with ground.

THETAA = Approach angle of the track envelope, deg.

TRKF = Track factor.

TRNF = Transmission factor.

TRNT = Transmission type (0 for manual, 1 for automatic).

TSL = Track shoe length, in.

VCI1 = Vehicle cone index for one pass.

WF = Weight factor.

WT = Weight of the vehicle, lb.

B.6 SUBROUTINE CONE (INPUT AND OUTPUT ONLY)

C = Static cohesive component of shear strength, psi.

CI = WES cone index.

CL = Cone length, in.

DI = Cone diameter, in.

G = Shear modulus, psi/in.

GAMA = Density, psi/in.

PHI = Angle of internal friction, deg.

Z = Depth of penetration, in.

APPENDIX C: DESCRIPTION OF THE FIELD DIRECT SHEAR DEVICE

C.1 BACKGROUND

The terrain-vehicle interaction model described in Chapter 2 requires six soil parameters as input that have to be determined experimentally. The parameters are (Figures 2.1-2.3):

- G Initial shear stiffness coefficient (assumed to be independent of rate of deformation)
- A Material constant describing the maximum shearing strength of the material at very high normal loading (Equation 2.1)
- M Material constant related to the parameter A and to the static soil cohesion C as $M = A - C$
- N Material parameter which appears in Equation 2.1
- C_d Increase in soil cohesion due to dynamic loading (maximum value achieved for loading rates of interest)
- Λ Material constant describing the effects of rate of deformation on the cohesive strength
- ϕ Angle of internal friction if Equation 2.2 is used

The soil parameters G, A, M, N, and ϕ can be determined from various existing laboratory test devices, such as the triaxial shear device or direct shear device. The triaxial shear and direct shear devices, however, may not yield the same values of G, A, M, N, and ϕ for identical specimens because of differences in test boundary conditions. The stress boundary conditions associated with the direct shear test more closely approximate the stress conditions experienced by the soil during steering of track-laying vehicles. It is, therefore, more appropriate to determine these parameters from direct shear tests. The parameters C_d and Λ can only be determined from special static and dynamic triaxial shear tests since dynamic direct shear devices are not presently available. Therefore, to adequately determine the five soil parameters, two separate test series may be required:

1. Direct shear tests to define G, A, M, N, and ϕ.
2. Static and dynamic triaxial shear tests to define C_d and Λ.

It should be noted that in determining C_d and Λ from triaxial tests rather than direct shear tests, it is assumed that these parameters are not sensitive to test boundary conditions. The validity of this assumption should, however, be evaluated.

The most important consideration in conducting laboratory soil tests is that the undisturbed specimens be representative of the materials over which the vehicle must travel. This fact implies that the upper several inches of surface material must be sampled, trimmed to necessary specimen size, and tested in the laboratory. Water content, soil structure, density, and vegetation root systems, all of which affect material response, must be preserved. With this in mind, a field-operated direct shear device capable of testing a variety of in situ surface soils for normal loads of interest was designed and fabricated. The description of the device and the procedure by which the soil parameters can be determined are documented in this appendix.

C.2 DIRECT SHEAR DEVICE

C.2.1 Design Consideration

Previously proposed field devices were considered but rejected because of one or more of the following reasons: some of the soil parameters could not be measured and hence required additional tests; the necessary support equipment was too massive to be easily field transportable; or specimen disturbances were encountered before testing. The idea of creating a new type of test was also rejected because any new device would contain inherent boundary problems, all of which would have to be evaluated with time and usage. The direct shear device, on the other hand, has been used extensively, and the direct shear test is a simple test to run. Furthermore, the five basic soil parameters (G , A , M , N , and ϕ) could be measured directly from this test. Figure C.1 shows a sketch of the field device that was fabricated as a result of this project. Figure C.2 contains photographs taken of the device during the conduct of actual field tests.

C.2.2 Specimen Container

Specimen configuration was the first consideration made in the design of the device. It was assumed that in many cases the in situ soil could not be sampled without disturbance; therefore, the specimen container would have to be placed around the soil. A round ring similar to a coring device would afford the least chance of soil disturbance. However, the stress distribution along a horizontal plane of a circular specimen is not uniform. To reduce the nonuniformity, a square-shaped specimen container was selected.

