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

by

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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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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:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
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 Jyozaki (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 Jyozaki 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 Jyozaki insofar as the kinematics of the vehicle are concerned. In contrast to the development by Kitano and Jyozaki (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:

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

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:

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

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:

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

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 associated

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,

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

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

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),

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

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

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 $\bar{T}_1$ and $\bar{T}_2$ are the track tensions in the outer and inner tracks, respectively. These forces can be obtained by integrating Equation 2.9. Thus,

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

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

$$n_1 = \bar{T}_1 \sin \theta_d \quad (2.13)$$

$$n_2 = \begin{cases} \bar{T}_2 \sin \theta_a & \text{if } \xi_2 \geq 0 \\ 0 & \text{if } \xi_2 < 0 \end{cases} \quad (2.14)$$

$$n'_2 = \begin{cases} -\bar{T}_2 \sin \theta_d & \text{if } \xi_2 < 0 \\ 0 & \text{if } \xi_2 \geq 0 \end{cases} \quad (2.15)$$

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):

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

and

$$\left. \begin{aligned} N_2(x) &= ax + m_I - \frac{2n_2}{d\ell} \left(x + \frac{1}{2} + \frac{\ell}{L}\right) & \text{for } \frac{1}{2} - \frac{\ell}{L} \leq x \leq \frac{1}{2} \\ N_2(x) &= ax + m_I & \text{for } \frac{\ell}{L} - \frac{1}{2} \leq x \leq \frac{1}{2} - \frac{\ell}{L} \\ N_2(x) &= ax + m_I + \frac{2n'_2}{d\ell} \left(x + \frac{1}{2} - \frac{\ell}{L}\right) & \text{for } -\frac{1}{2} \leq x \leq \frac{\ell}{L} - \frac{1}{2} \end{aligned} \right\} \quad (2.17)$$

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,

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

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

(2.19)

$$+ \frac{\ell}{L} - \frac{1}{2} \int_{-\frac{1}{2}}^{\frac{1}{2}} \frac{2n'_2}{d\ell} \left(x + \frac{1}{2} + \frac{\ell}{L}\right) dx = 0$$

and

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

(2.20)

$$+ \frac{1}{2} \int_{-\frac{1}{2}}^{\frac{1}{2}} \frac{2(n_1 + n'_2)}{d\ell} \left(x + \frac{1}{2} - \frac{\ell}{L}\right) \left(\frac{1}{2} + \frac{\ell}{L} - x\right) dx = 0$$

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

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

$$m_O = \frac{1}{dL} n_1 \quad (2.22)$$

$$m_I = \frac{1}{dL} (n_2 + n'_2) \quad (2.23)$$

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

$$N_1(x) = \frac{1}{dL} [(3 - 2\beta) (n_2 - n'_2 - n_1) x + n_1] \text{ for } \beta - \frac{1}{2} \leq x \leq \frac{1}{2}$$

$$N_1(x) = \frac{1}{dL} \left\{ \left[(3 - 2\beta) (n_2 - n'_2 - n_1) + \frac{2n_1}{\beta} \right] x + \left(\frac{1 - \beta}{\beta} \right)^2 n_1 \right\} \quad (2.24)$$

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

and

$$N_2(x) = \frac{1}{dL} \left\{ \left[(3 - 2\beta) (n_2 - n'_2 - n_1) - \frac{2n_2}{\beta} \right] x + \left(\frac{1 - \beta}{\beta} \right)^2 n_2 + n'_2 \right\}$$

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

$$N_2(x) = \frac{1}{dL} [(3 - 2\beta) (n_2 - n'_2 - n_1) x + n_2 + n'_2]$$

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

$$N_2(x) = \frac{1}{dL} \left\{ \left[(3 - 2\beta) (n_2 - n'_2 - n_1) + \frac{2n'_2}{\beta} \right] x + \left(\frac{1 - \beta}{\beta} \right)^2 n'_2 + n_2 \right\}$$

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

(2.25)

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

$$v = \sqrt{v_X^2 + v_Y^2} = \sqrt{v_\Psi^2 + v_\Phi^2} \quad (2.26)$$

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

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

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

$$\theta = \omega - \alpha, \quad \frac{d\theta}{dt} = \frac{d\omega}{dt} - \frac{d\alpha}{dt} \quad (2.28)$$

Substitution of Equation 2.27 into Equation 2.28 leads to

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

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

$$R_O = v / \frac{d\theta}{dt} = \frac{v^3}{v^2 \frac{d\omega}{dt} - v_X \frac{dv_Y}{dt} + v_Y \frac{dv_X}{dt}} \quad (2.30)$$

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

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

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)

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

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

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

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

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

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

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

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

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,

$$\epsilon = v_{X1}/v_{X2} \quad (2.37)$$

Substitution of Equations 2.32 and 2.37 into Equation 2.36 leads to

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

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

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

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

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

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

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 ϕ (i.e., $\frac{\Delta_{I1}}{L} = \frac{\Delta_{I2}}{L} = \phi$). The coefficient of rolling resistance ϕ 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

$$\left. \begin{aligned} v_\psi &= -v_X \cos \omega - v_Y \sin \omega \\ v_\phi &= v_X \sin \omega - v_Y \cos \omega \end{aligned} \right\} \quad (2.42)$$

The acceleration in ψ and ϕ direction, a_ψ and a_ϕ , can be written as

$$\left. \begin{aligned} a_\psi &= \frac{dv_\psi}{dt} \\ a_\phi &= \frac{dv_\phi}{dt} \end{aligned} \right\} \quad (2.43)$$

The forward and lateral accelerations, a_X and a_Y , can be written in terms of a_ψ and a_ϕ as

$$\left. \begin{aligned} a_X &= -a_\psi \cos \omega + a_\phi \sin \omega \\ a_Y &= -a_\psi \sin \omega - a_\phi \cos \omega \end{aligned} \right\} \quad (2.44)$$

Substitution of Equations 2.42 and 2.43 into Equation 2.44 leads to

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

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

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

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,

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

As stated above, the coefficient of rolling resistance $\int$ 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:

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

where¹

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

$$\begin{array}{ll} \text{Weight factor:} & \text{Less than 50,000 lb} = 1.0 \\ & 50,000 \text{ to } 69,999 \text{ lb} = 1.2 \\ & 70,000 \text{ to } 99,999 \text{ lb} = 1.4 \\ & 100,000 \text{ lb or greater} = 1.8 \end{array} \quad (2.50)$$

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

$$\begin{array}{ll} \text{Grouser factor:} & \text{Grousers less than 1.5 in. high} = 1.0 \\ & \text{Grousers more than 1.5 in. high} = 1.1 \end{array} \quad (2.52)$$

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

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

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

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

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

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:*

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

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 :

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

* In Reference 10, the rating cone index RCI rather than cone index CI is used to calculate ϕ . 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

$$CI = -C \cot \phi + \frac{2 \tan \tilde{\alpha} (1 + \sin \phi) G^{\tilde{m}}}{\left(\frac{\tilde{D}}{2} \gamma\right)^2 \tan^3 \phi} \left[\frac{3(\tan \tilde{\alpha} + \tan \phi)}{3 - \sin \phi} \right] \Omega \quad (2.60)$$

where

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

For granular materials $C = 0$ and Equation 2.60 reduces to

$$CI = \frac{2 \tan \tilde{\alpha} (1 + \sin \phi) G^{\tilde{m}}}{\left(\frac{\tilde{D}}{2} \gamma\right)^2 \tan^3 \phi} \left[\frac{3(\tan \tilde{\alpha} + \tan \phi)}{3 - \sin \phi} \right] \Omega \quad (2.61)$$

where

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

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

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

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

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

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:

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

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

$$\begin{aligned} & - \int_{-\frac{1}{2}}^{\frac{1}{2}} [q_1(x) + q_2(x)] (x - c_X) dx + \frac{b}{2} \int_{-\frac{1}{2}}^{\frac{1}{2}} [t_1(x) - t_2(x)] dx \\ & + \frac{b}{2} \int_{-\frac{1}{2}}^{\frac{1}{2}} [r_2(x) - r_1(x)] dx = \frac{I_z}{LW} \frac{d^2 \omega}{dt^2} \end{aligned} \quad (2.65)$$

where

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

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

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

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

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

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

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,

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

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,

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

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

$$\chi = \omega + \nu \quad (2.68)$$

where ν is a constant. The numerical value of ν depends on the initial position of the vehicle ($\nu = 0, 90, 180$, 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

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

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

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

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

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,

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

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

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

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

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

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

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

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

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:

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

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

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:

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

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

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

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

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 dw/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 $\epsilon(t)$ 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 $\epsilon(t)$ 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.

a. LOW SPEED

b. HIGH SPEED

Figure 2.7. Track tension at low and high speeds.

——— NORMAL STRESS DISTRIBUTION WITHOUT TRACK TENSION
 - - - - - NORMAL STRESS DISTRIBUTION WITH TRACK TENSION

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/sec².
- 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:

R0 = 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:

