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MULTIWHEEL LANDING GEAR/SOIL INTERACTION—PHASE III
BRAKED WHEEL SINKAGE PREDICTION TECHNIQUE AND COMPUTER PROGRAM

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FOREWORD

This report was prepared by the Aerospace Mechanics Group of the University of Dayton Research Institute under USAF Contract F33615-70-C-1170. The contract was initiated under Project No. 1369, "Launching and Alighting Systems for Military Aircraft," Task No. 136908, "Aircraft Surface Operation on Soil." This work was conducted under the direction of the Vehicle Equipment Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, Mr. George Sperry (AFFDL/FEM) Project Engineer.

This report covers work conducted from 18 December 1970 to 15 June 1972.

The authors wish to thank Mr. Sperry for his efforts and assistance in integrating the research program toward Air Force objectives. This report was submitted by the author in July 1972.

Publication of this technical report does not constitute Air Force approval of the reported findings or conclusions. It is published only for the exchange and stimulation of ideas.

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ABSTRACT

The design and utilization of military aircraft in forward area situations has required a continual investigation of those factors which define the aircraft flotation performance and surface operating capability on semi- and unprepared soil runways.

The following is a Research and Development Computer Program Report that documents the analytical braked wheel on soil sinkage prediction technique, the associated FORTRAN IV computer program, and also the numerical results which have been obtained. The material reported herein was developed under Contract No. F33615-70-C-1170.

The report is presented in four sections. The first section provides an introduction; the second section is concerned with a description of the analytical approach; the third section contains a description of the computer program, including instructions for the preparation of input data; and the fourth section describes a number of example cases which have been processed with the computer program.

It is recommended that the reader obtain referenced report (7) to obtain an overall approach to the braked wheel on soil problem.

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LIST OF SYMBOLS

Symbol	Definition	First Page Referenced
B	A variable related to the stress invariants	31
b	Tire section width	4
CBR	California bearing ratio	2
CI_{avg}	Average cone index of soil over 0" to 6" depth	2
c	Cohesion of soil	7
D	Tire outside diameter	4
E	Young's modulus	7
f	Yield function	30
G	Modulus of rigidity	31
h	Space mesh size	10
I	First invariant of the stress tensor	30
i	Location identifier (column)	10
J	Second invariant of the deviatoric stress tensor	30
j	Location identifier (row)	10
k	Shear yield stress	18
ℓ	Tire footprint length (rigid surface)	8
M'	Number of width mesh points	16
N'	Number of depth mesh points	16
P	Vertical load	4
p_{max}	Peak surface pressure	11
p_n	Uniform vertical pressure	6
p_s	Uniform shear distribution	6
Q	Constant for incremental stress-strain relation use	31
R	Rolling drag resistance to forward motion	4
RMI	Relative merit index	1
R_B	Braked tire drag force	4

LIST OF SYMBOLS (Continued)

Symbol	Definition	First Page Referenced
$(R/P)_M$	Multiple wheel drag ratio	2
t	Elapsed time	11
t_c	Characteristic time related to time variable	16
t_d	Time duration of load pulse	11
Δt	Time increment	14
$U, \dot{U}, \ddot{U}$	Displacement, velocity, acceleration in η-direction	29
ΔU	Incremental displacement in η direction	30
$V, \dot{V}, \ddot{V}$	Displacement, velocity, acceleration in the ζ-direction	29
ΔV	Incremental displacement in the ζ-direction	30
ΔW	Incremental work done on the soil medium	14
x	x-coordinate, horizontal axis	10
Z	Instantaneous soil sinkage	4
z	z-coordinate, vertical axis	10
(Z/D)	Sinkage ratio	4
α_1	Soil parameter related to the friction angle	30
β	Constant used to define loading and unloading, and (p_s/p_n) ratio.	14
$\Delta\gamma_{\eta\zeta}$	Shear strain increment in the $\eta\zeta$-coordinate system	31
$\Delta_{\epsilon_\eta}, \Delta_{\epsilon_\eta},$ Δ_{ϵ_ξ}	Normal strain increment in the η, ζ, and ξ direction	30
ζ	Coordinate system axis label	10
η	Coordinate system axis label	10
η_c	Stress correction equation parameter	32
λ	Lame's constant	31

LIST OF SYMBOLS (Continued)

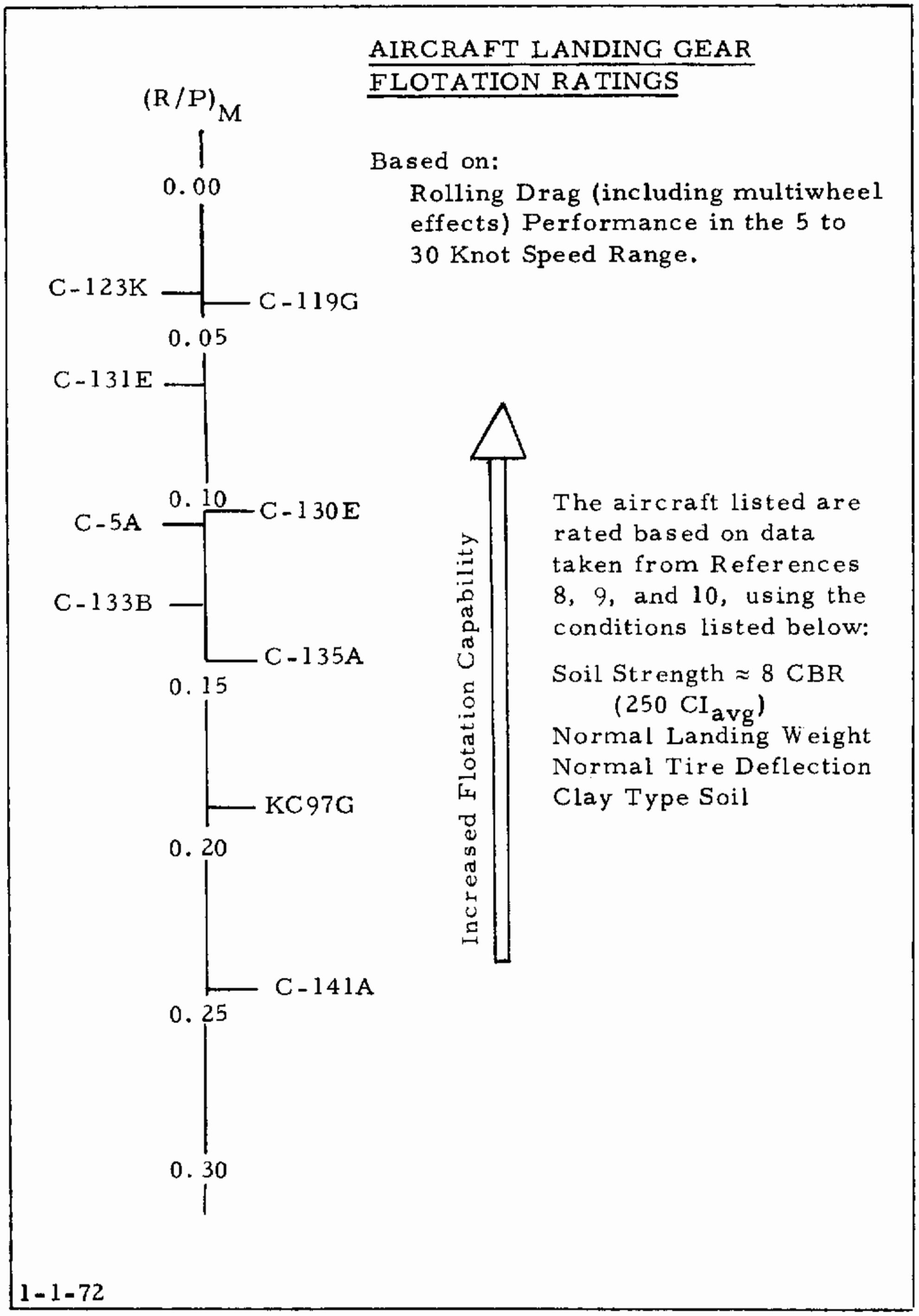
Symbol	Definition	First Page Referenced
ν	Poisson's ratio	7
ρ	Mass density of soil	15
σ_η, σ_ζ	Normal stresses in the η, and ζ directions	29
$\tau_{\eta\zeta}$	Shear stresse in the $\eta\zeta$-coordinate system	29
ϕ	Friction angle of soil	7

SECTION I

INTRODUCTION AND AIRCRAFT FLOTATION/ OPERATION SUMMARY GUIDE

A number of comprehensive efforts(1-7) have been conducted in recent years in studying the problems associated with the operation of military aircraft on forward area soil runways. The results of these efforts have led to an identification of what have been termed the primary and secondary variables which influence aircraft flotation/operation performance. The primary variables are aircraft surface drag, sinkage, multiple wheel effects, braking, soil surface type and strength, and tire size and contained air pressure. Secondary variables include multipass, speed, turning, landing impact, surface roughness, texture, and stress hardening characteristics.