A 4- by 4-in box was selected in order to keep the shear and normal loads within limits of interest to the analysis of track-laying vehicles and at the same time retain a reasonably large specimen size. The use of deadweights is the simplest way to produce normal load, but use of more than 200 lb in weights is awkward for field testing. Therefore, with the weight requirement below the 200-lb limit, normal stress of up to 12 psi can be produced on a 4- by 4-in, or 16-in^2 specimen. However, the largest particle or grain size permissible with a 4- by 4-in specimen is probably 1/2 in, which is a reasonable limit for most terrains of interest.

The overall specimen height was controlled by the depth of the desired shear plane as directed by grouser depth ranging from approximately 3/4 to 1-1/2 in. The compressibility of soil could significantly alter this depth, but for estimation purposes the depth was assumed to be no greater than 2 in. Therefore, the height of the upper box portion was set at 2 in, permitting testing of depths from approximately 1/4 to 2 in. This height can be altered should particular site conditions dictate. The lower box portion was set at a 1-1/4-in height, including the cutting edge. A 1/8-in wall thickness was used for both boxes.

Figure C.3 presents a series of sketches of the specimen container showing the various stages of placement. To minimize specimen disturbance, it was decided to use the specimen cutting box as the device container rather than remove the cutting and place a container over the specimen. The box consists of three parts: (a) a lower portion with knife-sharp edges to aid in cutting the soil, (b) an upper portion, and (c) an outer holder to keep the lower and upper portions in alignment. The box is alternately pushed and trimmed into the soil to the desired depth. Once in place, the outer holder can be carefully removed, leaving the two boxes on the specimen with the joint between the lower and upper box portion forming the shear test plane.

C.2.3 Base

A relatively narrow 1-in-thick aluminum plate was used to construct the base with a square hole at one end to fit around the 4- by 4-in lower specimen containers (Figure C.1). The shear loader was attached to the other end of the plate. A second 1-in-thick aluminum yoke was constructed to fit over the upper specimen container. Set screws through the yoke serve to raise the yoke off the baseplate, thus minimizing friction between the surfaces. The shear loader attached by cable to the yoke pulls the upper specimen while the base reacts against the lower specimen container. Guide rails along the edge of the base ensure that no torsional shear deformation or twisting is applied to the specimen.

C.2.4 Shear Loader

An electric 12-volt boat winch was incorporated into the base as the shear loader. This approach is the simplest for providing a shear loader. (If necessary, the winch can be replaced with a more sophisticated loader custom built for this device.) Currently, the winch is capable of pulling loads up to 2000 lb. Static loading rates can be applied by manually turning the winch via a socket-rachet arrangement. Fast loading rates (approximately 300-600 msec time to peak load that is equivalent to a strain rate of 0.5 to 1.5 per second, which is compatible with the strain rate under the track) can be applied using the electric feature of the winch. The power is supplied by a 12-volt car battery, which is also used as the instrumentation power supply.

C.2.5 Instrumentation

A 2-in travel film potentiometer is attached to the base and records relative movement between the upper specimen holder and the base. A strain gage load cell attaching the winch cable to the specimen yoke is used to measure shear load. A compact, two-channel DC instrumentation amplifier is used for signal conditioning. Output is recorded in the form of a shear load versus deflection plot on a commercially available DC-operated X-Y plotter. As previously mentioned, a simple car battery is the main power supply. All initial testing was done by recording the data on a time base light beam strip chart. This recording procedure was later dropped since the loading times remained fairly constant on the soils tested. A time base can be added at a later date through the use of a frequency oscillator and an X-Y-Z recorder.

C.2.6 Normal Load

A series of steel weights, the largest weighing 57 lb and the smallest weighing 8-1/2 lb, was fabricated for use with the device. Guide holes and studs permit stacking and centering of the weights on the specimen top surface. Although a variety of load combinations are possible, most tests have been conducted using weights totaling approximately 8.6, 36.6, 65.7, and 122.7 lb (i.e., normal stress levels of 0.54, 2.29, 4.11, and 7.67 psi).