R0 = 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.
 FCX¹ = Forward acceleration, g's.
 FCY¹ = 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).


```

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,THETA1,THETA2,IZ,VCI1 = 18000.,105.,35.7,15.,90.,0.,0.,0.,30.,0.,0.

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

TO HAVE CODE COMPUTE CONE INDEX, INPUT CI=0.
TO HAVE CODE COMPUTE ROLLING RESISTANCE, INPUT SF=0.
INPUT CI,A,SH,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 GAMMA,Z, INPUT GAMMA=0.07,Z=6.
INPUT CL,DI,GAMMA,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,IV,HFAV = 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,THETA0,THETA0A,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(MPH) 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(I)
19000.0 105.0 35.7 15.0 90.0 0. 0. 0. 30.0 0. 20.9

CI A(Psi) SM(Psi) C(Psi) SM(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 0.050 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

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 R0 (TURNING RADIUS)

DU = 1.0(MPH) HPAU = 1000.0(MPH) TEST NO. = SAMPLE RUN FOR USER'S GUIDE

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WT(IN)	L(IN)	H(IN)	D(IN)	R(IN)	SL(IN)	CX(IN)	THETA0(DEG)	THETA1(DEG)	IZ(IN LB/SEC**2)	VC11
18000.0	105.0	35.7	15.0	90.0	0.	2.	0.	30.0	0.	20.9

CI	A(PST)	SM(PST)	C(PST)	SN(1/PST)	SK	CD(PST)	CLAMDA(SEC/IN)	PHI(DEG)	G(PST/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	R0 FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	WD DEG/SEC	FCX G	FCY G	FTE HP	FTS 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	0.29	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	0.29	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 MP 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
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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)

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

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        0.        20.9

CI      A(PST)  SM(PST)  C(PST)  SN(1/PST)  SXI  CD(PST)  CLAMDA(SEC/IN)  PHI(DEG)  G(PST/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.
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PT	F/L	E	RO FT	VEL MPH	VX1 MPH	VX2 MPH	VS1 MPH	VS2 MPH	WD DEG/SEC	FCX G	FCY G	PTE MP	PTS MP
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	39.29	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	19.59	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 R0 (TURNING RADIUS) ; FIXED V (VELOCITY)

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

WT(IN)  L(IN)  H(IN)  D(IN)  R(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.          20.9

C!      A(PST) SM(PST) C(PST) SN(1/PST) SXI  CD(PST) CLAMDA(SEC/IN)  PHI(DEG)  G(PST/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.
=====
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PT	P/L	E	R0 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	18.4
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	24.9
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

HFAV = 1000.0(MP)

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)	THETA(D)	THETA(D)	IZ(IN LB/SEC**2)	UCI1
18000.0	105.0	35.7	15.0	90.0	0.	0.	0.	30.0	92000.0	20.9

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

PT	T	P/L	E	RO	VEL	VX1	VX2	VS1	VS2	W	WD	FCX	FCY	PTE	PTS	DXT	DYT
	SEC			FT	MPH	MPH	MPH	MPH	MPH	DEG	DEG/SEC	G	G	HP	HP	FT	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	324.8	-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	21.2	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	11.6
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	13.7
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-R! (VELOCITY, TURNING RADIUS)
NOTE: THIS CASE COULD BE MODIFIED TO INPUT TRAJECTORY INSTEAD OF RI

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

HFAU = 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)  THETA(D)  THETA(D)  IZ(IN LBS/SEC**2)  VCI:
18000.0 105.0  35.7  15.0  90.0   0.   0.   0.   30.0  72000.0  20.9

CI  A(PHI)  SM(PHI)  C(PHI)  SM(1/PSI)  SXI  CD(PHI)  CLAMDA(SEC/IN)  PHI(DEG)  G(PHI/IN)  SF  ETA(DEG)  CH(1/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	-3.1	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	63.6
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 [5,0] STEERING RATIO, INITIAL VELOCITY = VARY V (VELOCITY)

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=====
DT = 0.2(SEC)  NP = 40          TEST NO. = SAMPLE RUN FOR USER'S GUIDE          01/22/84

HFAV = 335.0  VI = 25.0

WT(IN)  L(IN)  H(IN)  D(IN)  R(IN)  SL(IN)  CX(IN)  THETA0(DEG)  THETA4(DEG)  IZ(IN LB/SEC**2)  UCI1
18000.0  105.0  35.7  15.0  90.0  0.  0.  0.  30.0  92000.0  20.5

CI  A(PST)  SM(PST)  C(PST)  SM(1/PST)  SX1  CD(PST)  CLAMDA(SEC/IN)  PHI(DEG)  G(PST/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.
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=====
PT  T  P/L  E  RO  VEL  VX1  VX2  VS1  VS2  W  WD  FCX  FCY  FTE  PTS  DXT  DYT
SEC  FT  MPH  MPH  MPH  MPH  DEG  DEG/SEC  G  G  HP  HP  FT  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  -0.02  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  316.0  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  306.6  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 VY1,VX2 (TRACK VELOCITIES)

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=====
DT = 0.2(SEC)  MP = 40          TEST NO. = SAMPLE RUN FOR USER'S GUIDE          01/27/86
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)  THETA(D)  THETA(D)  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)  SM(Psi)  C(Psi)  SM(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	16.9
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	2.19	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)	VC11
18000.0	105.0	35.7	15.0	90.0	26.2	0.	30.0	30.0	0.	20.7

CI	A(PST)	SM(PST)	C(PST)	SM(1/PST)	SXI	CD(PST)	CLAMDA(SEC/IN)	PHI(DEG)	G(PST/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	PTC 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	49.3	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	191.9
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	227.3
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	248.1
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	510.1	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	594.7
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	0.99	0.14	97.7	0.32	1.76	582.3	531.6
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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(MPH) TEST NO. = SAMPLE RUN FOR USER'S GUIDE

01/22/86

WT(IN) L(IN) H(IN) D(IN) B(IN) SL(IN) CX(IN) THETA(D) THETA(D) IZ(IN LB/SEC**2) VC(1)
18000.0 105.0 35.7 15.0 90.0 0. 0. 0. 30.0 0. 20.9

C1 A(PST) SM(PST) C(PST) SM(1/PST) SX1 CD(PST) CLAMDA(SEC/IN) PHI(DEG) G(PST/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. 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	1.20	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	25.1	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	78.5	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	89.1
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	0.16	158.3	134.6
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	287.1
14	0.24	1.20	52.42	26.0	28.6	23.8	0.72	-0.32	41.7	0.03	0.86	367.8	318.8