The current research effort described in this report is a part of a continuing research program sponsored by the United States Air Force. The objective of this continuing research program is to: (1) define analytically landing gear-soil interaction; (2) develop a system for comparing and rating the flotation capacity and surface operating capability of landing gear contact elements and landing gear systems during aircraft operations on soil runways; and (3) develop systematic design procedures for optimizing the flotation and surface operating capability of future aircraft. Phase I(3) of this program included a survey of the flotation problem, the establishment of the critical parameters, and an investigation of available flotation data leading to the development of a flotation analysis equation. Phase II(2) included the development of an empirical sinkage prediction equation, development of a lumped parameter simulation sinkage prediction technique, conduction of the Rolling Single Wheel Verification Tests, and the development of the Single Wheel Relative Merit Index (RMI) system for defining comparative flotation capacity (see Figure 1 for a typical comparative rating). Phase III - Part I(1) consisted of the development of the multiwheel sinkage-drag analysis



AIRCRAFT LANDING GEAR FLOTATION RATINGS

Based on:
Rolling Drag (including multiwheel effects) Performance in the 5 to 30 Knot Speed Range.

The aircraft listed are rated based on data taken from References 8, 9, and 10, using the conditions listed below:

Soil Strength ≈ 8 CBR ($250\ CI_{avg}$)
Normal Landing Weight
Normal Tire Deflection
Clay Type Soil

Figure 1. Cargo Type Aircraft Landing Gear Flotation Ratings

equations, conduction of the Multiwheel Verification Tests, and the development of a lumped parameter iteration technique for simulating the interaction of dual tires on soil. Phase III - Part II(7), describes:

- Braked Wheel Verification Tests
- Lumper Parameter Braking Simulation Technique Computer Program
- Development of Braking Analysis Equations for Defining Braking Drag Ratios
- Preliminary Studies of Multipass and Speed Effects.

The results of the tire/soil interaction studies conducted to date, as well as the results of numerous mobility studies, were used to develop the Aircraft Flotation/Operation Summary Guide presented in Table I. The information contained in Table I provides an up to date review of flotation information for aircraft operations and design personnel. The details of the development of this information are available in past reports(1-7). Reference to Table I indicates that considerable progress has been made to date (1972) in establishing and verifying the criteria for the primary flotation variables of sinkage, drag, multiwheel, and braking. Based on these criteria it is now possible to develop systematic landing gear design procedures. One such system(5) which was recently developed is detailed in Figure 2. The basis of the design approach uses drag and sinkage as the optimizing variables in selecting candidate landing gear designs. Each design is then further evaluated by the multipass analysis procedure and the resulting information is used to select the finalized landing gear design. As additional information becomes available on landing gear loads, aircraft turning interactions, landing gear storage volumes, and weight trade-offs, a full optimization design procedure will be developed.

TABLE I

QUICK REFERENCE-TIRES ON SOIL FLOTATION GUIDE

FLOTATION VARIABLE	SINKAGE AND DRAG	VELOCITY
Single Wheel	- Drag Ratio (R/P) correlates with sinkage ratio (Z/D) $R/P = 0.018 + 3.23(Z/D)$, all soils, Region II velocity range - Sinkage prediction techniques available for sand and clay, Region II velocity range UDRI WES - High speed (Region III) sinkage/drag theory preliminarily defined by UDRI - Low speed (Region I) sinkage/drag relationship not important - Flotation performance improves with: increasing tire diameter increasing tire deflection increasing soil strength decreasing tire load	3 Regions of sinkage/drag variance Approximate $0 \leq$ Region I ≤ 5 knots 5 knots $\leq$ Region II ≤ 40 knots 40 knots $<$ Region III
Multiple Wheel	Optimum spacing based on drag minimization (Region II velocity range) (see Reference 1)	Velocity influence on optimum multiple wheel spacing is not known. Very likely optimum spacing not influenced by Region I and III velocities.
Twin	- 1.75 b to 2.5 b, sand - 2.5 b to 3.5 b, clay	
Tandem-Tracking	- ≤ 1.75 D or ≥ 2.5 D, sand - 1.5 D to 2.5 D, clay	
Tandem-Nontracking	- > 1.25 b > 1.25 D all soils	
Braked Wheel	- Braking drag ratio (R_B/P) analysis equations available - Braking drag ratio (R_B/P) independent of initial sand soil strength - Sinkages increase markedly for braking in sand - Sinkages increase moderately for braking in clay - Braking drag ratio increases with: increasing sinkage, sand and clay increasing slip, sand and clay	**Velocity is known not to effect the R_B/P for clay soils in the 3 to 15 knot range. Velocity does affect the braked sinkage in sand in the 3 to 15 knot speed range. The effects of higher speeds on braking has not been established as of 1-1-72.**

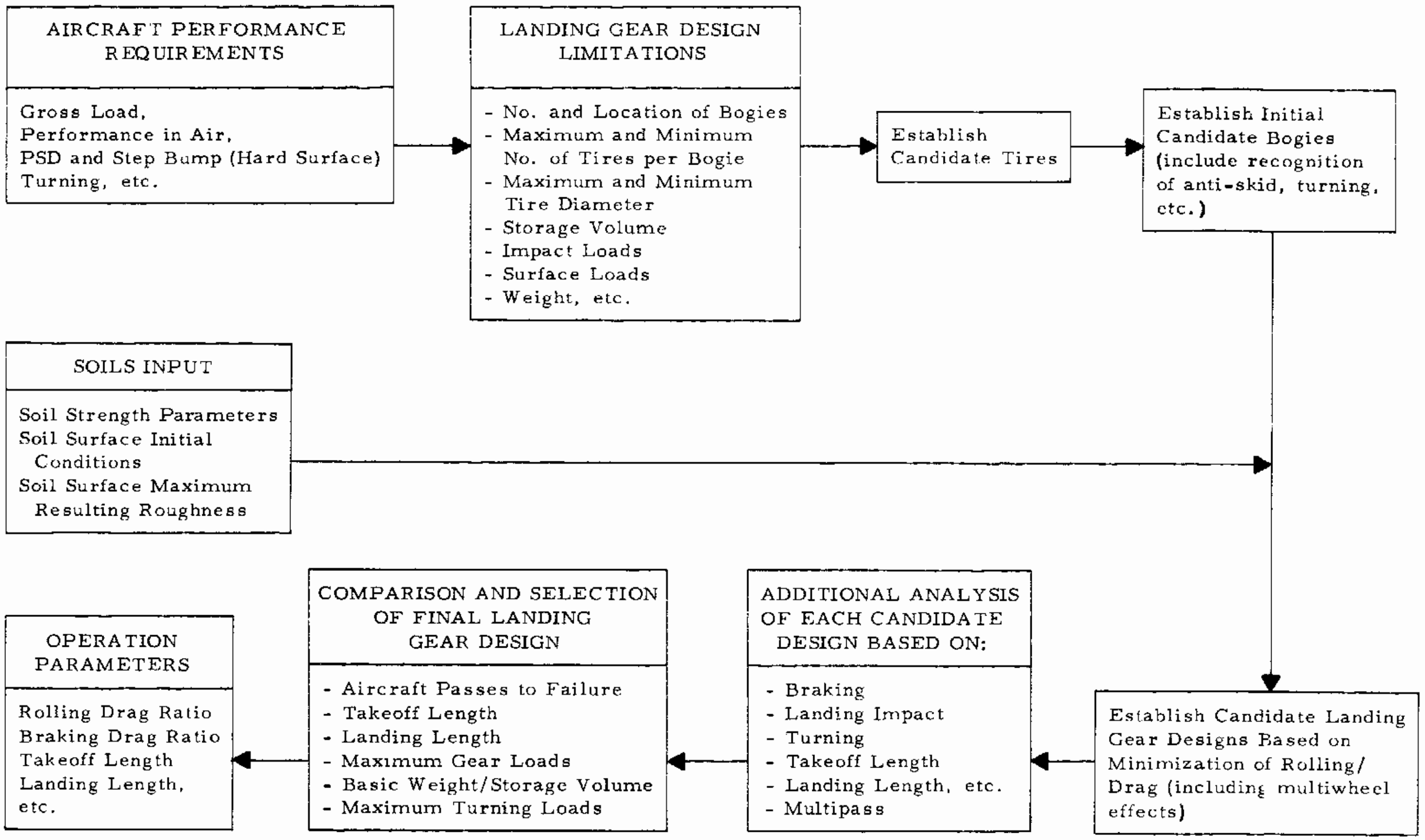


Figure 2. Landing Gear System Design for Aircraft Flotation/Operation on Soil Runways

SECTION II

ANALYTICAL BRAKING ANALYSIS

The interaction of aircraft tires with soil runways while an aircraft tire is being braked is a complex phenomenon.(7) In actuality, braking does not occur independently of other equally complicated effects such as the rolling action of tires, the speed of the aircraft, and turning. Also, proximate tires interact, the behavior is basically three-dimensional, the composition and material properties of soils are usually uncertain, etc. The purpose of this section is to describe the idealized problem considered and the analytical/numerical approach utilized to approximate the sinkage of a braked aircraft tire into a soil runway.

A. PROBLEM DEFINITION

The idealized problem which was considered is defined below by listing the assumptions which were made and discussing the loading, region of solution, and boundary conditions.

Assumptions

- A single wheel is in contact with the sample of soil under consideration.

- Only vertical loading and horizontal shear loading are applied to the soil surface.