C.3 MEASUREMENT OF SOIL PARAMETERS

A series of two or more tests is required at a site to define the necessary soil parameters. A typical testing program may call for the conduct of four fast and four slow tests at normal stresses of 0.54, 2.29, 4.11, and 7.67 psi. For each test, an X-Y data record of shear load versus deflection is obtained. In addition, measurements of soil density and water content are made on each test specimen (generally on the posttest specimen contained in the upper and lower specimen holders).

For each test, a plot of shear stress versus deflection is obtained. The initial slope of the plot defines G, the peak stress defines the maximum shear stress, and the deflection at peak stress divided by time to peak stress defines the deflection rate. A table listing of each test is used to summarize the data and contains the specimen number, wet density, water content, dry density, normal load/stress, maximum shear load/stress, initial G, deflection at peak stress, and deflection rate. Figure C.4 presents the test results obtained from the series of field tests conducted at a given site.

The analysis plots are shown graphically in Figure C.5. A summary plot of shear stress versus shear deformation is made to obtain either static or dynamic failure envelopes. From the static failure envelope, the values of A, M, N, and ϕ are obtained. The value of C_d and Λ are obtained from the dynamic failure envelope as shown in the plot of cohesion versus rate of deformation. The value of G is the initial slope of shear stress-shear deformation curve (Figure C.4).