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	450.9
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	597.5	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.

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APPENDIX A: PROGRAM LISTING

C		TRACK001
C	*****	TRACK002
C	*	TRACK003
C	* TVSTEER IS A MODEL USED FOR PREDICTING STEERING *	TRACK004
C	* PERFORMANCE OF HIGH-MOBILITY/AGILITY TRACKED VEHICLES *	TRACK005
C	* IN STEADY-STATE TURNING MOTION AND/OR TRANSIENT MOTION. *	TRACK006
C	*	TRACK007
C	*****	TRACK008
C		TRACK009
C	INPUT FOR TVSTEER	TRACK010
C	-----	TRACK011
C	TESTN -- TEST TITLE (40 CHARACTERS MAX)	TRACK012
C	IRUN -- RUNTYPE (0 = STEADY-STATE, 1 = TRANSIENT)	TRACK013
C		TRACK014
C	VEHICLE PARAMETERS	TRACK015
C	-----	TRACK016
C		TRACK017
C	WT -- VEHICLE WEIGHT (LB)	TRACK018
C	L -- CONTACT LENGTH OF TRACK (IN)	TRACK019
C	H -- HEIGHT OF THE CENTER OF GRAVITY (IN)	TRACK020
C	D -- TRACK WIDTH (IN)	TRACK021
C	B -- TRACK TREAD, DISTANCE BETWEEN CENTER LINES (IN)	TRACK022
C	SL -- DISTANCE BETWEEN CENTERS OF ADJACENT WHEELS (IN)	TRACK023
C	CX -- ABSCISSA FOR CENTER OF GRAVITY (IN)	TRACK024
C	THETAD -- DEPARTURE ANGLE OF TRACK ENVELOPE (DEG)	TRACK025
C	THETAA -- APPROACH ANGLE OF TRACK ENVELOPE (DEG)	TRACK026
C	IZ -- MASS MOMENT OF INERTIA (IN LB/SEC**2),	TRACK027
C	NOT APPLICABLE FOR STEADY STATE	TRACK028
C	VCI1 -- ONE PASS VEHICLE CONE INDEX	TRACK029
C	TO HAVE CODE COMPUTE VCI1,	TRACK030
C	THE FOLLOWING INPUT IS REQUIRED BY SUBROUTINE MIVCI	TRACK031
C		TRACK032
C	GH -- GROUSER HEIGHT (IN)	TRACK033
C	NB -- TOTAL NUMBER OF BOGIES ON TRACK	TRACK034
C	TSL -- TRACK SHOE LENGTH (IN)	TRACK035
C	HP -- HORSEPOWER	TRACK036
C	TRNT -- TRANSMISSION TYPE (0=MANUAL, 1=AUTOMATIC)	TRACK037
C		TRACK038
C		TRACK039
C	SOIL MODEL PARAMETERS	TRACK040
C	-----	TRACK041
C		TRACK042
C	CI -- WES CONE INDEX	TRACK043
C	TO HAVE CODE COMPUTE CI,	TRACK044
C	THE FOLLOWING INPUT IS REQUIRED BY SUBROUTINE CONE	TRACK045
C		TRACK046
C	CL -- CONE LENGTH (IN)	TRACK047
C	DI -- CONE DIAMETER (IN)	TRACK048
C	GAMA -- DENSITY (PSI/IN)	TRACK049
C	Z -- DEPTH (IN)	TRACK050
C		TRACK051

C	A	-- SHEAR STRENGTH OF SOIL (PSI)	TRACK052
C	SM	-- MATERIAL CONSTANT IN FAILURE ENVELOPE (PSI)	TRACK053
C	SN	-- MATERIAL CONSTANT IN FAILURE ENVELOPE (1/PSI)	TRACK054
C	SXI	-- TYPE OF SOIL MODEL (0 = NONLINEAR, 1 = LINEAR)	TRACK055
C	CD	-- ADDED COHESIVE STRENGTH DUE TO DYNAMIC LOADING (PSI)	TRACK056
C	CLAMDA	-- MATERIAL CONSTANT RELATED TO RATE EFFECT (SEC/IN)	TRACK057
C	PHI	-- ANGLE OF INTERNAL FRICTION (DEG)	TRACK058
C	G	-- SHEAR MODULUS (PSI/IN)	TRACK059
C	SF	-- ROLLING RESISTANCE (MAY BE COMPUTED BY CODE)	TRACK060
C	ETA	-- ANGLE OF SLOPING TERRAIN (DEG)	TRACK061
C	CHI	-- DIRECTIONAL ANGLE ON SLOPING TERRAIN (DEG)	TRACK062
C	C	-- COHESION (PSI), C = A-SM	TRACK063
C			TRACK064
C		-----	TRACK065
C		INPUT FOR STEADY	TRACK066
C		-----	TRACK067
C			TRACK068
C	ICASE	-- TYPE OF RUN	TRACK069
C	E	-- STEERING RATIO	TRACK070
C	DV	-- VELOCITY INCREMENT (MPH)	TRACK071
C	HPAV	-- AVAILABLE HORSEPOWER	TRACK072
C	RO	-- TURNING RADIUS (FT)	TRACK073
C	DE	-- STEERING RATIO INCREMENT	TRACK074
C	NP	-- NUMBER OF POINTS	TRACK075
C	DR	-- TURNING RADIUS INCREMENT (FT)	TRACK076
C			TRACK077
C		-----	TRACK078
C		INPUT FOR TRANS	TRACK079
C		-----	TRACK080
C			TRACK081
C	DT	-- TIME INCREMENT (SEC)	TRACK082
C	NP	-- NUMBER OF POINTS	TRACK083
C	IPRINT	-- PRINT SKIP INCREMENT	TRACK084
C	ICASE	-- TYPE OF RUN	TRACK085
C	HPAV	-- AVAILABLE HORSEPOWER	TRACK086
C	VI	-- INITAIL VELOCITY (MPH)	TRACK087
C	EP	-- ARRAY CONTAINING STEERING RATIO TIME HISTORY	TRACK088
C			TRACK089
C		DRIVER COEFFICIENTS	TRACK090
C		V1-V4, E1-E4, RI1-RI4, VX11-VX14, VX21-VX24	TRACK091
C			TRACK092
C		=====	TRACK093
C		OUTPUT	TRACK094
C		-----	TRACK095
C			TRACK096
C	PT	-- POINT NUMBER	TRACK097
C	T	-- TIME (SEC), NOT APPLICABLE FOR STEADY-STATE	TRACK098
C	P/L	-- OFFSET	TRACK099
C	E	-- STEERING RATIO	TRACK100
C	RO	-- RADIUS OF TRAJECTORY AT CENTER OF GRAVITY (FT)	TRACK101
C	VEL	-- VEHICLE VELOCITY (MPH)	TRACK102
C	VX1	-- OUTER TRACK VELOCITY (MPH)	TRACK103
C	VX2	-- INNER TRACK VELOCITY (MPH)	TRACK104
C	VS1	-- OUTER TRACK SLIP VELOCITY (MPH)	TRACK105
C	VS2	-- INNER TRACK SLIP VELOCITY (MPH)	TRACK106
C	W	-- YAW ANGLE (DEG), NOT APPLICABLE FOR STEADY-STATE	TRACK107

C	WD -- YAW RATE (DEG/SEC)	TRACK108
C	FCX -- LONGITUDINAL ACCELERATION (G)	TRACK109
C	FCY -- LATERAL ACCELERATION (G)	TRACK110
C	PTE -- POWER REQUIRED FROM ENGINE (HP)	TRACK111
C	PTS -- POWER REQUIRED AT SPROCKET (HP)	TRACK112
C	DXT -- ABSCISSA OF TRAJECTORY (FT),	TRACK113
C	NOT APPLICABLE FOR STEADY-STATE	TRACK114
C	DYT -- ORDINATE OF TRAJECTORY (FT),	TRACK115
C	NOT APPLICABLE FOR STEADY-STATE	TRACK116
C	PT1 -- POWER REQUIRED BY SPROCKET OF OUTER TRACK (HP)	TRACK117
C	PT2 -- POWER REQUIRED BY SPROCKET OF INNER TRACK (HP)	TRACK118
C	PT1 AND PT2 ARE NOT TABULATED	TRACK119
C	VX -- LONGITUDINAL COMPONENT OF VEHICLE VELOCITY (MPH)	TRACK120
C	VY -- LATERAL COMPONENT OF VEHICLE VELOCITY (MPH)	TRACK121
C	VX AND VY ARE NOT TABULATED	TRACK122
C	=====	TRACK123
C	=====	TRACK124
C	PARAMETER (N2 = 100)	TRACK125
	REAL L,IZ	TRACK126
	CHARACTER TESTN*40,DATE*8	TRACK127
	DATA GRAV,DRAD,VMP / 386.4, 0.017453293, 0.056818182 /	TRACK128
	DATA MPR,RDEG / 0040075040021, 57.29578 /	TRACK129
C	COMMON /ARRAYS/ TP(N2),VXF(N2),VYP(N2),FCXP(N2),FCYP(N2),	TRACK130
	& VSX1P(N2),VSX2P(N2),ROP(N2),PTEP(N2),PTSP(N2),	TRACK131
	& DXTP(N2),DYTP(N2),WDP(N2),WP(N2),VX1P(N2),	TRACK132
	& VX2P(N2),EP(N2),VF(N2),PF(N2),PT1P(N2),PT2P(N2)	TRACK133
	COMMON /INOUT / E,VX1,VX2,V,RIOL,LOGRE,LUX	TRACK134
	COMMON /IN / DTIM1,DTIM2,WPRV,WDPV,VXPRV,VYPRV,TESTN,DATE	TRACK135
	COMMON /VPARAM/ WT,L,H,D,B,SL,CX,THETAA,THETAD,IZ,VCI1	TRACK136
	COMMON /SPARAM/ CI,A,SM,SN,C,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI	TRACK137
	COMMON /OUT / FCX,FCY,VSX1,VSX2,PTE,PTS,WD,W,VX,VY,	TRACK138
	& P,Z1,Z2,IDIR,VXD,VYD,PT1,PT2	TRACK139
	COMMON /MISC / GRAV,DRAD,VMP,RDEG	TRACK140
C		TRACK141
C	=====	TRACK142
C	THESE ARE CALLS TO SYSTEM DEPENDENT SUBROUTINES	TRACK143
C		TRACK144
	CALL FPARAM(3,MPR)	TRACK145
	CALL FPARAM(1,132)	TRACK146
	CALL PTIME(PTI)	TRACK147
	CALL DATIM(DATE,TIM)	TRACK148
C		TRACK149
C	END SYSTEM DEPENDENT CALLS	TRACK150
C	=====	TRACK151
C		TRACK152
	PRINT *, 'INPUT TEST NO. (UP TO 40 CHARACTERS)'	TRACK153
	READ 240, TESTN	TRACK154
	PRINT *,	TRACK155
	PRINT *, 'TO HAVE CODE COMPUTE VCI1, INPUT VCI1=0.'	TRACK156
	PRINT *, 'INPUT WT,L,H,D,B,SL,CX,THETAD,THETAA,IZ,VCI1'	TRACK157
	READ *, WT,L,H,D,B,SL,CX,THETAD,THETAA,IZ,VCI1	TRACK158
	PRINT *,	TRACK159
	IF (VCI1 .LE. 0.) CALL MIVCI	TRACK160
C		TRACK161
		TRACK162
		TRACK163

PRINT *, 'TO HAVE CODE COMPUTE CONE INDEX, INPUT CI=0.'	TRACK164
PRINT *, 'TO HAVE CODE COMPUTE ROLLING RESISTANCE, INPUT SF=0.'	TRACK165
PRINT *, 'INPUT CI,A,SM,SN,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI'	TRACK166
READ *, CI,A,SM,SN,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI	TRACK167
C	TRACK168
C = A - SM	TRACK169
IF (SXI .LT. 1.) C = 0.	TRACK170
C	TRACK171
IF (CI .LE. 0.) CALL CONE	TRACK172
IF (SF .LE. 0.) SF = .045 + (2.3075/(CI-VCI1+6.5))	TRACK173
C	TRACK174
PRINT *,	TRACK175
PRINT *, 'INPUT RUNTYPE : '	TRACK176
PRINT *, ' FOR STEADY-STATE RUN, INPUT 0'	TRACK177
PRINT *, ' FOR TRANSIENT RUN, INPUT 1'	TRACK178
PRINT *, 'INPUT YOUR CHOICE'	TRACK179
READ *, IRUN	TRACK180
IF (IRUN .EQ. 0) CALL STEADY	TRACK181