- The deformation of the soil material due to the loading considered results in a state of plane strain; thus, the problem is considered to be two-dimensional.

Loading

Figure 3 shows the portion of the soil surface which is loaded by a uniform vertical pressure, p_n, and a uniform shear distribution, p_s. The indicated loading is intended to represent the effective loading applied by an aircraft tire during braking.

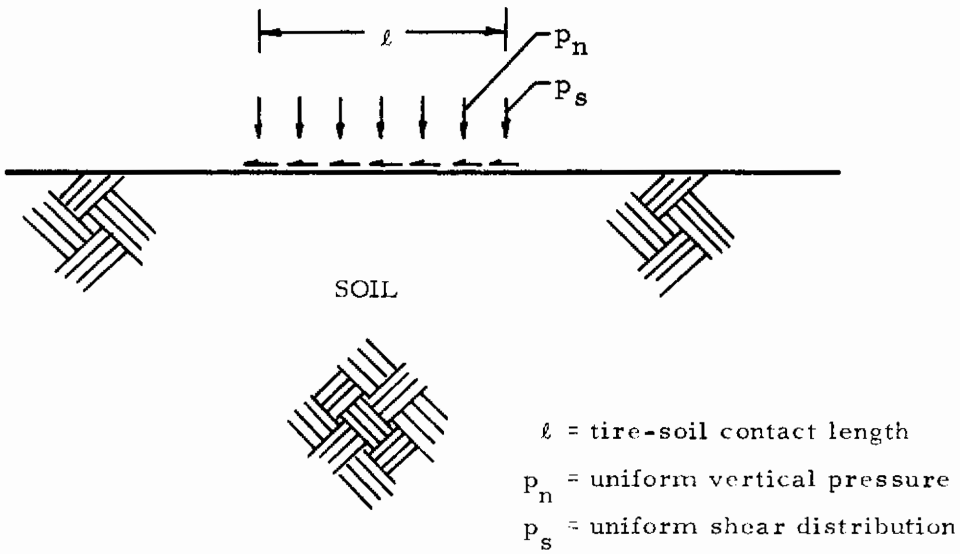


Figure 3. Simulated Loading During Braking

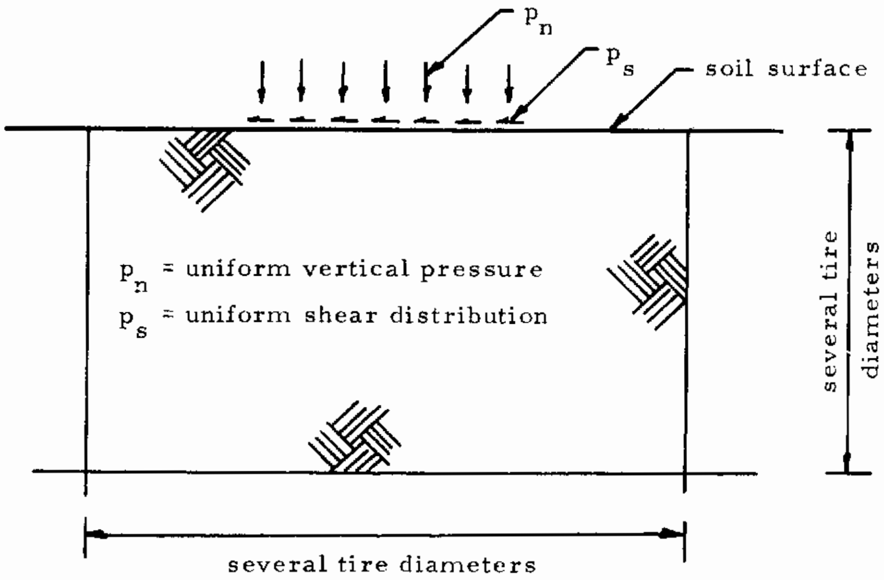


Figure 4. Region of Solution

Region of Solution

The loading shown in Figure 3 is applied to a soil surface which is infinite in length and depth. In order to obtain a solution by numerical means, the extent of the region affected by the loads must be restricted to be finite. Figure 4 shows the region of the soil medium considered in the computations. The dimensions of the considered region were selected such that the applied loading has negligible effect on the displacements at the extremities of the region.

Boundary Conditions

- Under the applied loads the normal stress is equal to the applied vertical pressure and the shear stress is equal to the applied shear stress.

- The shear and normal stresses are zero on the remainder of the soil surface.

- The displacements are zero on the artificial boundaries which limit the extent of the soil medium (Figure 4).

B. ANALYTICAL/NUMERICAL APPROACH

The soil medium was taken to be elastic-perfectly plastic with the elastic deformations governed by Hooke's Law, the plastic deformations governed by an incremental stress-strain relation based on the normality flow rule, and the plastic yielding governed by the Drucker-Prager yield criterion. The primary soil parameters of the soil model consist of the elastic Young's modulus (E), the Poisson's ratio (ν), the cohesion (c), and the friction angle (ϕ).

The analytical/numerical approach utilized to obtain approximate solutions to idealized braked tire/soil interactions problems is the lumped parameter iteration technique. This approach has been used in all other phases of this project and is well documented. Therefore, the reader is referred to other reports, such as References 1 and 6, for a detailed description of the lumped parameter technique.

The soil region of Figure 4 was modeled by the lumped parameter technique as shown in Figure 5. The mathematical relations, which govern the behavior of the lumped parameter model of a soil medium subjected to surface loading, are summarized in Appendix I.

The vertical pressure-time curve is shown in Figure 6; this is taken to be the same pressure pulse used previously so that comparisons can be made between various phases of this project in the future if desired. For the case in which braking effects are present, the horizontal shear loading (Figure 3) is taken to have the same time variation as the vertical load (Figure 6) and the magnitude of the shear load is expressed as a percentage of the vertical pressure($\beta = P_s/P_n$).