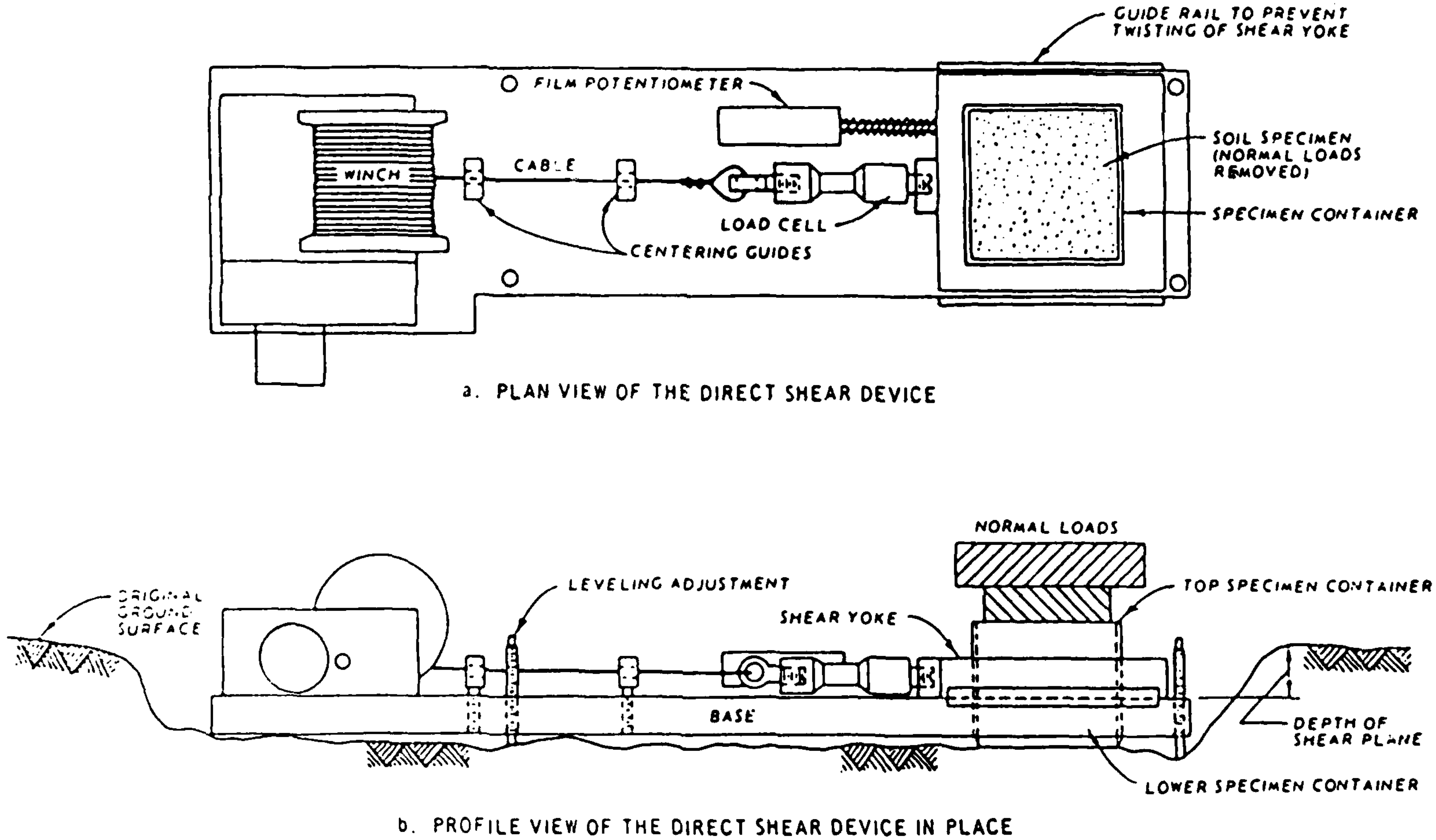
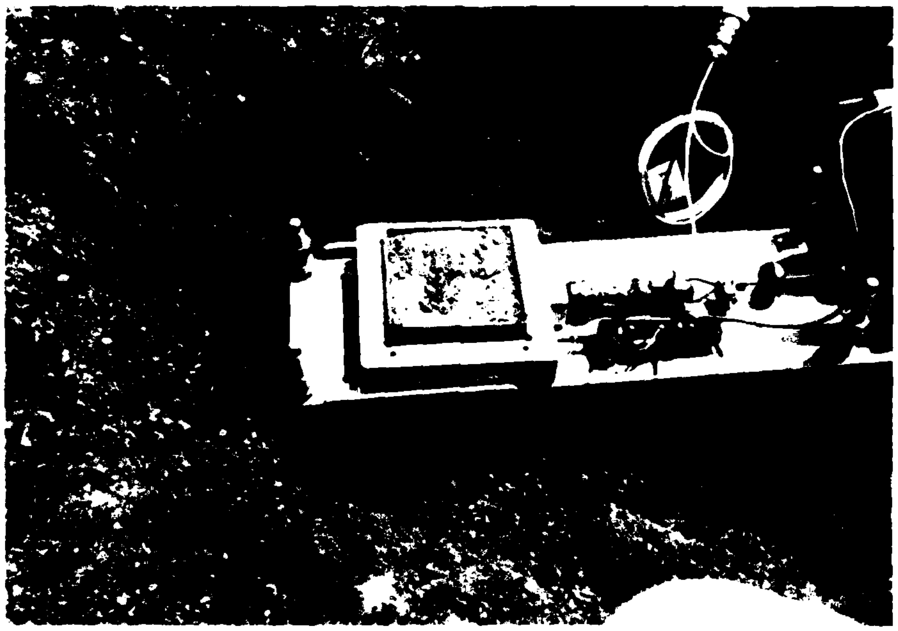


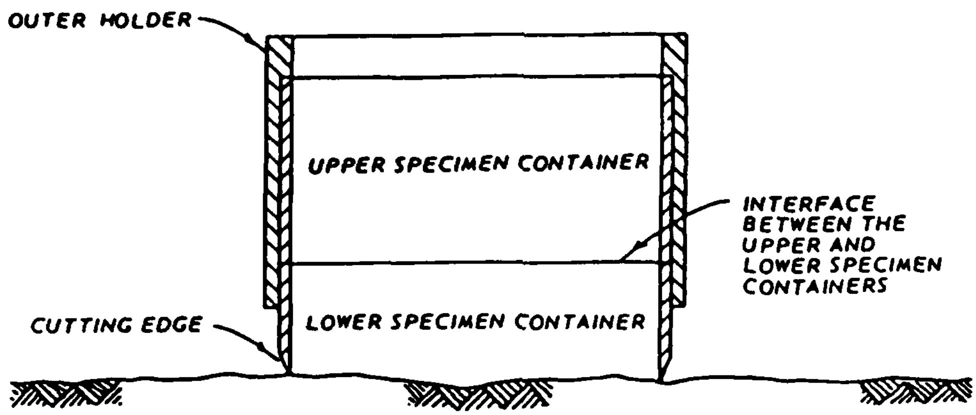
Figure C.1. Plan and profile views of the direct shear device.

a. Direct shear device assembled for test.