IF (IRUN .EQ. 1) CALL TRANS	TRACK182
C	TRACK183
C	TRACK184
C	TRACK185
CALL PTIME(PTU)	TRACK186
PTU = (PTU-PTI)*60	TRACK187
PRINT 250, PTU	TRACK188
PRINT 246	TRACK189
C	TRACK190
STOP	TRACK191
C	TRACK192
C	TRACK193
240 FORMAT(A40)	TRACK194
246 FORMAT(1H1)	TRACK195
250 FORMAT(/, ' PROCESSOR TIME (CPU-MIN) = ',1PE13.5)	TRACK196
C	TRACK197
END	TRACK198
C	STEAD001
C	STEAD002
C	STEAD003
C	STEAD004
C	STEAD005
C	STEAD006
C	STEAD007
C	STEAD008
C	STEAD009
C	STEAD010
C	STEAD011
C	STEAD012
C	STEAD013
C	STEAD014
C	STEAD015
C	STEAD016
C	STEAD017
C	STEAD018
C	STEAD019
C	STEAD020
C	STEAD021

COMMON /INOUT / E,VX1,VX2,V,RIOL,LOGRE,LVX	STEAD022
COMMON /IN / DTIM1,DTIM2,WPRV,WDPV,VXPRV,VYPRV,TESTN,DATE	STEAD023
COMMON /VPARAM/ WT,L,H,D,B,SL,CX,THETAA,THETAD,IZ,VC11	STEAD024
COMMON /SPARAM/ CI,A,SM,SN,C,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI	STEAD025
COMMON /OUT / FCX,FCY,VSX1,VSX2,PTE,PTS,WD,W,VX,VY,	STEAD026
& P,Z1,Z2,IDIR,VXD,VYD,PT1,PT2	STEAD027
COMMON /MISC / GRAV,DRAD,VMP,RDEG	STEAD028
C	STEAD029
PRINT *,	STEAD030
PRINT *, 'INPUT CASE: 1,2,3,4, OR ? '	STEAD031
READ *, INPUT	STEAD032
IF (INPUT .EQ. 1H?) GO TO 900	STEAD033
DECODE(INPUT,VFMT) ICASE	STEAD034
IF (ICASE.GE.1 .AND. ICASE.LE.4) GO TO 915	STEAD035
900 PRINT 910	STEAD036
PRINT 245, LFMT	STEAD037
PRINT 916	STEAD038
READ *, ICASE	STEAD039
910 FORMAT(' CASE SELECTIONS:')	STEAD040
DATA LFMT /	STEAD041
& 64H CASE [1].....VARY V (VELOCITY) ;	STEAD042
& INPUT E (STEERING RATIO) ,	STEAD043
& 64H CASE [2].....VARY V (VELOCITY) ;	STEAD044
& INPUT R0 (TURNING RADIUS),	STEAD045
& 64H CASE [3]....VARY E (STEERING RATIO) ;	STEAD046
& FIXED V (VELOCITY) ,	STEAD047
& 64H CASE [4]...VARY R0 (TURNING RADIUS) ;	STEAD048
& FIXED V (VELOCITY) /	STEAD049
916 FORMAT(' INPUT YOUR CHOICE: ')	STEAD050
915 PRINT *,	STEAD051
C	STEAD052
IF (ICASE .GT. 2) GO TO 5	STEAD053
IF (ICASE .EQ. 2) GO TO 4	STEAD054
C	STEAD055
PRINT *, 'INPUT E,DV,HPAV '	STEAD056
READ *, E,DV,HPAV	STEAD057
LOGRE = .FALSE.	STEAD058
GO TO 75	STEAD059
C	STEAD060
4 CONTINUE	STEAD061
LOGRE = .TRUE.	STEAD062
PRINT *, 'INPUT R0,DV,HPAV '	STEAD063
READ *, R0,DV,HPAV	STEAD064
RI = R0	STEAD065
RIOL = 12.*RI/L	STEAD066
C	STEAD067
75 CONTINUE	STEAD068
V = 0.	STEAD069
NF = N4	STEAD070
IHP = 0	STEAD071
IF (HPAV .LE. 0.) IHP = 1	STEAD072
GO TO 7	STEAD073
C	STEAD074
5 CONTINUE	STEAD075
DV = 0.	STEAD076
IHP = 1	STEAD077

IF (ICASE .EQ. 4) GO TO 6	STEAD078
PRINT 165, N2	STEAD079
PRINT *, 'INPUT V,E,DE,NP'	STEAD080
READ *, V,E,DE,NP	STEAD081
LOGRE = .FALSE.	STEAD082
DR = 0.	STEAD083
GO TO 7	STEAD084
C	STEAD085
6 CONTINUE	STEAD086
PRINT 165, N4	STEAD087
PRINT *, 'INPUT V,R0,DR,NP'	STEAD088
READ *, V,R0,DR,NP	STEAD089
LOGRE = .TRUE.	STEAD090
DE = 0.	STEAD091
RI = R0	STEAD092
RIOL = 12.*RI/L	STEAD093
C	STEAD094
7 CONTINUE	STEAD095
PRINT 246	STEAD096
PRINT 250	STEAD097
PRINT 245, LFMT(ICASE)	STEAD098
PRINT 207	STEAD099
IF (ICASE.EQ.1 .OR. ICASE.EQ.2)	STEAD100
8 PRINT 202, DV,HPAV,TESTN,DATE	STEAD101
IF (ICASE .EQ. 3) PRINT 203, DE,NP,TESTN,DATE	STEAD102
IF (ICASE .EQ. 4) PRINT 204, DR,NP,TESTN,DATE	STEAD103
PRINT 170	STEAD104
PRINT 180, WT,L,H,D,B,SL,CX,THETAD,THETAA,IZ,VCI1	STEAD105
PRINT *	STEAD106
PRINT 190	STEAD107
PRINT 200, CI,A,SM,C,SN,IFIX(SXI),CD,	STEAD108
8 CLAMDA,PHI,G,SF,ETA,CHI	STEAD109
PRINT 207	STEAD110
PRINT 205	STEAD111
PRINT 209	STEAD112
C	STEAD113
LSTB = .FALSE.	STEAD114
V = V*17.6	STEAD115
DV = DV*17.6	STEAD116
DR = 12.*DR/L	STEAD117
DTIM1 = 0.	STEAD118
WDPRV = 0.	STEAD119
VXPRV = 0.	STEAD120
VYPRV = 0.	STEAD121
LUX = .FALSE.	STEAD122
C	STEAD123
C	STEAD124
C	STEAD125
C	STEAD126
C	STEAD127
DO 400 II = 1,NP	STEAD128
C	STEAD129
11 CALL AGIL(\$115)	STEAD130
C	STEAD131
IF(II,EQ.1 .OR. ICASE.GT.2) GO TO 390	STEAD132
IF((P-PP(II-1)) .GT. 0.1) GO TO 115	STEAD133

C	390 CONTINUE	STEAD134
	PP(II) = P	STEAD135
	Z1P = Z1	STEAD136
	Z2P = Z2	STEAD137
	VP(II) = V*VMP	STEAD138
	ROP(II) = RIOL*L/12.	STEAD139
	EP(II) = E	STEAD140
	IF (E .LT. 1.) EP(II) = -1./E	STEAD141
	V = V+DV	STEAD142
	VSX1P(II) = VSX1*VMP	STEAD143
	VSX2P(II) = VSX2*VMP	STEAD144
	VX2P(II) = VX2*VMP	STEAD145
	VX1P(II) = VX1*VMP	STEAD146
	WDP(II) = WD*RDEG	STEAD147
	PTEP(II) = PTE	STEAD148
	PTSP(II) = PTS	STEAD149
	PT1P(II) = PT1	STEAD150
	PT2P(II) = PT2	STEAD151
	FCXP(II) = FCX	STEAD152
	FCYP(II) = FCY	STEAD153
	PRINT 14, II, PP(II), EP(II), ROP(II), VP(II), VX1P(II), VX2P(II),	STEAD154
	& VSX1P(II), VSX2P(II), WDP(II), FCXP(II), FCYP(II),	STEAD155
	& PTEP(II), PTSP(II)	STEAD156
C		STEAD157
	392 CONTINUE	STEAD158
	IF (ICASE .GT. 2) GO TO 160	STEAD159
	IF (P.GT.0.555 .AND. LSTB) GO TO 404	STEAD160
C		STEAD161
C	CALCULATES MAXIMUM POWER	STEAD162
C		STEAD163
	IF(IHP) 393,393,396	STEAD164
	393 IF(PTEP(II)-HPAV) 396,394,394	STEAD165
C		STEAD166
	394 PFC = (PTEP(II)-HPAV) / (PTEP(II)-PTEP(II-1))	STEAD167
	IHP = 1	STEAD168
	ROPF = ROP(II) - (ROP(II)-ROP(II-1))*PFC	STEAD169
	VPF = VP(II) - (VP(II)-VP(II-1))*PFC	STEAD170
	VX1F = VX1P(II) - (VX1P(II)-VX1P(II-1))*PFC	STEAD171
	VX2F = VX2P(II) - (VX2P(II)-VX2P(II-1))*PFC	STEAD172
	VSX1F = VSX1P(II) - (VSX1P(II)-VSX1P(II-1))*PFC	STEAD173
	VSX2F = VSX2P(II) - (VSX2P(II)-VSX2P(II-1))*PFC	STEAD174
	PTEF = PTEP(II) - (PTEP(II)-PTEP(II-1))*PFC	STEAD175
	PTSF = PTSP(II) - (PTSP(II)-PTSP(II-1))*PFC	STEAD176
	FCXF = FCXP(II) - (FCXP(II)-FCXP(II-1))*PFC	STEAD177
	FCYF = FCYP(II) - (FCYP(II)-FCYP(II-1))*PFC	STEAD178
	PF = PP(II) - (PP(II)-PP(II-1))*PFC	STEAD179
	EF = EP(II) - (EP(II)-EP(II-1))*PFC	STEAD180
	WDF = WDP(II) - (WDP(II)-WDP(II-1))*PFC	STEAD181
	PRINT *, 'POWER LIMIT'	STEAD182
	PRINT 14, II, PF, EF, ROPF, VPF, VX1F, VX2F, VSX1F, VSX2F,	STEAD183
	& WDF, FCXF, FCYF, PTEF, PTSF	STEAD184
	PRINT *,	STEAD185
C		STEAD186
	396 CONTINUE	STEAD187
	IF(LSTB) GO TO 400	STEAD188
		STEAD189

IF(II .EQ. 1) GO TO 400	STEAD190
IF(P-.5) 397,462,460	STEAD191
397 IF((VSX2P(II)-VSX2P(II-1))/DV/VMP-1.) 398,398,464	STEAD192
398 IF((VSX1P(II)-VSX1P(II-1))/DV/VMP-1.) 400,400,466	STEAD193
C	STEAD194
160 CONTINUE	STEAD195
E = E+DE	STEAD196
RIOL = RIOL - DR	STEAD197
C	STEAD198
400 CONTINUE	STEAD199
C	STEAD200
C	STEAD201
IF (ICASE.GT.2) GO TO 480	STEAD202
PRINT 165, N4	STEAD203
IF (.NOT. LSTB) GO TO 480	STEAD204
C	STEAD205
404 PRINT 207	STEAD206
PRINT *, ' STABILITY LIMIT ON',LAB2	STEAD207
PRINT *,	STEAD208
PRINT 14, N3,PS,ES,ROPS,VPS,VX1S,VX2S,VSX1S,	STEAD209
& VSX2S,WDS,FCXS,FCYS,PTES,PTSS	STEAD210
GO TO 99	STEAD211
C	STEAD212
460 N3 = II	STEAD213
PDC = (PP(N3)-.5) / (PP(N3)-PP(N3-1))	STEAD214
IF(P .GT. 0.555) LSTB = .TRUE.	STEAD215
GO TO 463	STEAD216
C	STEAD217
462 N3 = II	STEAD218
PDC = 0.	STEAD219
463 LAB2 = ' P '	STEAD220
GO TO 468	STEAD221
C	STEAD222
464 N3 = II-1	STEAD223
PDC = 0.	STEAD224
LAB2 = ' VS2'	STEAD225
GO TO 468	STEAD226
C	STEAD227
466 N3 = II-1	STEAD228
PDC = 0.	STEAD229
LAB2 = ' VS1'	STEAD230
GO TO 468	STEAD231
C	STEAD232
467 N3 = II - 1	STEAD233
LSTB = .TRUE.	STEAD234
PDC = 0.	STEAD235
LAB2 = ' DV '	STEAD236
C	STEAD237
468 CONTINUE	STEAD238
ROPS = ROP(N3) - (ROP(N3)-ROP(N3-1))*PDC	STEAD239
VPS = VP(N3) - (VP(N3)-VP(N3-1))*PDC	STEAD240
VSX1S = VSX1P(N3) - (VSX1P(N3)-VSX1P(N3-1))*PDC	STEAD241
VSX2S = VSX2P(N3) - (VSX2P(N3)-VSX2P(N3-1))*PDC	STEAD242
VX1S = VX1P(N3) - (VX1P(N3)-VX1P(N3-1))*PDC	STEAD243
VX2S = VX2P(N3) - (VX2P(N3)-VX2P(N3-1))*PDC	STEAD244
PTES = PTEP(N3) - (PTEP(N3)-PTEP(N3-1))*PDC	STEAD245

PTSS = PTSP(N3) - (PTSP(N3)-PTSP(N3-1))*PDC	STEAD246
FCXS = FCXP(N3) - (FCXP(N3)-FCXP(N3-1))*PDC	STEAD247