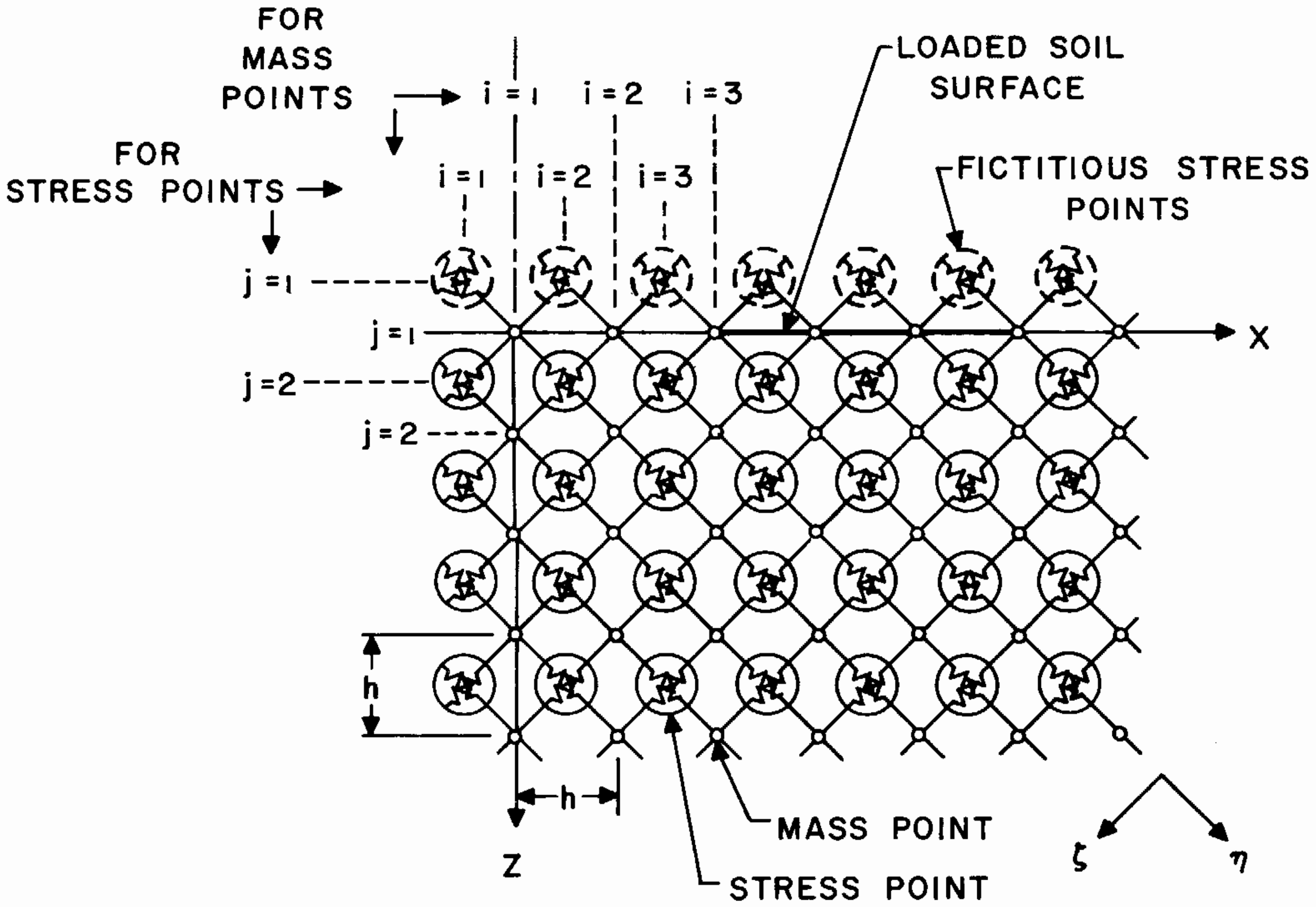


Figure 5. Lumped Parameter Model for Plane Strain

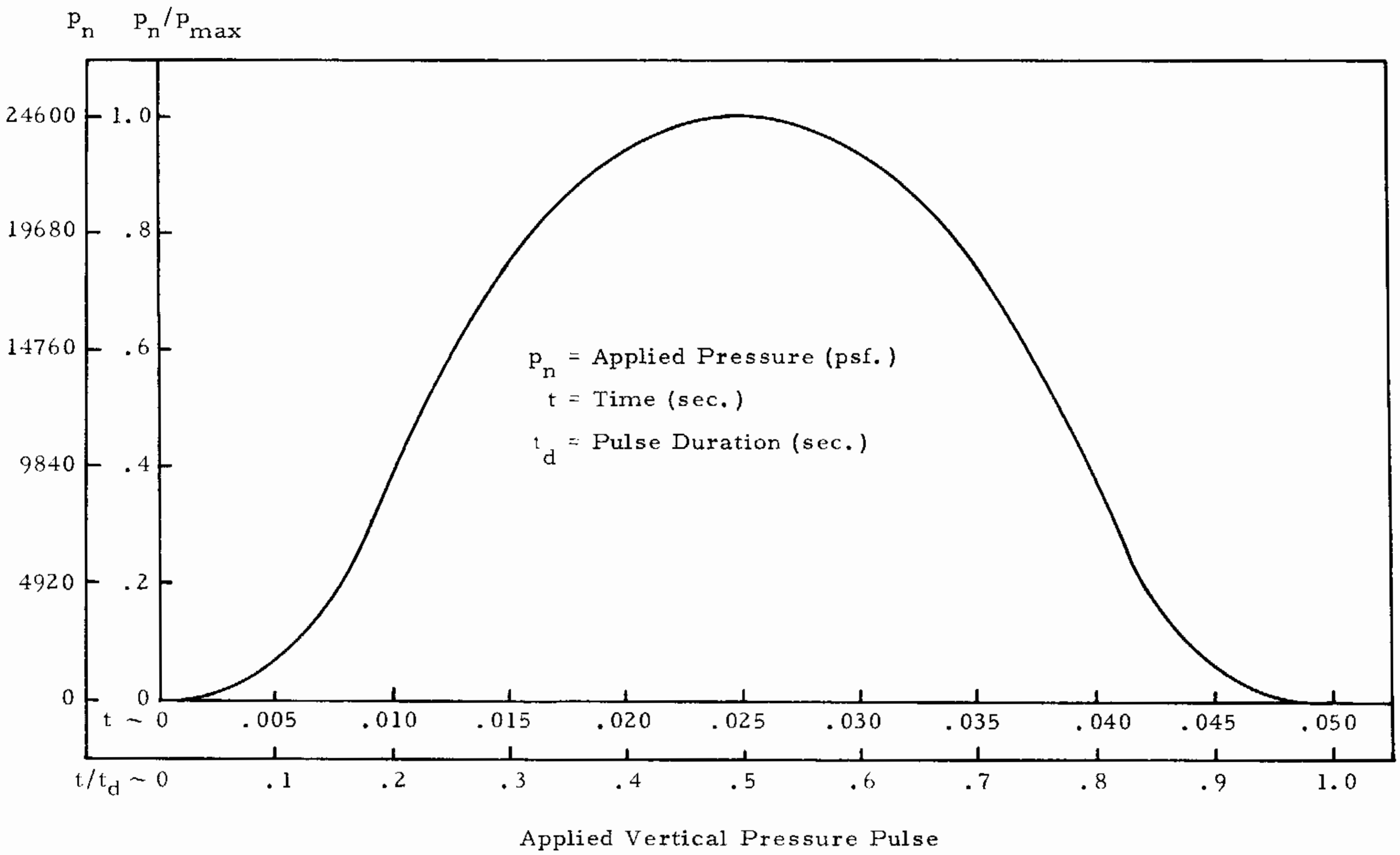


Figure 6. Applied Vertical Pressure Pulse - Braking Problem

SECTION III

COMPUTER PROGRAM

A FORTRAN IV computer program has been prepared to implement the braked-wheel/soil interaction mathematical model on the CDC 6600 computer at Wright-Patterson Air Force Base. This section contains a description of the subject computer program as well as instructions for the use of the program to obtain numerical results for particular problems.

A. PROGRAM DESCRIPTION

The braked wheel sinkage prediction computer program consists of five FORTRAN IV subroutines which are overlaid to conserve core storage. The source deck listings of the various subroutines, as well as the overlay and calling programs, are contained in Appendix II. A general flow chart of the computer program is presented in Figure 7, and a more detailed flow diagram is given in Figure 8 of the displacement and stress calculation procedure. Brief descriptions of the particular function(s) of each of the subroutines shown in Figure 7 are given below.

Subroutine SRDAT

The sole purpose of this subroutine is to read input data from punched cards which contain a complete description of the problem to be considered, e.g., geometry, material properties, loading, input and output tape information.

Subroutine SDAT1

The functions of this subroutine are to print out the input data in a convenient tabular form, to calculate and print out a number of soil parameters using the input data, and to nondimensionalize various parameters needed for other parts of the computation.