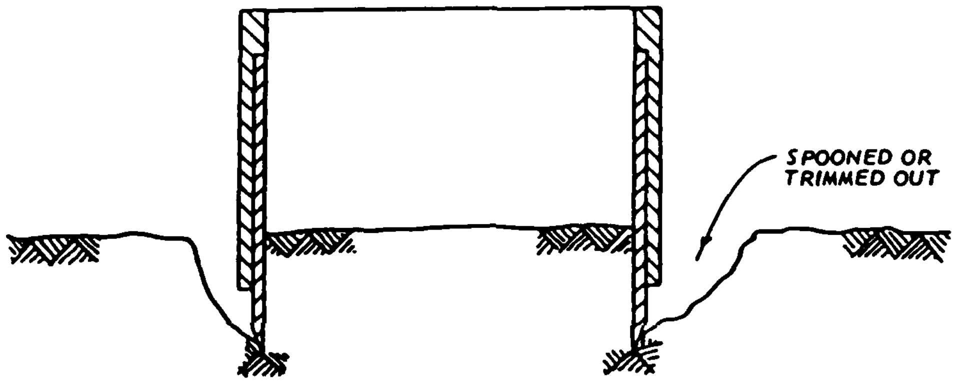


b. Specimen immediately following test with normal loads removed.

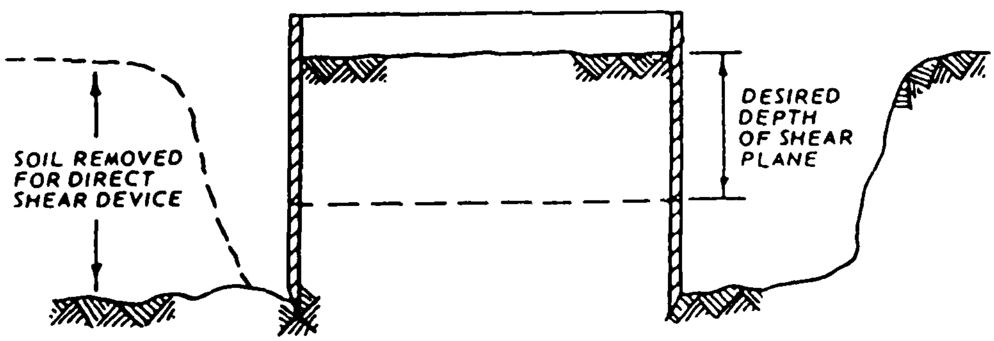
Figure C.2. Photographs of the direct shear device taken during actual field testing.