FCYS = FCYP(N3) - (FCYP(N3)-FCYP(N3-1))*PDC	STEAD248
PS = PP(N3) - (PP(N3)-PP(N3-1))*PDC	STEAD249
ES = EP(N3) - (EP(N3)-EP(N3-1))*PDC	STEAD250
WDS = WDP(N3) - (WDP(N3)-WDP(N3-1))*PDC	STEAD251
IF(LSTB) GO TO 404	STEAD252
LSTB = .TRUE.	STEAD253
GO TO 400	STEAD254
C	STEAD255
115 IF(II.EQ.1 .OR. ICASE.GT.2) GO TO 119	STEAD256
IF(DV .LT. 1.) GO TO 467	STEAD257
DV = DV/2.	STEAD258
V = V - DV	STEAD259
P = PP(II-1)	STEAD260
Z1 = Z1P	STEAD261
Z2 = Z2P	STEAD262
GO TO 11	STEAD263
C	STEAD264
119 PRINT *, 'THE VEHICLE WILL NOT GO IN THIS PARTICULAR SOIL.'	STEAD265
GO TO 99	STEAD266
C	STEAD267
480 PRINT 207	STEAD268
C	STEAD269
99 RETURN	STEAD270
C	STEAD271
=====	STEAD272
C	STEAD273
14 FORMAT(13X,I3,1X,F6.2,F7.2,F10.2,1X,F5.1,2X,F5.1,1X,F5.1,2F7.2,	STEAD274
& F7.1,2F7.2,2F7.1)	STEAD275
165 FORMAT(' MAXIMUM POINTS NP SET TO',I5)	STEAD276
170 FORMAT(2X,'WT(IN)',3X,'L(IN)',3X,'H(IN)',2X,'D(IN)',4X,	STEAD277
& 'B(IN)',3X,'SL(IN)',1X,'CX(IN)',4X,'THETAD(DEG)',3X,	STEAD278
& 'THETAA(DEG)',1X,'IZ(IN LB/SEC**2)',3X,'VCI1')	STEAD279
180 FORMAT(1X,F8.1,2X,F5.1,2(3X,F4.1),4X,F5.1,5X,F4.1,2X,F5.1,	STEAD280
& 7X,F5.1,10X,F5.1,7X,F8.1,8X,F4.1)	STEAD281
190 FORMAT(4X,'CI',5X,'A(PSI)',1X,'SM(PSI)',1X,'C(PSI)',1X,	STEAD282
& 'SN(1/PSI)',2X,'SXI',3X,'CD(PSI)',1X	STEAD283
& 'CLAMDA(SEC/IN)',4X,'PHI(DEG)',2X,'G(PSI/IN)',2X,	STEAD284
& 'SF',4X,'ETA(DEG)',1X,'CHI(DEG)')	STEAD285
200 FORMAT(2X,F5.1,1X,2(3X,F5.1),3X,F4.1,3X,F6.4,5X,I1,5X,F5.1,	STEAD286
& 6X,F6.3,10X,F4.1,6X,F5.1,3X,F5.3,4X,F4.1,4X,F5.1)	STEAD287
202 FORMAT(2X,'DV = ',F6.1,'(MPH)',1X,'HPAV = ',F6.1,'(HP)',	STEAD288
& 3X,'TEST NO. = ',A40,3X,A8,3X,//)	STEAD289
203 FORMAT(2X,'DE = ',F6.2,1X,'NF = ',I3,	STEAD290
& 6X,'TEST NO. = ',A40,3X,A8,3X,//)	STEAD291
204 FORMAT(2X,'DR = ',F6.1,'(FT)',1X,'NF = ',I3,	STEAD292
& 6X,'TEST NO. = ',A40,3X,A8,3X,//)	STEAD293
205 FORMAT(14X,'PT',4X,'P/L',4X,'E',6X,'R0',7X,'VEL',4X,'VX1',	STEAD294
& 3X,'VX2',3X,'VS1',4X,'VS2',4X,'WD',5X,'FCX',	STEAD295
& 4X,'FCY',4X,'PTE',4X,'PTS')	STEAD296
207 FORMAT(/,1X,119(1H=),//)	STEAD297
209 FORMAT(34X,'FT',7X,'MPH',4X,2('MPH',3X),'MPH',4X,'MPH',2X,	STEAD298
& 'DEG/SEC',3X,'G',6X,'G',1X,2(5X,'HP'),//)	STEAD299
245 FORMAT(28X,A64)	STEAD300
246 FORMAT(1H1)	STEAD301
250 FORMAT(46X,'STEADY-STATE TURNING MOTION')	

C		STEAD302
	END	STEAD303
C		TRANS001
C	*****	TRANS002
C	*	TRANS003
C	* THIS SUBROUTINE IS FOR TRANSIENT MOTION. *	TRANS004
C	*	TRANS005
C	*****	TRANS006
C		TRANS007
	SUBROUTINE TRANS	TRANS008
C		TRANS009
	PARAMETER (N2 = 100)	TRANS010
	REAL L,IZ	TRANS011
	LOGICAL LOGRE,LVX,LSTB,LOGV	TRANS012
C		TRANS013
	CHARACTER TESTN*40,DATE*8	TRANS014
	CHARACTER INPUT,VFMT*3,LFMT*76(4)	TRANS015
	DATA VFMT /3H(V)/	TRANS016
C		TRANS017
	COMMON /ARRAYS/ TP(N2),VXF(N2),VYP(N2),FCXP(N2),FCYP(N2),	TRANS018
&	VSX1P(N2),VSX2P(N2),ROP(N2),PTEP(N2),PTSP(N2),	TRANS019
&	DXTP(N2),DYTP(N2),WDP(N2),WP(N2),VX1P(N2),	TRANS020
&	VX2P(N2),EP(N2),VP(N2),PP(N2),PT1P(N2),PT2P(N2)	TRANS021
	COMMON /INOUT / E,VX1,VX2,V,RIOL,LOGRE,LVX	TRANS022
	COMMON /IN / DTIM1,DTIM2,WPRV,WDPV,VXPRV,VYPRV,TESTN,DATE	TRANS023
	COMMON /VPARAM/ WT,L,H,D,B,SL,CX,THETAA,THETAD,IZ,VC11	TRANS024
	COMMON /SPARAM/ CI,A,SM,SN,C,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI	TRANS025
	COMMON /OUT / FCX,FCY,VSX1,VSX2,PTE,PTS,WD,W,VX,VY,	TRANS026
&	P,Z1,Z2,IDIR,VXD,VYD,PT1,PT2	TRANS027
	COMMON /MISC / GRAV,DRAD,VMP,RDEG	TRANS028
C		TRANS029
C	=====	TRANS030
C	THE DIGITIZED TIME HISTORY (FOR CASE 3) AND THE FUNCTION	TRANS031
C	(FOR CASES 1,2, AND 4) USED FOR SAMPLE PROBLEMS	TRANS032
C		TRANS033
	DATA EP /10*1.1,10*1.0,10*-1.1,70*1./	TRANS034
C		TRANS035
	EXPS(X) = EXP(AMAX1(X,-88.))	TRANS036
	FT(T,X1,X2,X3,X4) =	TRANS037
&	X1 + X2*(EXPS(-X3*T) + X3*T*EXPS(-X4*T) - 1.)	TRANS038
C		TRANS039
C		TRANS040
C	NOTE: TO DRIVE THE MODEL, THE ABOVE MAY BE REPLACED BY ANY	TRANS041
C	DIGITIZED TIME HISTORY AND/OR ANY FUNCTION	TRANS042
C	=====	TRANS043
C		TRANS044
	PRINT *,	TRANS045
	PRINT 165, N2	TRANS046
	PRINT *, 'INPUT DT,NP,IPRINT'	TRANS047
	READ *, DT,NP,IPRINT	TRANS048
C		TRANS049
	PRINT *,	TRANS050
	PRINT *, 'INPUT CASE: 1,2,3,4, OR ? '	TRANS051
	READ *, INPUT	TRANS052
	IF (INPUT .EQ. 1H?) GO TO 900	TRANS053
	IF (INPUT .EQ. 1H1) ICASE = 1	TRANS054

IF (INPUT .EQ. 1H2) ICASE = 2	TRANS055
IF (INPUT .EQ. 1H3) ICASE = 3	TRANS056
IF (INPUT .EQ. 1H4) ICASE = 4	TRANS057
IF (ICASE.GE.1 .AND. ICASE.LE.4) GO TO 915	TRANS058
900 PRINT 910	TRANS059
PRINT 245, LFMT	TRANS060
PRINT 916	TRANS061
READ *, ICASE	TRANS062
910 FORMAT(/' CASE SELECTIONS:')	TRANS063
DATA LFMT /	TRANS064
& 54H CASE [1].....INPUT V,E (VELOCITY,STEERING RATIO) ,	TRANS065
& 54H CASE [2].....INPUT V,RI (VELOCITY,TURNING RADIUS) ,	TRANS066
& 76H CASE [3]...INPUT E,VI (STEERING RATIO,INITIAL VELOCITY) ;	TRANS067
& VARY V (VELOCITY) ,	TRANS068
& 54H CASE [4].....INPUT VX1,VX2 (TRACK VELOCITIES) /	TRANS069
916 FORMAT('INPUT YOUR CHOICE: ')	TRANS070
915 PRINT *,	TRANS071
C	TRANS072
LOGRE = .FALSE.	TRANS073
LUX = .FALSE.	TRANS074
IF (ICASE .GT. 2) GO TO 3	TRANS075
C	TRANS076
PRINT *, 'INPUT HPAV,V1,V2,V3,V4'	TRANS077
READ *, HPAV,V1,V2,V3,V4	TRANS078
VI = V1	TRANS079
IF (ICASE .EQ. 2) GO TO 2	TRANS080
PRINT *, 'INPUT E1,E2,E3,E4'	TRANS081
READ *, E1,E2,E3,E4	TRANS082
GO TO 7	TRANS083
C	TRANS084
C	TRANS085
C	TRANS086
C	TRANS087
2 PRINT *, 'INPUT RI1,RI2,RI3,RI4'	TRANS088
READ *, RI1,RI2,RI3,RI4	TRANS089
LOGRE = .TRUE.	TRANS090
GO TO 7	TRANS091
C	TRANS092
3 IF (ICASE .EQ. 4) GO TO 4	TRANS093
PRINT *, 'INPUT HPAV,VI'	TRANS094
READ *, HPAV,VI	TRANS095
GO TO 7	TRANS096
C	TRANS097
4 LUX = .TRUE.	TRANS098
PRINT *, 'INPUT VX11,VX12,VX13,VX14'	TRANS099
READ *, VX11,VX12,VX13,VX14	TRANS100
PRINT *, 'INPUT VX21,VX22,VX23,VX24'	TRANS101
READ *, VX21,VX22,VX23,VX24	TRANS102
VI = AMAX1(VX11,VX21)	TRANS103
C	TRANS104
7 PRINT 246	TRANS105
PRINT 250	TRANS106
PRINT 245, LFMT(ICASE)	TRANS107
IF (ICASE .EQ. 2) PRINT 225	TRANS108
PRINT 207	TRANS109
PRINT 203, DT,NP,TESTN,DATE	TRANS110

IF (ICASE .EQ. 1) PRINT 210, HPAV,V1,V2,V3,V4,E1,E2,E3,E4	TRANS111
IF (ICASE .EQ. 2) PRINT 220, HPAV,V1,V2,V3,V4,RI1,RI2,RI3,RI4	TRANS112
IF (ICASE .EQ. 3) PRINT 230, HPAV,VI	TRANS113
IF (ICASE .EQ. 4) PRINT 240, VI,VX11,VX12,VX13,VX14,	TRANS114
8 VX21,VX22,VX23,VX24	TRANS115
PRINT *,	TRANS116
PRINT 170	TRANS117
PRINT 180, WT,L,H,D,B,SL,CX,THETAD,THETAA,IZ,VCI1	TRANS118
PRINT *,	TRANS119
PRINT 190	TRANS120
PRINT 200, CI,A,SM,C,SN,IFIX(SXI),CD,	TRANS121
8 CLAMDA,PHI,G,SF,ETA,CHI	TRANS122
PRINT 207	TRANS123
PRINT 205	TRANS124
PRINT 209	TRANS125
C	TRANS126
C SET UP INITIAL CONDITIONS	TRANS127
C	TRANS128
T = DT	TRANS129
VX = VI*17.6	TRANS130
VY = 0.	TRANS131
WD = 0.	TRANS132
DXTFS = 0.	TRANS133
DYTPS = 0.	TRANS134
THETA = 0.	TRANS135
LOGV = .FALSE.	TRANS136
DTIM1 = 1./DT	TRANS137
DTIM2 = DT/2.	TRANS138
DT012 = DTIM2/12.	TRANS139
DXTPRV = VX	TRANS140
DYTPRV = VY	TRANS141
THDPRV = 0.	TRANS142
WPRV = 0.	TRANS143
WDPRV = WD	TRANS144
VXPRV = VX	TRANS145
VYPRV = VY	TRANS146
C	TRANS147
C -----	TRANS148
C TRANSIENT CALCULATIONS	TRANS149
C -----	TRANS150
C	TRANS151
DO 400 II = 1,NP	TRANS152
C	TRANS153
LSTB = .FALSE.	TRANS154
DA = 8.8	TRANS155
DV = 8.8	TRANS156
GO TO (10,20,30,40) ,ICASE	TRANS157
C	TRANS158
10 CONTINUE	TRANS159
E = FT(T,E1,E2,E3,E4)	TRANS160
V = FT(T,V1,V2,V3,V4)*17.6	TRANS161
IF(LOGV) V = AMIN1(VF(II-1)*17.6 + 2.*DA*DT , V)	TRANS162
GO TO 11	TRANS163
C	TRANS164
20 CONTINUE	TRANS165
RIOL = FT(T,RI1,RI2,RI3,RI4)*12./L	TRANS166