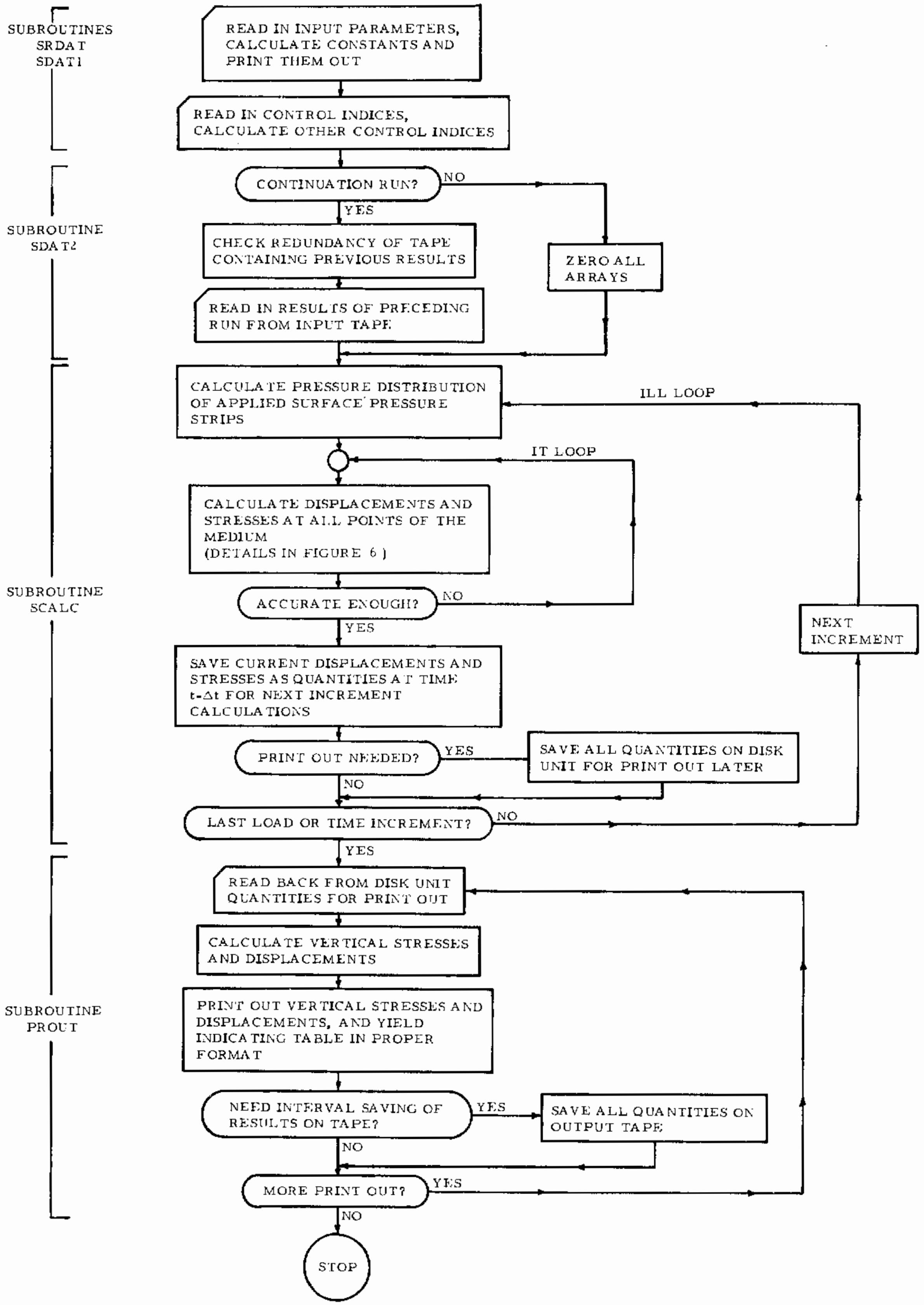


Figure 7. General Flow Chart of Computer Program

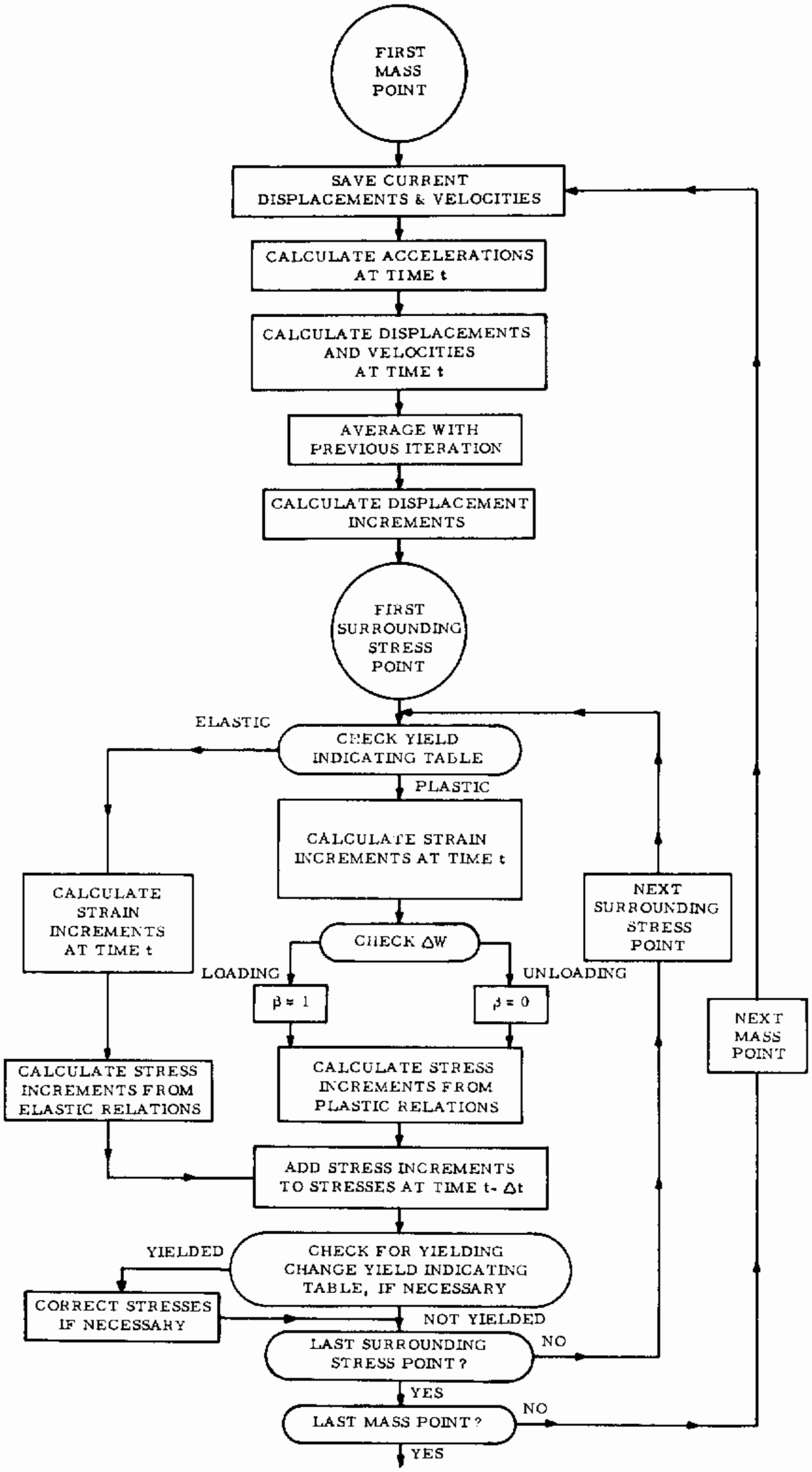


Figure 8. Part of Program for Calculation of Displacements and Stresses

Subroutine SDAT2

This subroutine performs different functions depending on whether the input data indicates that a new problem is being considered or that a restart run is desired. The former option causes this subroutine to initialize various arrays required in the computations. The latter option causes this subroutine to read the restart information from tape.

Subroutine SCALC

This subroutine represents the main part of the computer program since all of the solution loops are contained in SCALC. As indicated in Figure 7, SCALC increments the applied loading, computes displacements and stresses, stores information on disc as required, etc.

Subroutine PROUT

This subroutine prints out the results of the numerical computations performed in subroutine SCALC in a convenient form, and stores on magnetic tape sufficient information to restart the computations in a later run.

B. PREPARATION OF INPUT DATA

Instructions for preparing input data for the braked wheel sinkage prediction computer program are given below. The data are divided into sets of one or more cards each.

Set 1 (one card) - This set is provided so that the user can supply title information which appears on the first page of output. The first 40 columns can be filled with any alphanumeric characters.

Set 2 (one card) - Material properties are specified with this set:

RHO (Cols. 1-8) - Soil density (lb/ft.^{3}) (ρ)
PO (Cols. 9-14) - Poisson's ratio (ν)
E (Cols. 15-22) - Young's modulus (psi) (E)
C (Cols. 23-30) - Cohesion (psf) (c)
PHI (Cols. 31-38) - Friction angle (deg.) (ϕ)

Set 3 (one card) - This set contains information about the loading and geometry:

TD (Cols. 1-10) - Total time duration (sec) of the applied loading of Figure 6

FPL (Cols. 11-20) - Tire footprint length (in.) (ℓ) of Figure 3

PKP (Cols. 21-30) - Peak load (psf) (p_{max}) of Figure 6

WOT (Cols. 31-40) - Yield function unloading tolerance (β) (dimensionless). A value of 5.0×10^{-5} is suggested.

IB (Cols. 41-45) - Mass point number at left-hand extremity of applied pressure (Figures 5 and 9)

IEN (Cols. 46-50) - Mass point station number at right-hand extremity of applied pressure (Figures 5 and 9)

BETA (Cols. 51-60) - Ratio of the applied shear loading to the applied vertical pressure (p_s/p_n)

Set 4 (one card) - This set provides geometry and load incrementation information:

H (Cols. 1-8) - Distance (in.) between mass points (h) (Figure 5)

DT (Cols. 9-20) - Time increment (sec) (t_c)

M (Cols. 21-25) - Number of mass points horizontally (M')

N (Cols. 26-30) - Number of mass points vertically (N')

Set 5 (five cards) - This set specifies the time variation of the applied loading. The left half of the pressure vs. time curve of Figure 6 is divided into 20 equal parts; then the 21 pressure magnitudes are punched onto cards in 5F11.2 format.

Set 6 (one card) - Blank

Set 7 (one card) - This card specifies input and output tape numbers:

NIT (Cols. 2-6) - Input tape number

NOT (Cols. 6-11) - Output tape number

Set 8 (one card) - This set specifies various indices which control input, output, and tape operations. The 16 indices provided by this set are punched in a 1X, 16I5 format. Initially this card is prepared completely by the user; however, after the first run all but one piece of data are printed out and all the user has to do is supply one data item.

a) For the first run Set 8 has the form

1 LEN ILI IEI JLI 0 0 0 0 1 9 10 0 0 1 0

The user supplies:

LEN - First load increment for this run

ILI - Print every ILI load increments

IRI - same as ILI

JLI - Write on tape every JLI increments

b) For continuation runs all information except LEN is printed out on the output tab of the previous run. The user simply punches this onto a punched card and supplies a new value of LEN.

SECTION IV

NUMERICAL RESULTS

Several example cases have been processed with the braked wheel sinkage prediction computer program. The soil, load, and computational parameters which are common to all of the examples are:

Soil Parameters:	
Density	ρ = 130 lb/cu. ft.
Poisson's Ratio	ν = 0.45
Young's Modulus	E = 8950 psi
Cohesion	c = 2000 psf
Friction Angle	$\phi = 15^\circ$
Shear Yield Stress	k = 2440 psi
Load Parameters:	
Tire Footprint Length	ℓ = 12.0 in.
Peak Surface Pressure	p_{max} = 24600 psf
Pulse Duration	t_d = 0.05 sec
Computational Parameters:	
Time Increment	$\Delta t = 6.25 \times 10^{-5}$ sec.
Space Mesh Size	h = 3.0 in.
No. Width Mesh Points	M' = 47
No. Depth Mesh Points	N' = 27

The difference between the various sample cases is the magnitude of the applied surface shear loading. In particular, the loading conditions considered were $\beta = p_s/p_n = 0, .1, .2, .25$, where the normal load p_n was applied according to Figure 6.