a. CONTAINER WITH OUTER HOLDER ON SOIL SURFACE

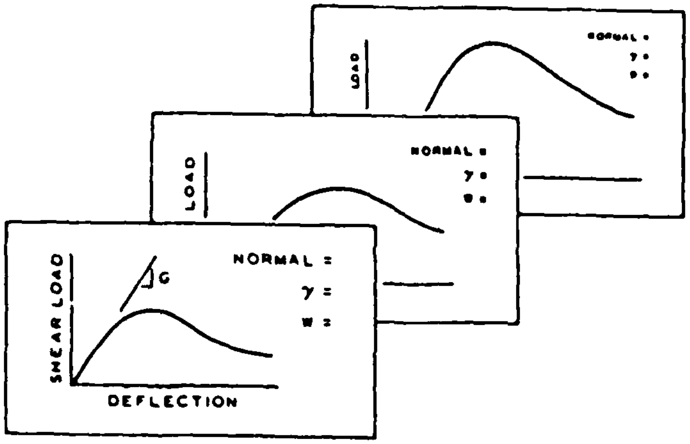


b. CONTAINER DURING PLACEMENT – ALTERNATELY PUSHED AND EXCESS MATERIAL SPOONED (OR TRIMMED) OUT

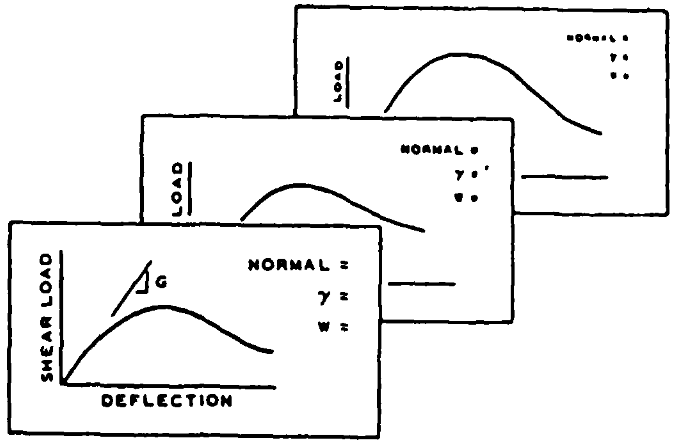


c. CONTAINER AT DESIRED DEPTH - OUTER HOLDER REMOVED AND READY FOR PLACEMENT OF DIRECT SHEAR DEVICE

Figure C.3. Cross sections through the specimen container showing various stages of placement.



DATA FROM A SERIES OF FAST TESTS



DATA FROM A SERIES OF SLOW TESTS

SITE	TEST	WET DENSITY	WATER CONTENT	DRY DENSITY	RATE	INITIAL MODULUS	NORMAL LOAD	NORMAL STRESS	AT PEAK SHEAR LOAD	AT PEAK SHEAR STRESS	AT PEAK DEFLECTION	REMARKS
A	S10S	108.0	16.1	93.0	0.002	100	8.5	0.64	34.9	2.18	0.064	GOOD TEST
A	S15S	109.0	15.0	94.7	0.002	190	90.0	5.6	121.9	7.63	0.071	
A	S110S	106.0	17.0	93.7	0.002	250	180.0	11.25	241.3	15.08	0.053	γ MAY BE QUEST
A	S10F	107.0	16.1	92.2	0.2	115						
A	S15F											

TABLE SUMMARIZING PERTINENT DATA FROM TESTS CONDUCTED AT A GIVEN SITE

Figure C.4. Presentation of test results obtained from the direct shear device.