V = FT(T,V1,V2,V3,V4)*17.6	TRANS167
IF(LOGV) V = AMIN1(VP(II-1)*17.6 + 2.*DA*DT , V)	TRANS168
GO TO 11	TRANS169
C	TRANS170
30 CONTINUE	TRANS171
V = SQRT(VXPRV**2+VYPRV**2) + DA*DT	TRANS172
E = EP(II)	TRANS173
IF(.NOT.LOGV) GO TO 11	TRANS174
EI = E	TRANS175
IF(VPREV .GE. VI) GO TO 48	TRANS176
IF(ABS(EP(II-1)-1.) .LE. 0.05) GO TO 47	TRANS177
IF(VPREV .LT. VI) E = EP(II-1) - .05*IDIR	TRANS178
GO TO 49	TRANS179
47 E = 1. + (EI-1.)/ABS(EI-1.)*.000001	TRANS180
49 CONTINUE	TRANS181
IF(RIOL*(E/EI-1.)) 11,48,46	TRANS182
46 E = EI	TRANS183
48 LOGV = .FALSE.	TRANS184
GO TO 11	TRANS185
C	TRANS186
40 CONTINUE	TRANS187
VX1 = FT(T,VX11,VX12,VX13,VX14)*17.6	TRANS188
VX2 = FT(T,VX21,VX22,VX23,VX24)*17.6	TRANS189
E = VX1/VX2	TRANS190
C	TRANS191
11 CALL AGIL(\$115)	TRANS192
C	TRANS193
Z1P = Z1	TRANS194
Z2P = Z2	TRANS195
PP(II) = P	TRANS196
IF(LUX) V = SQRT(VX**2 + VY**2)	TRANS197
VP(II) = V*VMP	TRANS198
VPREV = V	TRANS199
IF(LUX .OR. HPAV.LE.0.) GO TO 160	TRANS200
RATIO = ABS(PTE/HPAV)	TRANS201
IF(RATIO .GT. 1.0) GO TO 154	TRANS202
IF(RATIO .GE. 0.95) GO TO 160	TRANS203
IF(ICASE.NE.3) GO TO 156	TRANS204
IF(LSTB) GO TO 160	TRANS205
C	TRANS206
V = V+DA*DT	TRANS207
GO TO 11	TRANS208
C	TRANS209
154 CONTINUE	TRANS210
V = V-DA*DT	TRANS211
DA = AMAX1(DA/1.2,.05)	TRANS212
IF(V.LE.VI .AND. ICASE.EQ.3) LOGV = .TRUE.	TRANS213
IF(ICASE .LT. 3) LOGV = .TRUE.	TRANS214
GO TO 11	TRANS215
C	TRANS216
156 LOGV = .FALSE.	TRANS217
160 CONTINUE	TRANS218
WDP(II) = WD*RDEG	TRANS219
ALPHD = (VX*VYD-VY*VXD) / V**2	TRANS220
THED = WD - ALPHD	TRANS221
ROP(II) = V/THED/12.	TRANS222

THETA = THETA + (THED+THDPRV)*DTIM2	TRANS223
DXT = V*COS(THETA)	TRANS224
DYT = V*SIN(THETA)	TRANS225
DXTPS = DXTPS + (DXTPRV+DXT)*DT012	TRANS226
DYTPS = DYTPS + (DYTPRV+DYT)*DT012	TRANS227
DXTP(II) = DXTPS	TRANS228
DYTP(II) = DYTPS	TRANS229
DXTPRV = DXT	TRANS230
DYTPRV = DYT	TRANS231
THDPRV = THED	TRANS232
WDPRV = WD	TRANS233
VXPRV = VX	TRANS234
VYPRV = VY	TRANS235
WPRV = W	TRANS236
WF(II) = W*RDEG	TRANS237
TF(II) = T	TRANS238
EF(II) = E	TRANS239
IF (E .LT. 1.) EF(II) = -1./E	TRANS240
FCXP(II) = FCX	TRANS241
FCYP(II) = FCY	TRANS242
VX1P(II) = VX1*VMP	TRANS243
VX2P(II) = VX2*VMP	TRANS244
VSX1P(II) = VSX1*VMP	TRANS245
VSX2P(II) = VSX2*VMP	TRANS246
VXP(II) = VX*VMP	TRANS247
VYP(II) = VY*VMP	TRANS248
PTEP(II) = PTE	TRANS249
PTSP(II) = PTS	TRANS250
PT1P(II) = PT1	TRANS251
PT2P(II) = PT2	TRANS252
T = T + DT	TRANS253
IF (MOD(II,IPRINT).NE.0) GO TO 400	TRANS254
PRINT 14, II,TF(II),PF(II),	TRANS255
& EP(II),ROP(II),VP(II),VX1P(II),VX2P(II),	TRANS256
& VSX1P(II),VSX2P(II),WF(II),WDP(II), FCXP(II),	TRANS257
& FCYP(II), PTEP(II),PTSP(II),DXTP(II),DYTP(II)	TRANS258
C	TRANS259
400 CONTINUE	TRANS260
C	TRANS261
C	TRANS262
PRINT 207	TRANS263
GO TO 99	TRANS264
C	TRANS265
115 IF (II .EQ. 1) GO TO 119	TRANS266
V = V - DV	TRANS267
IF(DV .LT. 1.) GO TO 116	TRANS268
DV = DV/2.	TRANS269
LSTB = .TRUE.	TRANS270
P = PF(II-1)	TRANS271
Z1 = Z1P	TRANS272
Z2 = Z2P	TRANS273
IF(.NOT.LVX) GO TO 11	TRANS274
VX1 = VX1P(II-1)*17.6	TRANS275
VX2 = VX2P(II-1)*17.6	TRANS276
E = VX1/VX2	TRANS277
GO TO 11	TRANS278

C		TRANS279
	116 PRINT 207	TRANS280
	PRINT *, 'VEHICLE GOES UNSTABLE AT THIS POINT',	TRANS281
	& ' (TOO VIOLENT MANEUVER ATTEMPTED)'	TRANS282
	PRINT *,	TRANS283
	II = II-1	TRANS284
	PRINT 14, II, TP(II), PP(II),	TRANS285
	& EP(II), ROP(II), VP(II), VX1P(II), VX2P(II),	TRANS286
	& VSX1P(II), VSX2P(II), WP(II), WDP(II), FCXP(II),	TRANS287
	& FCYP(II), PTEP(II), PTSP(II), DXTP(II), DYTP(II)	TRANS288
	GO TO 99	TRANS289
C		TRANS290
	119 PRINT *, 'THE VEHICLE WILL NOT GO IN THIS PARTICULAR SOIL.'	TRANS291
C		TRANS292
	99 RETURN	TRANS293
C	=====	TRANS294
C		TRANS295
	14 FORMAT(1X, I3, F6.2, F7.2, F6.2, F10.2, 3F6.1, 2F7.2, F7.1, F6.1,	TRANS296
	& 2F6.2, 2F7.1, 2F8.1)	TRANS297
	165 FORMAT(' MAXIMUM POINTS NP SET TO', I5)	TRANS298
	170 FORMAT(2X, 'WT(IN)', 3X, 'L(IN)', 3X, 'H(IN)', 2X, 'D(IN)', 4X,	TRANS299
	& 'B(IN)', 3X, 'SL(IN)', 1X, 'CX(IN)', 4X, 'THETAD(DEG)', 3X,	TRANS300
	& 'THETAA(DEG)', 1X, 'IZ(IN LB/SEC**2)', 3X, 'VCI1')	TRANS301
	180 FORMAT(1X, F8.1, 2X, F5.1, 2(3X, F4.1), 4X, F5.1, 5X, F4.1, 2X, F5.1,	TRANS302
	& 7X, F5.1, 10X, F5.1, 7X, F8.1, 8X, F4.1)	TRANS303
	190 FORMAT(4X, 'CI', 5X, 'A(PSI)', 1X, 'SM(PSI)', 1X, 'C(PSI)', 1X,	TRANS304
	& 'SN(1/PSI)', 2X, 'SXI', 3X, 'CD(PSI)', 1X	TRANS305
	& 'CLAMDA(SEC/IN)', 4X, 'PHI(DEG)', 2X, 'G(PSI/IN)', 2X,	TRANS306
	& 'SF', 4X, 'ETA(DEG)', 1X, 'CHI(DEG)')	TRANS307
	200 FORMAT(2X, F5.1, 1X, 2(3X, F5.1), 3X, F4.1, 3X, F6.4, 5X, I1, 5X, F5.1,	TRANS308
	& 6X, F6.3, 10X, F4.1, 6X, F5.1, 3X, F5.3, 4X, F4.1, 4X, F5.1)	TRANS309
	203 FORMAT(2X, 'DT = ', F4.1, '(SEC)', 3X, 'NP = ', I3,	TRANS310
	& 12X, 'TEST NO. = ', A40, 3X, A8, 3X, '//)	TRANS311
	205 FORMAT(2X, 'PT', 3X, 'T', 5X, 'P/L', 4X, 'E', 6X, 'R0', 7X, 'VEL', 3X, 'VX1',	TRANS312
	& 3X, 'VX2', 3X, 'VS1', 4X, 'VS2', 5X, 'W', 5X, 'WD', 4X, 'FCX',	TRANS313
	& 3X, 'FCY', 3X, 'PTE', 4X, 'PTS', 5X, 'DXT', 5X, 'DYT')	TRANS314
	207 FORMAT(/, 1X, 119(1H=), //)	TRANS315
	209 FORMAT(6X, 'SEC', 18X, 'FT', 7X, 3('MPH', 3X), 2('MPH', 4X), 'DEG',	TRANS316
	& 2X, 'DEG/SEC', 2X, 'G', 5X, 'G', 2(5X, 'HP'), 2(6X, 'FT'), //)	TRANS317
	210 FORMAT(2X, 'HFAV = ', F6.1, '(HP)', 7X, 'DRIVER COEFFICIENTS FOR',	TRANS318
	& ' VELOCITY :', F6.2, 3(' ', F6.2), /, 50X,	TRANS319
	& 'STEERING RATIO:', F6.2, 3(' ', F6.2))	TRANS320
	220 FORMAT(2X, 'HFAV = ', F6.1, '(HP)', 7X, 'DRIVER COEFFICIENTS FOR',	TRANS321
	& ' VELOCITY :', F8.1, 3(' ', F8.1), /, 50X,	TRANS322
	& 'TURNING RADIUS:', F8.1, 3(' ', F8.1))	TRANS323
	225 FORMAT(25X, 'NOTE: THIS CASE COULD BE MODIFIED TO INPUT',	TRANS324
	& ' TRAJECTORY INSTEAD OF RI')	TRANS325
	230 FORMAT(2X, 'HFAV = ', F6.1, 4X, 'VI = ', F4.1)	TRANS326
	240 FORMAT(2X, 'VI = ', F4.1, '(MPH)', 3X, 'DRIVER COEFFICIENTS FOR',	TRANS327
	& ' OUTERTRACK:', F6.1, 3(' ', F6.1), /, 43X,	TRANS328
	& ' INNER TRACK:', F6.1, 3(' ', F6.1))	TRANS329
	245 FORMAT(28X, A76)	TRANS330
	246 FORMAT(1H1)	TRANS331
	250 FORMAT(48X, 'TRANSIENT TURNING MOTION')	TRANS332
C		TRANS333
	END	TRANS334

C		AGIL0001
C	*****	AGIL0002
C	*	AGIL0003
C	* THIS SUBROUTINE CALCULATES THE SLIP RADII AND OFFSET.	AGIL0004
C	* (TECHNICAL REPORT GL-79-6)	AGIL0005
C	*	AGIL0006
C	*****	AGIL0007
C		AGIL0008
	SUBROUTINE AGIL(*)	AGIL0009
C		AGIL0010
	PARAMETER (N = 10 , N1 = N+1)	AGIL0011
	REAL L,JACK,IZ,IZB	AGIL0012
	LOGICAL LOGRE,LVX	AGIL0013
	CHARACTER TESTN*40,DATE*8	AGIL0014
	SAVE	AGIL0015
	DATA PTA,PTAD,PTAPM,IFIRST /0.95 , 0.95 , 0.75 , 0/	AGIL0016
C		AGIL0017
	DIMENSION T1(N1),T2(N1),Q1(N1),Q2(N1),DX(N1)	AGIL0018
C		AGIL0019
	COMMON /INOUT / E,VX1,VX2,V,RIOL,LOGRE,LVX	AGIL0020
	COMMON /IN / DTIM1,DTIM2,WPRV,WDPV,VXPRV,VYPRV,TESTN,DATE	AGIL0021
	COMMON /VPARAM/ WT,L,H,D,B,SL,CX,THETAA,THETAD,IZ,VCI1	AGIL0022
	COMMON /SPARAM/ CI,A,SM,SN,C,SXI,CD,CLAMDA,PHI,G,SF,ETA,CHI	AGIL0023
	COMMON /OUT / FCX,FCY,VSX1,VSX2,PTE,PTS,WD,W,VX,VY,	AGIL0024
	& P,Z1,Z2,IDIR,VXD,VYD,PT1,PT2	AGIL0025
	COMMON /MISC / GRAV,DRAD,VMP,RDEG	AGIL0026
C		AGIL0027
C	=====	AGIL0028
C		AGIL0029
C	FUNCTION FOR R (INPUT E)	AGIL0030
C		AGIL0031
	FR(Z1,Z2,E) = (E*(BOL-2.*Z2)+BOL+2.*Z1) / (E-1.)*.5	AGIL0032
C		AGIL0033
C	FUNCTION FOR E (INPUT R0)	AGIL0034
C		AGIL0035
	FE(Z1,Z2,R0L) = (Z1+BOL/2.+R0L) / (Z2-BOL/2.+R0L)	AGIL0036
C		AGIL0037
C	-----	AGIL0038
C		AGIL0039
C	FUNCTIONS FOR NORMAL STRESSES WITHOUT TRACK TENSION TERM	AGIL0040
C		AGIL0041
	FR1B(X) = CZ2 + CXCZT6*X - HOBFCY - HOBFCX*X	AGIL0042