Figures 9 through 14 summarize the results obtained using the braked wheel sinkage prediction computer program described in the previous section. Figures 9 and 10 show the maximum deflection and the permanent deflection

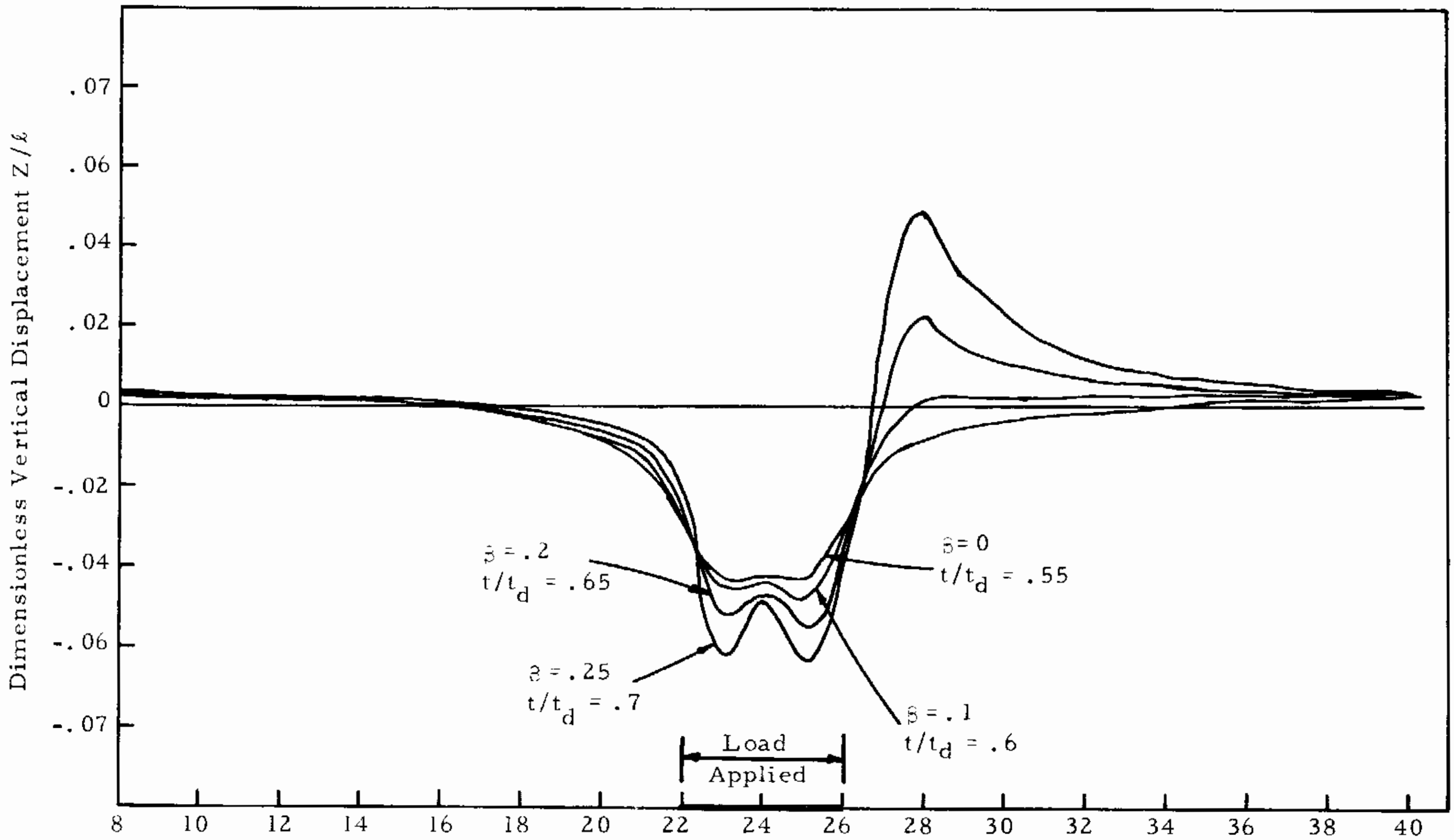


Figure 9. Maximum Vertical Displacement of Soil Surface

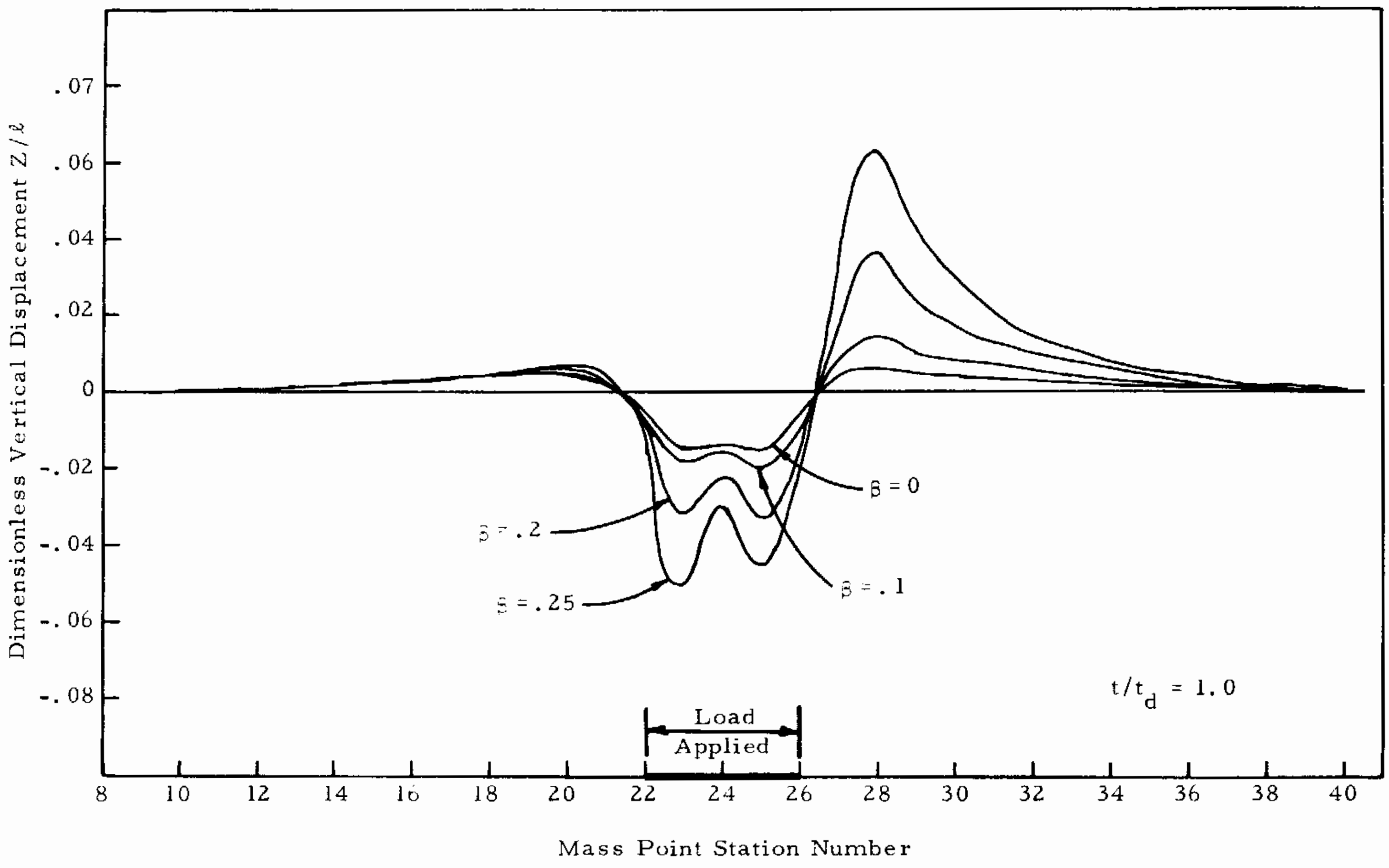


Figure 10. Permanent Vertical Displacement of Soil Surface