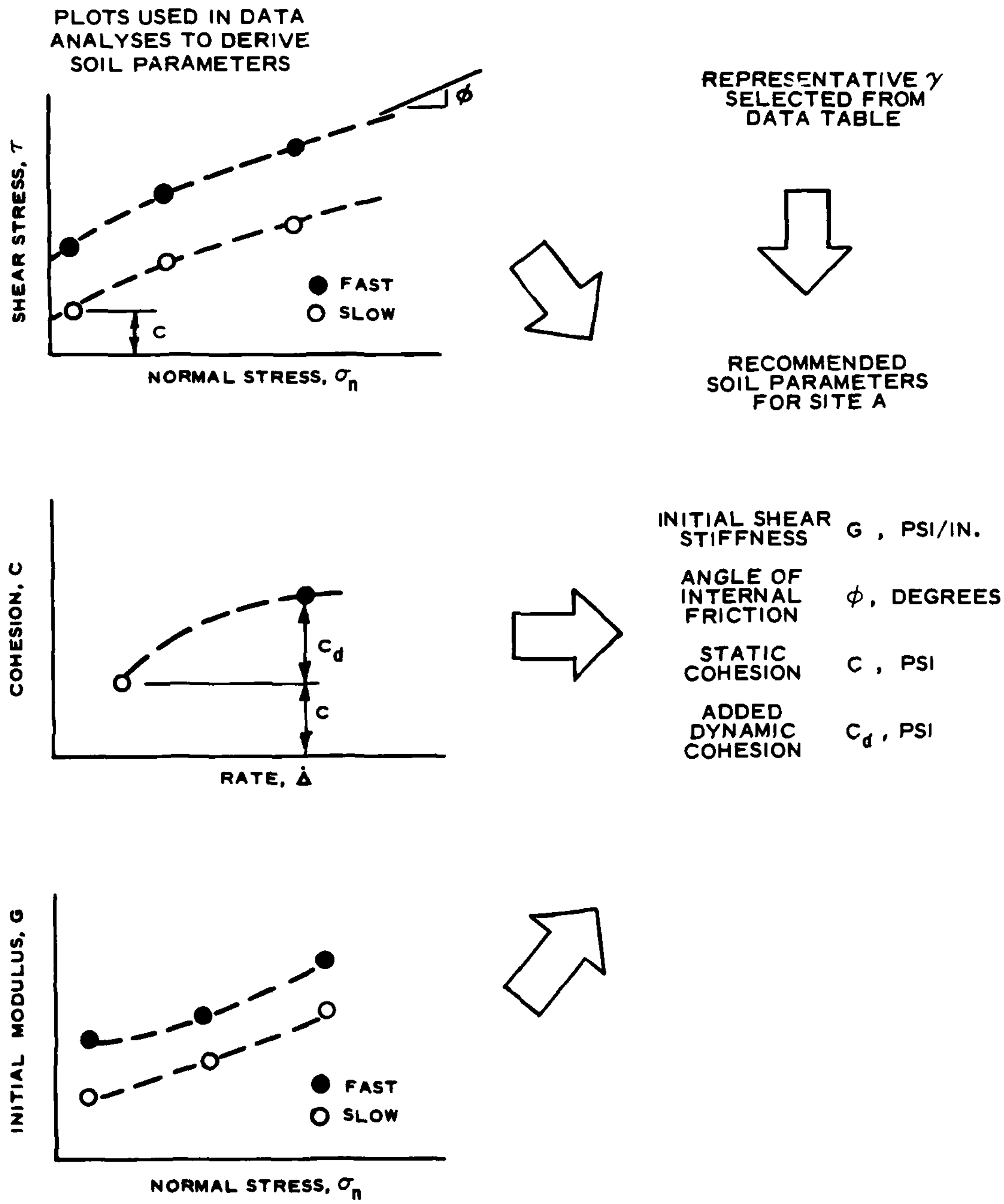


Figure C.5. Graphical presentation of the selection of recommended soil parameters based on the field data.

APPENDIX D: NOTATION

a_X	Forward acceleration of the vehicle
a_Y	Lateral acceleration of the vehicle
a_Φ	Acceleration of the vehicle along the Φ axis
a_Ψ	Acceleration of the vehicle along the Ψ axis
A	Material constant in failure envelope
b	B/L
B	Track tread (distance between the centerlines of the tracks)
c	CL^2/W
c_d	$C_d L^2/W$
c_X	C_X/L
C	Static cohesive component of shear strength
C_d	Added cohesive strength due to dynamic loading
C_X	Abscissa of the center of gravity of the vehicle
C_1	Slip radius of the outer track
C_2	Slip radius of the inner track
CG	Center of gravity of the vehicle
CI	WES cone index
CR	Center of rotation of the vehicle
d	D/L
D	Track width
$\tilde{D}$	Cone diameter
f_{CX}	F_{CX}/W
f_{CY}	F_{CY}/W
F_C	Inertial force
F_{CX}	Longitudinal component of inertial force
F_{CY}	Transverse component of inertial force
$\mathcal{f}$	Coefficient of rolling resistance
g	Acceleration due to gravity
G	Initial shear stiffness coefficient
h	H/L
H	Height of center of gravity