	FR2B(X) = CZ2 + CXCZT6*X + HOBFCY - HOBFCX*X	AGIL0043
C		AGIL0044
C	WHERE	AGIL0045
C	HOBFCY = HOL/BOL*(-FCY-SZSC)	AGIL0046
C	HOBFCX = 6*HOL*(FCX+SZCC)	AGIL0047
C	CXCZT6 = 6*CXOL*COS(ETA)	AGIL0048
C		AGIL0049
C	-----	AGIL0050
C		AGIL0051
C	FUNCTIONS FOR TRACK TENSION TERMS	AGIL0052
C		AGIL0053
	FSD(X) = AL3PRX + (ALSAN1*X+AL1AN1)*DU1 + AN1*DU4	AGIL0054
	FSI(X) = AL3PRX + (ALSA2P*X+AL1AN2)*DU1 + AN2A2P*DU2	AGIL0055
	& - (ALSAN2*X-AL1A2P)*DU3	AGIL0056

C		AGIL0057
C	-----	AGIL0058
C		AGIL0059
C	EQUATIONS FOR TRACK TENSION	AGIL0060
C		AGIL0061
	FA(T1S) = AN1 - STETD*T1S	AGIL0062
	GA(T2S) = DUM1*(AN2-STHETA*T2S) + DUM2*(AN2P+STETD*T2S)	AGIL0063
	FA2(T1S) = (FA(T1S)-AA) / DT	AGIL0064
	GA2(T2S) = (GA(T2S)-BB) / DT	AGIL0065
C	-----	AGIL0066
C		AGIL0067
C		AGIL0068
C	FUNCTION FOR TOTAL SHEAR STRENGTH	AGIL0069
C		AGIL0070
	EXPS(X) = EXP(AMAX1(X,-88.))	AGIL0071
	FSM(XCD,SIG) = (ABAR+SMBAR*EXPS(-SN*SIG))*(1.-SXI) +	AGIL0072
	& (CBAR+SIG*TPHI)*SXI + XCD	AGIL0073
C	-----	AGIL0074
C		AGIL0075
C		AGIL0076
C	EQUATIONS OF MOTION	AGIL0077
C		AGIL0078
	FB(TS) = TS - SF - FCX - SZCC	AGIL0079
	GB(QS) = QS + FCY + SZSC	AGIL0080
	HB(QX,TD) = QX + BOL/2.*TD + SF*HOL*(FCY+SZSC) + IZB*WDD	AGIL0081
	F2(TS) = (FB(TS)-AV) / DT	AGIL0082
	G2(QS) = (GB(QS)-BV) / DT	AGIL0083
	H2(QX,TD) = (HB(QX,TD)-CV) / DT	AGIL0084
C	=====	AGIL0085
C		AGIL0086
C		AGIL0087
	IF (IFIRST .NE. 0) GO TO 20	AGIL0088
	IFIRST = 1	AGIL0089
C		AGIL0090
	DT = .0005	AGIL0091
	CHI = CHI*DRAD	AGIL0092
	DX(1) = 0.	AGIL0093
	CONT = 1.E-5	AGIL0094
	HPF = WT/6600.	AGIL0095
	HPFE = 0.5/PTA	AGIL0096
	EPREV = E	AGIL0097
	P = 0.	AGIL0098
	Z1 = .1	AGIL0099
	Z2 = -.1	AGIL0100
C	-----	AGIL0101
C		AGIL0102
C	VARIABLES RELATED TO VEHICLE PARAMETERS	AGIL0103
C	-----	AGIL0104
C		AGIL0105
	ALSQOW = L*L/WT	AGIL0106
	HOB = H/B	AGIL0107
	DOL = D/L	AGIL0108
	IZB = IZ/L/WT	AGIL0109
	HOL = H/L	AGIL0110
	HOLT6 = 6.*HOL	AGIL0111
	BOL = B/L	AGIL0112

C	CXOL = CX/L	AGIL0113
C		AGIL0114
C	USED FOR TRACK TENSION ONLY (SL .NE. 0.)	AGIL0115
		AGIL0116
	IF(SL) 69,73,69	AGIL0117
69	TETD1 = THETAD*DRAD	AGIL0118
	THETA1 = THETAA*DRAD	AGIL0119
	STETD = SIN(TETD1)	AGIL0120
	STHETA = SIN(THETA1)	AGIL0121
	AN2 = STHETA	AGIL0122
	AN1 = STETD	AGIL0123
	AN2P = -STETD	AGIL0124
	SLOL = SL/L	AGIL0125
	AL2 = SLLOL*2.	AGIL0126
	M = SLLOL*N+.5	AGIL0127
	M1 = M+1	AGIL0128
	M2 = N1-M	AGIL0129
	DX(2) = SLLOL/M	AGIL0130
	DO 70 I = 3,M1	AGIL0131
70	DX(I) = DX(2)	AGIL0132
	DX(M+2) = (1,-AL2) / (N-2*M)	AGIL0133
	DO 71 I = M+3,M2	AGIL0134
71	DX(I) = DX(M+2)	AGIL0135
	DO 72 I = M2+1,N1	AGIL0136
72	DX(I) = DX(2)	AGIL0137
	M1 = M1 + 1	AGIL0138
	M2 = M2 + 1	AGIL0139
	AL3 = 3. - AL2	AGIL0140
	ALS = 2./SLLOL**2	AGIL0141
	AL1 = ((1,-SLLOL)/SLLOL)**2	AGIL0142
	GO TO 75	AGIL0143
C		AGIL0144
C	USED ONLY FOR ZERO TRACK TENSION (SL .EQ. 0.)	AGIL0145
C		AGIL0146
	73 DXT = 1./N	AGIL0147
	DO 74 I = 2,N1	AGIL0148
	74 DX(I) = DXT	AGIL0149
C		AGIL0150
C	-----	AGIL0151
C	VARIABLES RELATED TO SOIL MODEL PARAMETERS	AGIL0152
C	-----	AGIL0153
C		AGIL0154
	75 CONTINUE	AGIL0155
	PHI1 = PHI*DRAD	AGIL0156
	TPHI = TAN(PHI1)	AGIL0157
	CBAR = DOL*ALSQOW*C	AGIL0158
	ABAR = DOL*ALSQOW*A	AGIL0159
	SMBAR = DOL*ALSQOW*SM	AGIL0160
	GBAR = DOL*G*ALSQOW*L	AGIL0161
	CDBAR = DOL*CD*ALSQOW	AGIL0162
	CLMDAB = CLAMDA*L	AGIL0163
	DI = SF	AGIL0164
	CZ = COS(ETA*DRAD)	AGIL0165
	CZ2 = CZ/2.	AGIL0166
	SZ = SIN(ETA*DRAD)	AGIL0167
	CXCZT6 = CXOL*CZ*6.	AGIL0168

C		AGIL0169
C		AGIL0170
C	-----	AGIL0171
C	DETERMINE DIRECTION VEHICLE IS TURNING	AGIL0172
C	-----	AGIL0173
	20 CONTINUE	AGIL0174
	IDIR = 1	AGIL0175
	IF (LOGRE) GO TO 47	AGIL0176
	IF (E-1.) 41,44,47	AGIL0177
C		AGIL0178
	41 IF (E) 42,43,43	AGIL0179
	42 E = -1./E	AGIL0180
	IF (E-1.) 43,44,47	AGIL0181
C		AGIL0182
	43 CONTINUE	AGIL0183
	IDIR = -1	AGIL0184
	GO TO 47	AGIL0185
C		AGIL0186
	44 CONTINUE	AGIL0187
	IF (EPREV-1.) 45,46,46	AGIL0188
C		AGIL0189
	45 E = 0.9999	AGIL0190
	IF (LVX) VX1 = VX2*E	AGIL0191
	IDIR = -1	AGIL0192
	GO TO 47	AGIL0193
C		AGIL0194
	46 E = 1.0001	AGIL0195
	IF (LVX) VX2 = VX1/E	AGIL0196
C		AGIL0197
	47 CONTINUE	AGIL0198
	EPREV = E	AGIL0199
C		AGIL0200
C	-----	AGIL0201
C	ITERATE TO FIND SOLUTIONS	AGIL0202
C	-----	AGIL0203
C		AGIL0204
	DO 100 IL = 1,36	AGIL0205
C		AGIL0206
	K = 1	AGIL0207
	8 PSQ = P**2	AGIL0208
	IF (LOGRE) GO TO 510	AGIL0209
C		AGIL0210
C	FOR CASES WHERE E IS INPUT	AGIL0211
C		AGIL0212
	ROL = FR(Z1,Z2,E)	AGIL0213
	RIOL = SIGN(SQRT(PSQ+ROL**2),ROL)	AGIL0214
	GO TO 520	AGIL0215
C		AGIL0216
C	FOR CASES WHERE RI IS INPUT (RI=R0 FOR STEADY-STATE)	AGIL0217
C		AGIL0218
	510 CONTINUE	AGIL0219
	RIOLSQ = RIOL*RIOL	AGIL0220
	IF (PSQ .GE. RIOLSQ) RETURN 1	AGIL0221
	ROL = SIGN(SQRT(RIOLSQ-PSQ),RIOL)	AGIL0222
	E = FE(Z1,Z2,ROL)	AGIL0223
C		AGIL0224

520	CONTINUE	AGIL0225
	IF (LVX) GO TO 530	AGIL0226
	WDL = V/RIOL	AGIL0227
	VX2 = WDL*(BOL+Z1-Z2)/(E-1.)	AGIL0228
	VX1 = VX2*E	AGIL0229
	GO TO 540	AGIL0230
C		AGIL0231
530	CONTINUE	AGIL0232
	WDL = VX2*(E-1.) / (BOL+Z1-Z2)	AGIL0233
C		AGIL0234
540	WDL02 = WDL*.5	AGIL0235
	WD = WDL/L	AGIL0236
	VX = ROL*WDL	AGIL0237
	VY = F*WDL	AGIL0238
	WDD = (WD-WDPRV)*DTIM1	AGIL0239
	VXD = (VX-VXPRV)*DTIM1	AGIL0240
	VYD = (VY-VYPRV)*DTIM1	AGIL0241
	FCY = (VX*WD-VYD)/GRAV	AGIL0242
	FCX = (VY*WD+VXD)/GRAV	AGIL0243
	W = WPRV + (WD+WDPREV)*DTIM2	AGIL0244
	CC = COS(CHI+W)	AGIL0245
	SC = SIN(CHI+W)	AGIL0246
	SZSC = SZ*SC	AGIL0247
	SZCC = SZ*CC	AGIL0248
	HOBFCY = HOB*(-FCY-SZSC)	AGIL0249
	HOBFCX = HOLT6*(FCX+SZCC)	AGIL0250
	Z1SQ = Z1*Z1	AGIL0251
	Z2SQ = Z2*Z2	AGIL0252
	IF(V) 77,78,77	AGIL0253
77	TEM1 = WDL02/VX1	AGIL0254
	TEM2 = WDL02/VX2	AGIL0255
	GO TO 79	AGIL0256
C		AGIL0257
78	TEM1 = 0.	AGIL0258
	TEM2 = 0.	AGIL0259
C		AGIL0260
79	CONTINUE	AGIL0261
	VX2 = Z2*WDL	AGIL0262
	K2 = 4	AGIL0263
C		AGIL0264
C	USED FOR TRACK TENSION ONLY (SL .NE. 0.)	AGIL0265
C		AGIL0266
	IF(SL) 80,85,80	AGIL0267
80	IF(VSX2) 81,82,82	AGIL0268
81	AN2 = 0.	AGIL0269
	DUM1 = 0.	AGIL0270
	DUM2 = 1.	AGIL0271
	GO TO 83	AGIL0272
82	AN2P = 0.	AGIL0273
	DUM1 = 1.	AGIL0274
	DUM2 = 0.	AGIL0275
83	CONTINUE	AGIL0276
	K2 = 1	AGIL0277
	IL2 = 1	AGIL0278
84	ALAN1 = ALS*AN1	AGIL0279
	AL1AN1 = AL1*AN1	AGIL0280

AL3PR = AL3*(AN2-AN2F-AN1)	AGIL0281
ALSA2F = ALS*AN2F	AGIL0282
AL1AN2 = AL1*AN2F + AN2	AGIL0283
AN2A2F = AN2+AN2F	AGIL0284
ALSAN2 = ALS*AN2	AGIL0285
AL1A2F = AL1*AN2 + AN2F	AGIL0286
DU1=1.	AGIL0287
DU2=0.	AGIL0288
DU3=0.	AGIL0289
DU4=0.	AGIL0290
C	AGIL0291
85 CONTINUE	AGIL0292
X = -.5	AGIL0293
UP1 = .5 - P - CXOL	AGIL0294
UP1S = UP1**2	AGIL0295
UP1Z1S = SQRT(UP1S+Z1SQ)	AGIL0296
UP1Z2S = SQRT(UP1S+Z2SQ)	AGIL0297
ARG1 = AMAX1(UP1+UP1Z1S,1.E-20)	AGIL0298
ARG2 = AMAX1(UP1+UP1Z2S,1.E-20)	AGIL0299
D1BF = UP1*UP1Z1S + Z1SQ*ALOG(ARG1)	AGIL0300
D2BF = UP1*UP1Z2S + Z2SQ*ALOG(ARG2)	AGIL0301
C	AGIL0302
C	AGIL0303
C	AGIL0304
C	AGIL0305
C	AGIL0306
DO 10 I = 1,N1	AGIL0307
C	AGIL0308
X = X + DX(I)	AGIL0309
R1B = FR1B(X)	AGIL0310
R2B = FR2B(X)	AGIL0311
C	AGIL0312
C	AGIL0313
C	AGIL0314
IF(SL) 32,37,32	AGIL0315
32 IF(I-M1) 36,33,34	AGIL0316
33 DU1=0.	AGIL0317
DU2=1.	AGIL0318
DU4=1.	AGIL0319
34 IF(I-M2) 36,35,36	AGIL0320
35 DU2=0.	AGIL0321
DU3=1.	AGIL0322
36 CONTINUE	AGIL0323
AL3PRX = AL3PR*X	AGIL0324
R1B = R1B + FSO(X)	AGIL0325
R2B = R2B + FSI(X)	AGIL0326
C	AGIL0327
37 CONTINUE	AGIL0328
XMP = X - P - CXOL	AGIL0329
XMPSQ = XMP**2	AGIL0330
RTZ1 = SQRT(XMPSQ+Z1SQ)	AGIL0331
RTZ2 = SQRT(XMPSQ+Z2SQ)	AGIL0332
SG1 = XMP/RTZ1	AGIL0333
CG1 = Z1/RTZ1	AGIL0334
SG2 = XMP/RTZ2	AGIL0335
CG2 = Z2/RTZ2	AGIL0336