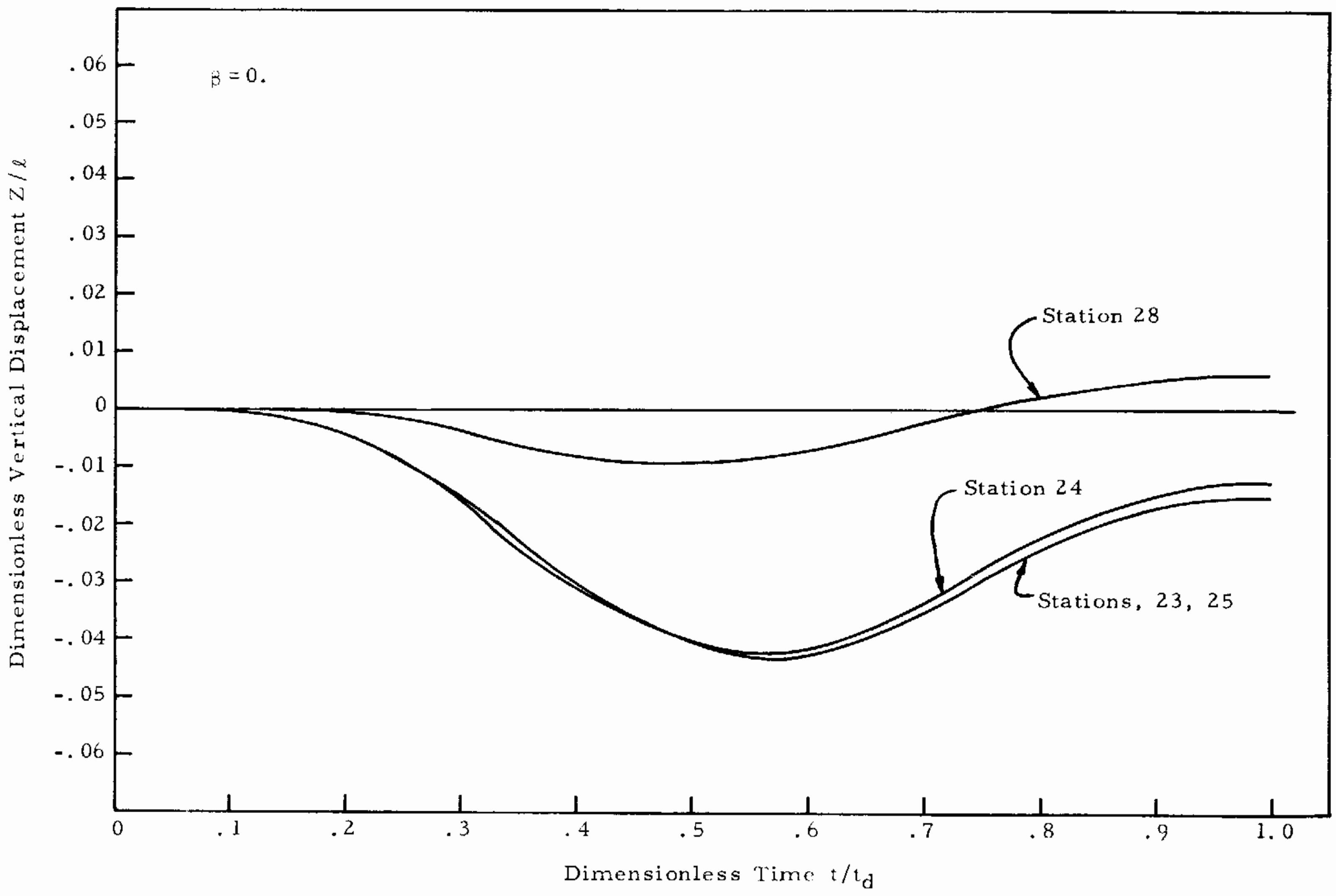


Figure **11.** Vertical Displacements of Mass Points 23, 24, 25, 28 vs. Time ($\beta = 0$)

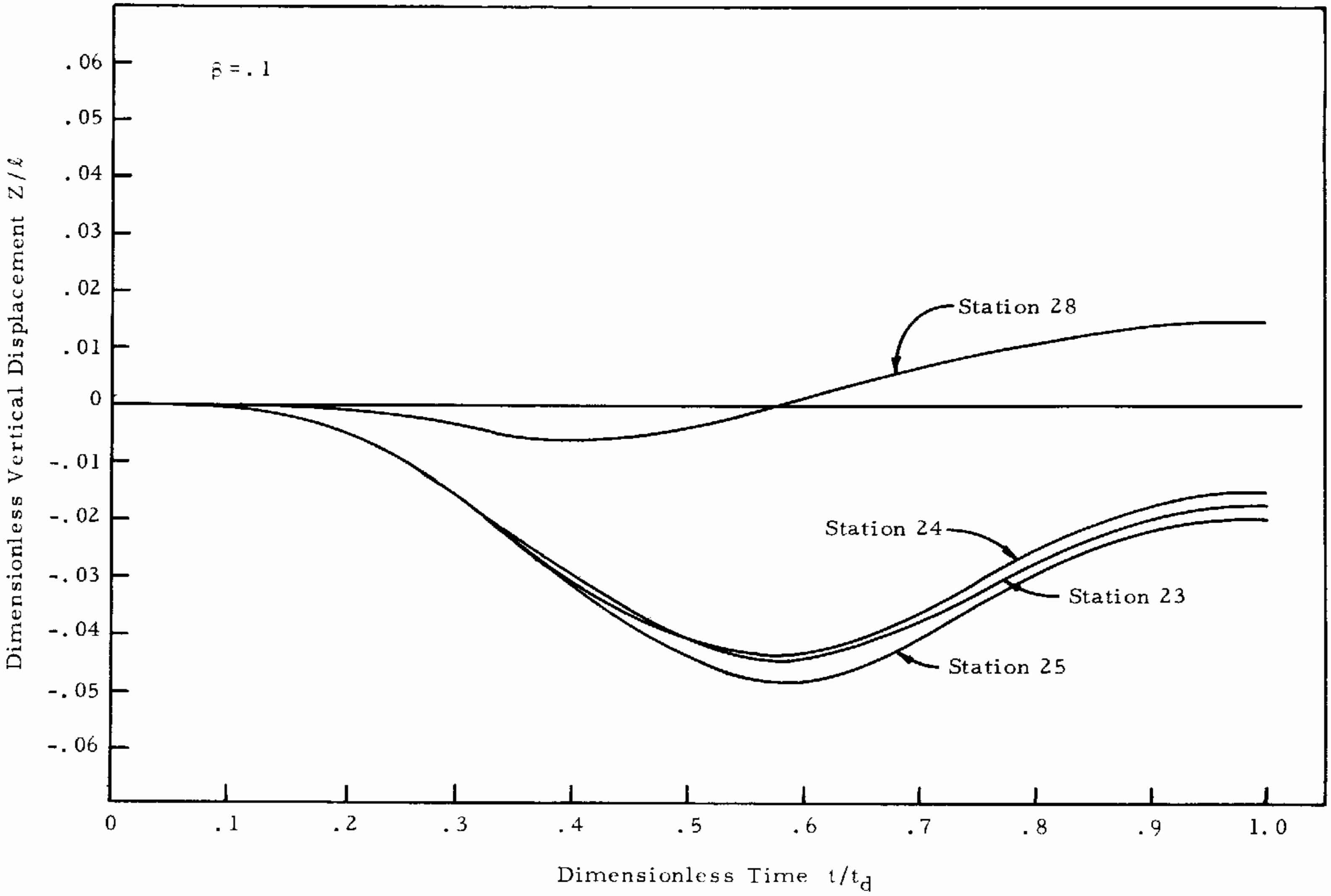


Figure **12.** Vertical Displacements of Mass Points 23, 24, 25, 28 vs. Time ($\beta = .1$)

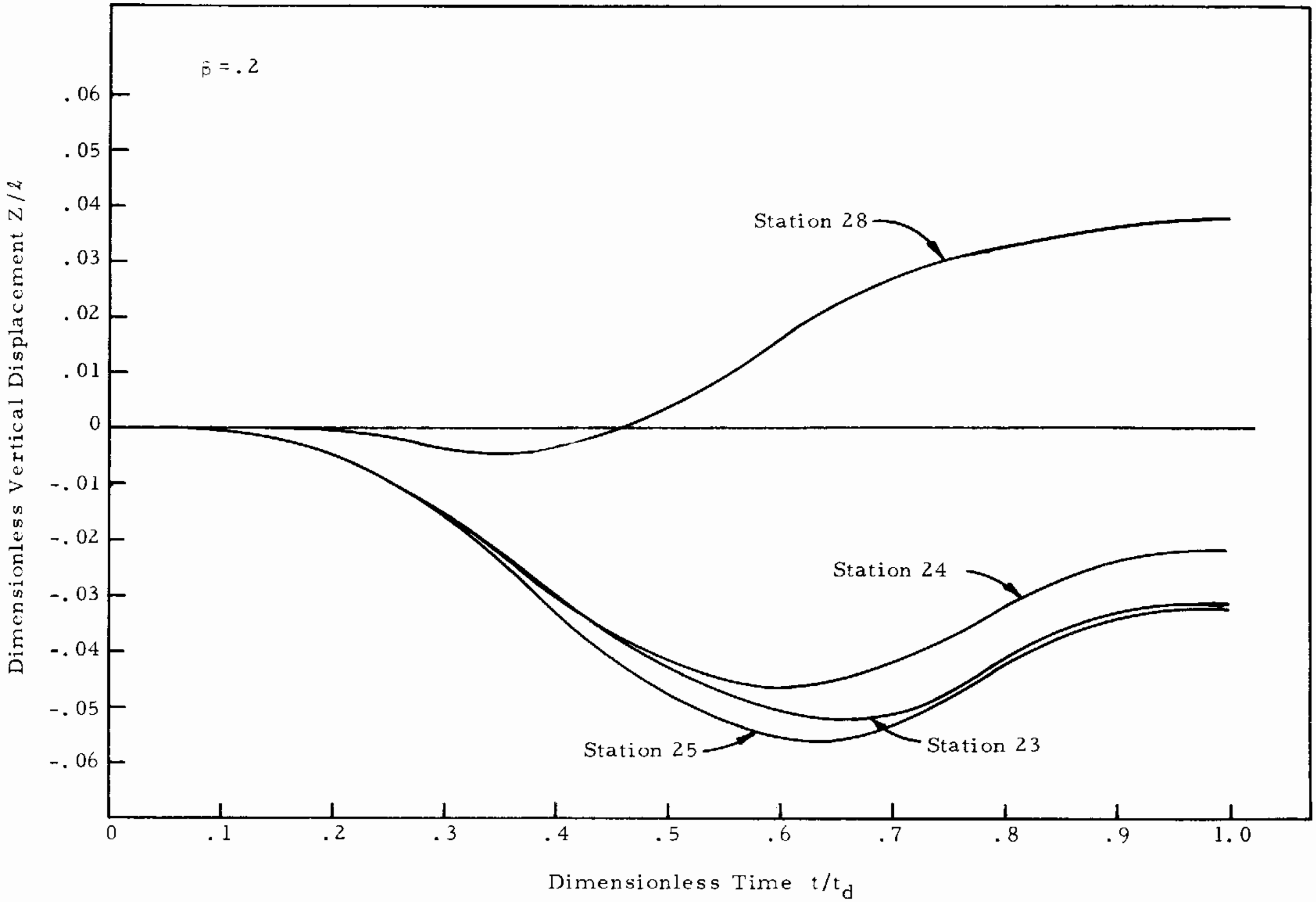


Figure 13. Vertical Displacementsof Mass Points 23, 24, 25, 28 vs. Time ($\beta = .2$)