I_z	Mass moment of inertia of the vehicle about an axis passing through its center of gravity and parallel to the Z axis
IC_1	Center of slip rotation of the outer track
IC_2	Center of slip rotation of the inner track
ICR	Instantaneous center of rotation of the vehicle
ℓ	Distance between adjacent wheels
L	Length of the track in contact with the ground
$\tilde{L}$	Cone length
m	ML^2/W
M	Material constant in failure envelope
MI	Mobility index
n	NW/L^2
n_1	Vertical component of $\bar{T}_1$
n_2 or n_2'	Vertical component of $\bar{T}_2$
N	Material constant in failure envelope
$N_1(X)$	Contribution due to the outer track tension
$N_2(X)$	Contribution due to the inner track tension
p	P/L
P	Offset (distance from center of gravity to pivot point of vehicle)
PT	Total power = PT1 + PT2
PT1	Power required by the sprocket of the outer track
PT2	Power required by the sprocket of the inner track
PTD	Differential power = PT1 - PT2
PTT	Power required from the engine
$q_1(x)$	$dL^2Q_1(x)/W$
$q_2(x)$	$dL^2Q_2(x)/W$
$Q_1(X)$	Transverse component of shear stress along the outer track
$Q_2(X)$	Transverse component of shear stress along the inner track
$r_1(x)$	$dL^2R_1(x)/W$
$r_2(x)$	$dL^2R_2(x)/W$

$\tilde{R}$	Ordinate of the instantaneous center of rotation of the vehicle
R_o	Radius of trajectory of center of gravity of vehicle
R_s	Rolling resistance
$R_1(X)$	Normal stress under the outer track
$R_2(X)$	Normal stress under the inner track
R_I	Instantaneous radius of curvature
t	Time
$t_1(x)$	$dL^2T_1(x)/W$
$t_2(x)$	$dL^2T_2(x)/W$
$\bar{T}_1$	Track tension in the inner track
$\bar{T}_2$	Track tension in the outer track
$T_1(X)$	Longitudinal component of shear stress along the outer track
$T_2(X)$	Longitudinal component of shear stress along the inner track
v	Velocity of the vehicle
v_e, v_{ex}, v_{ey}	Instantaneous velocity of an arbitrary point of the hull and its components along X and Y coordinates
v_{s1}	Total slip velocity of the outer track
v_{s2}	Total slip velocity of the inner track
v_{sX1}	Longitudinal component of slip velocity of the outer track
v_{sX2}	Longitudinal component of slip velocity of the inner track
V_{sY1}	Transverse component of slip velocity of the outer track
v_{sY2}	Transverse component of slip velocity of the inner track
v_X	Longitudinal component of velocity of the vehicle
v_{X1}	Longitudinal component of velocity of the outer track
v_{X2}	Longitudinal component of velocity of the inner track
v_Y	Transverse component of velocity of the vehicle
v_Φ	Component of velocity of the vehicle along the Φ axis
v_Ψ	Component of velocity of the vehicle along the Ψ axis
VCI_1	Vehicle cone index for one pass
W	Weight of the vehicle

W_N	Component of weight of the vehicle normal to the terrain
W_T	Component of weight of the vehicle parallel to the terrain
x	X/L
X,Y,Z	Local coordinate system
y	Y/L
z	Z/L
$\tilde{Z}$	Depth of penetration of the cone
α	Side-slip angle
$\tilde{\alpha}$	Half of the apex angle of the cone
β	ℓ/L
γ	Density of the material
γ_1	Angle of slip direction of the outer track
γ_2	Angle of slip direction of the inner track
Δ	Shearing deformation
Δ_{I1}	Initial displacement of the outer track
Δ_{I2}	Initial displacement of the inner track
Δ_1	Shearing deformation of soil under the outer track
$\dot{\Delta}_1$	Time rate of shearing deformation
Δ_2	Shearing deformation of soil under the inner track
$\dot{\Delta}_2$	Time rate of shearing deformation
δ_1	Δ_1/L
$\dot{\delta}_1$	$\dot{\Delta}_1/L$
δ_2	Δ_2/L
$\dot{\delta}_2$	$\dot{\Delta}_2/L$
ϵ	Steering ratio
η	Angle of sloping terrain
θ	Directional angle
θ_a	Approach angle of the track envelope
θ_d	Departure angle of the track envelope
Λ	Material constant related to rate effect
λ	ΛL
μ	GL^3/W
ν	Angle related to initial position of the vehicle
ξ_1	C_1/L
ξ_2	C_2/L

σ	Normal stress
τ	Shear stress
τ_M	Maximum shear strength
Ø	Angle of internal friction
Ψ, Φ	Coordinate system fixed on level ground
ω	Yaw angle