DD1B = WD*RTZ1	AGIL0337
DD2B = WD*RTZ2	AGIL0338
ARG1 = AMAX1(XMP+RTZ1,1.E-20)	AGIL0339
ARG2 = AMAX1(XMP+RTZ2,1.E-20)	AGIL0340
D1B = DI + TEM1*(D1BP-XMP*RTZ1-Z1SQ*ALOG(ARG1))	AGIL0341
D2B = DI + TEM2*(D2BP-XMP*RTZ2-Z2SQ*ALOG(ARG2))	AGIL0342
GD1B = D1B*GBAR	AGIL0343
GD2B = D2B*GBAR	AGIL0344
CCD1 = CDBAR * (1.0-EXPS(-CLMDAB*ABS(DD1B)))	AGIL0345
CCD2 = CDBAR * (1.0-EXPS(-CLMDAB*ABS(DD2B)))	AGIL0346
TAU1 = FSM(CCD1,AMAX1(R1B,0.))	AGIL0347
TAU2 = FSM(CCD2,AMAX1(R2B,0.))	AGIL0348
TQ1 = GD1B*TAU1 / (TAU1+ABS(GD1B))	AGIL0349
TQ2 = GD2B*TAU2 / (TAU2+ABS(GD2B))	AGIL0350
C	AGIL0351
T1(I) = TQ1*CG1	AGIL0352
T2(I) = TQ2*CG2	AGIL0353
Q1(I) = TQ1*SG1 + TQ2*SG2	AGIL0354
Q2(I) = Q1(I)*(X-CXOL)	AGIL0355
C	AGIL0356
10 CONTINUE	AGIL0357
C	AGIL0358
C	AGIL0359
T1S = 0.	AGIL0360
T2S = 0.	AGIL0361
DO 21 I = 2,N1	AGIL0362
DX02 = DX(I)*.5	AGIL0363
T1S = T1S + (T1(I)+T1(I-1))*DX02	AGIL0364
21 T2S = T2S + (T2(I)+T2(I-1))*DX02	AGIL0365
T1S = T1S*IDIR	AGIL0366
T2S = T2S*IDIR	AGIL0367
GO TO (87,88,89,90) ,K2	AGIL0368
C	AGIL0369
C	AGIL0370
C	AGIL0371
87 AA = FA(T1S)	AGIL0372
BB = GA(T2S)	AGIL0373
IF(ABS(AA).LT.CONT .AND. ABS(BB).LT.CONT) GO TO 90	AGIL0374
K2 = 2	AGIL0375
AN2 = AN2 + DUM1*DT	AGIL0376
AN2P = AN2P + DUM2*DT	AGIL0377
GO TO 84	AGIL0378
88 FAX = FA2(T1S)	AGIL0379
GAX = GA2(T2S)	AGIL0380
AN2 = AN2 - DUM1*DT	AGIL0381
AN2P = AN2P - DUM2*DT	AGIL0382
AN1 = AN1 + DT	AGIL0383
K2 = 3	AGIL0384
GO TO 84	AGIL0385
89 FAY = FA2(T1S)	AGIL0386
GAY = GA2(T2S)	AGIL0387
AN1 = AN1 - DT	AGIL0388
RJAC2 = FAX*GAY - FAY*GAX	AGIL0389
IF(ABS(RJAC2) .LT. 1.E-37) RETURN 1	AGIL0390
DELTTT = (-AA*GAY+BB*FAY) / RJAC2	AGIL0391
DELTT3 = (-BB*FAX+AA*GAX) / RJAC2	AGIL0392

AN2 = AN2 + DUM1*DELTTT	AGIL0393
AN2P = AN2P + DUM2*DELTTT	AGIL0394
AN1 = AN1 + DELTT3	AGIL0395
IL2 = IL2 + 1	AGIL0396
K2 = 1	AGIL0397
IF (IL2 .LT. 36) GO TO 84	AGIL0398
RETURN 1	AGIL0399
C	AGIL0400
90 CONTINUE	AGIL0401
QS = 0.	AGIL0402
QX = 0.	AGIL0403
DO 23 I = 2,N1	AGIL0404
DX02 = DX(I)*.5	AGIL0405
QS = QS + (Q1(I)+Q1(I-1))*DX02	AGIL0406
23 QX = QX + (Q2(I)+Q2(I-1))*DX02	AGIL0407
QS = QS*IDIR	AGIL0408
QX = QX*IDIR	AGIL0409
TS = T1S + T2S	AGIL0410
TD = T2S - T1S	AGIL0411
GO TO (30,40,50,60) ,K	AGIL0412
C	AGIL0413
30 AV = FB(TS)	AGIL0414
BV = GB(QS)	AGIL0415
CV = HB(QX,TD)	AGIL0416
IF (ABS(AV).LT.CONT .AND. ABS(BV).LT.CONT	AGIL0417
& .AND. ABS(CV).LT.CONT) GO TO 120	AGIL0418
P = P+DT	AGIL0419
K = 2	AGIL0420
GO TO 8	AGIL0421
C	AGIL0422
40 FX = F2(TS)	AGIL0423
GX = G2(QS)	AGIL0424
HX = H2(QX,TD)	AGIL0425
P = P - DT	AGIL0426
Z1 = Z1 + DT	AGIL0427
K = 3	AGIL0428
GO TO 8	AGIL0429
C	AGIL0430
50 FY = F2(TS)	AGIL0431
GY = G2(QS)	AGIL0432
HY = H2(QX,TD)	AGIL0433
Z1 = Z1 - DT	AGIL0434
Z2 = Z2 + DT	AGIL0435
K = 4	AGIL0436
GO TO 8	AGIL0437
C	AGIL0438
60 FZ = F2(TS)	AGIL0439
GZ = G2(QS)	AGIL0440
HZ = H2(QX,TD)	AGIL0441
Z2 = Z2 - DT	AGIL0442
A1F = GY*HZ - GZ*HY	AGIL0443
B1F = FY*HZ - FZ*HY	AGIL0444
C1F = FY*GZ - FZ*GY	AGIL0445
A2F = BV*HX - CV*GX	AGIL0446
B2F = AV*HX - CV*FX	AGIL0447
C2F = AV*GX - BV*FX	AGIL0448

C	JACK = FX*A1F - GX*B1F + HX*C1F	AGIL0449
	IF(ABS(JACK).LT.1.E-37) RETURN 1	AGIL0450
C		AGIL0451
	P = P + (BV*B1F - AV*A1F - CV*C1F)/JACK	AGIL0452
	Z1 = Z1 + (FZ*A2F - GZ*B2F + HZ*C2F)/JACK	AGIL0453
	Z2 = Z2 + (GY*B2F - FY*A2F - HY*C2F)/JACK	AGIL0454
C		AGIL0455
	100 CONTINUE	AGIL0456
	RETURN 1	AGIL0457
C	-----	AGIL0458
C		AGIL0459
	120 CONTINUE	AGIL0460
	PT1 = VX1*T1S*HPF	AGIL0461
	PT2 = VX2*T2S*HPF	AGIL0462
	PTS = PT1 + PT2	AGIL0463
	IF(E-1.) 140,130,130	AGIL0464
C		AGIL0465
	130 PTE = HPFE*(PT1/E*(E+1.+(E-1.)/PTAPM)+	AGIL0466
	& PT2*(E+1.-PTAD*(E-1.)/PTAPM))	AGIL0467
	GO TO 150	AGIL0468
C		AGIL0469
	140 ONEOE = 1./E	AGIL0470
	PTE = HPFE*(PT2*E*(ONEOE+1.+(ONEOE-1.)/PTAPM)+	AGIL0471
	& PT1*(ONEOE+1.-PTAD*(ONEOE-1.)/PTAPM))	AGIL0472
C		AGIL0473
	150 CONTINUE	AGIL0474
	VX1 = Z1*WDL	AGIL0475
C		AGIL0476
	RETURN	AGIL0477
	END	AGIL0478
C		AGIL0479
C	*****	MIVCI001
C	*	MIVCI002
C	* THIS SUBROUTINE CALCULATES THE VEHICLE CONE INDEX *	MIVCI003
C	* FOR ONE-PASS TRAFFIC USING THE MOBILITY INDEX. *	MIVCI004
C	* (TECHNICAL REPORT GL-79-6) *	MIVCI005
C	*	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,VC11	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	MIVCI026
IF(WT .GE. 100000.0) WF = 1.8	MIVCI027
C	MIVCI028
TRKF = D/100.	MIVCI029
C	MIVCI030
GF = 1.0	MIVCI031
IF(GH .GT. 1.5) GF = 1.1	MIVCI032
C	MIVCI033
BF = (WT/10.)/(NB*TSL*D)	MIVCI034
CF = 1.5*L/(NB-1)/TAN(THETAA*DRAD)/10.	MIVCI035
HPT = HP/(WT/2000.)	MIVCI036
C	MIVCI037
EF = 1.0	MIVCI038
IF(HPT .LT. 10.) EF = 1.05	MIVCI039
C	MIVCI040
TRNF = 1.05	MIVCI041
IF(TRNT .GT. 0.) TRNF = 1.0	MIVCI042
C	MIVCI043
AMI = ((CPF*WF)/(TRKF*GF)+BF-CF) * EF * TRNF	MIVCI044
C	MIVCI045
C	MIVCI046
C	MIVCI047
VCII = 7.0 + 0.2*AMI - 39.2/(AMI+5.6)	MIVCI048
C	MIVCI049
C	MIVCI050
C	MIVCI051
RETURN	MIVCI052
END	MIVCI053
C	CONE0001
C	CONE0002
C	CONE0003
C	CONE0004
C	CONE0005
C	CONE0006
C	CONE0007
C	CONE0008
C	CONE0009
C	CONE0010
C	CONE0011
C	CONE0012
C	CONE0013
C	CONE0014
C	CONE0015
C	CONE0016
C	CONE0017
C	CONE0018
C	CONE0019
C	CONE0020
C	CONE0021
C	CONE0022
C	CONE0023
C	CONE0024
C	CONE0025
C	CONE0026
C	CONE0027
C	CONE0028

TPHI = TAN(PHI1)	CONE0029
ELP = 4.*SPHI/(1.+SPHI)/3.	CONE0030
ELP2 = 2. - ELP	CONE0031
ELP3 = 3. - ELP	CONE0032
C	CONE0033
IF(PHI) 30,20,30	CONE0034
C	CONE0035
20 CONTINUE	CONE0036
C	CONE0037
C	CONE0038
C	CONE0039
CI = 4.*C/3.*(1.+DLOG(AG/C)) +	CONE0040
& 2.*C*TL/DI + AGM*((Z+TL)-2.*TL/3.)	CONE0041
C	CONE0042
C	CONE0043
C	CONE0044
RETURN	CONE0045
C	CONE0046
30 CONTINUE	CONE0047
C	CONE0048
A1 = AGM*TPHI	CONE0049
AA = A1*(Z+TL) + C	CONE0050
A12 = A1**2	CONE0051
A2 = A12*TPHI*(DI/2.):**2	CONE0052
A3 = 2.*TAL*(1.+SPHI)*AG**ELP	CONE0053
A4 = 3.*(TAL+TPHI)/(3.-SPHI)	CONE0054
A5 = AA**ELP3	CONE0055
A6 = (AA+ELP2*A1*TL)*DMAX1(0.,(AA-TL*AGM*TPHI))**ELP2	CONE0056
C	CONE0057
C	CONE0058
C	CONE0059
CI = -C/TPHI + A3/A2*A4*(A5-A6)/ELP2/ELP3	CONE0060
C	CONE0061
C	CONE0062
C	CONE0063
RETURN	CONE0064
END	CONE0065

*

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, = Coefficients for calculating the instantaneous radius of
 RI4 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, = Coefficients for computing the longitudinal component of
 VX13, VX14 velocity of the outer track (VX1).
 VX1P = Array for storing VX1.
 VX2 = Longitudinal component of velocity of the inner track,
 in/sec.
 VX21, VX22, = Coefficients for calculating the longitudinal component
 VX23, VX24 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-in² 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-ratchet 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	AT PEAK					REMARKS
							NORMAL LOAD	NORMAL STRESS	SHEAR LOAD	SHEAR STRESS	DEFLECTION	
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
$\bar{D}$	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
δ	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 = $PT_1 + PT_2$
PT_1	Power required by the sprocket of the outer track
PT_2	Power required by the sprocket of the inner track
PTD	Differential power = $PT_1 - PT_2$
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
$t_1(x)$	$dL^2 T_1(x)/W$
$t_2(x)$	$dL^2 T_2(x)/W$
$\bar{T}_1$	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
$\bar{Z}$	Depth of penetration of the cone
α	Side-slip angle
$\bar{\alpha}$	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
$\emptyset$	Angle of internal friction
Ψ, Φ	Coordinate system fixed on level ground
ω	Yaw angle