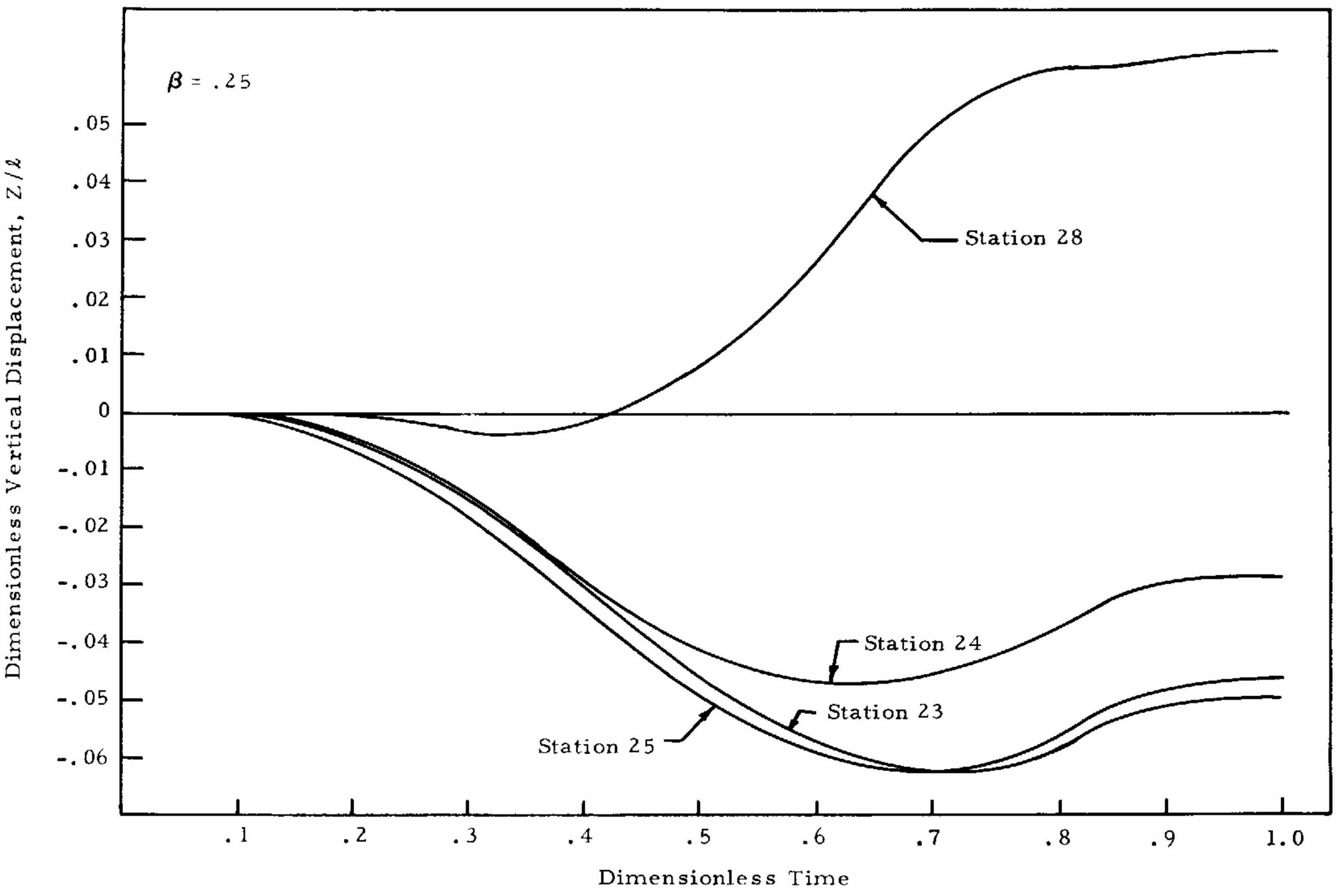


Figure 14. Vertical Displacements of Mass Points 23, 24, 25, 28 vs. Time (β = .25)

profiles of the soil surface for each of the four loading cases. Figures 11, 12, 13, and 14 trace the complete time history of the vertical deflections of mass point Stations 23, 24, 25, and 28. Stations 23, 24, and 25 are situated within the loaded surface area while Station 28 is located at the point of maximum soil build-up in front of the loaded area.

The sinkage profile under the loaded region (Stations 22-26) did not appear too realistic at first glance since that is not what one would expect if a metal plate were subjected to the same loading. However, it must be realized that a metal plate is very stiff and would resist such a deformation, whereas the idealized problem considered actually corresponds to the case when the loading is transmitted to the soil through a thin flexible membrane since the soil surface is completely free to deform. When this is taken into consideration it is not too difficult to imagine the displacement profile shown under the applied loading in Figures 9 and 10. Figures 9 and 10 also indicate that there is a substantial build-up of soil immediately in front of the braked tire; this certainly is an expected phenomenon.

Figures 11 through 14 show clearly the "rebound effect" which occurs under the loaded region (Stations 23, 24, and 25); that is, as time increases the vertical displacement first grows to a maximum value and then diminishes until a permanent steady state sinkage is attained. Figures 11 through 14 also show the vertical displacement time history of Station 28, the point at which maximum build-up of soil occurs in front of the loaded region. For small times, this point behaves as though no braking were present (the displacement of this point is in the same direction as the points under the load for small times) and then pile-up begins. The upward displacement of Station 28 also increases to a maximum value, but instead of decreasing to a steady state value, it increases further until steady state is reached (this is most apparent in Figure 14). Apparently, the rebounding of the soil under the load causes additional pile-up of soil in front of the loaded region. Also, the build-up of soil in front of the loaded region begins to occur at an earlier time as the shear load is increased.

Another interesting phenomenon can be seen in Figures 9 through 14 when the relative magnitudes of the displacements of Stations 23 and 25 are noted. For the zero braking case ($\beta = 0$, Figure 9) Stations 23 and 25 deflect the same amount. For the $\beta = .1$ and $\beta = .2$ cases the deflections of Station 25 is greater than that of Station 23 which indicates that the tire "noses down". However, for the largest shear loading ($\beta = .25$, Figure 14), the loaded region "noses down" until the maximum deflection is attained and then "noses up" during the rebound period.

The following table shows the maximum and permanent nondimensional displacements and also the ratios $(Z_{max})_{braked}/(Z_{max})_{unbraked}$ and $(Z_{perm})_{braked}/(Z_{perm})_{unbraked}$ for the various loading cases.

TABLE II

NONDIMENSIONAL DISPLACEMENTS AND RATIOS

β	Max $\frac{Z}{\ell}$	Ratio	Perm $\frac{Z}{\ell}$	Ratio
0	.0435	1.0	.015	1.0
.1	.0480	1.1	.020	1.3
.2	.0560	1.3	.0325	2.2
.25	.0625	1.4	.0495	3.3

Braking Verification Tests show the ratio of $(Z_{max})_{braked}$ to $(Z_{max})_{unbraked}$ to be in the range of 1.5 to 3.0 for predominately cohesive type soils when the ratio of $\beta = P_s/P_n$ approaches one (1.0).

The total computer run time to compute the permanent steady state sinkage by incrementing the load to its maximum value and then completely removing it was about 35 minutes for each load case.

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APPENDIX I

GOVERNING EQUATIONS, LUMPED PARAMETER MODEL

GOVERNING EQUATIONS

The equations of continuum elasticity and plasticity used in the lumped parameter iteration method are listed in this section in the form applicable to the lumped parameter model shown in Figure 5.

A. DYNAMIC EQUATIONS OF MOTION

$$\rho \ddot{U}(i,j) = \frac{\sigma_\eta(i+1,j+1) - \sigma_\eta(i,j)}{h/\sqrt{2}} + \frac{\tau_{\eta\zeta}(i,j+1) - \tau_{\eta\zeta}(i+1,j)}{h/\sqrt{2}} \quad \text{(A-1a)}$$

$$\rho \ddot{V}(i,j) = \frac{\sigma_\zeta(i,j+1) - \sigma_\zeta(i+1,j)}{h/\sqrt{2}} + \frac{\tau_{\eta\zeta}(i+1,j+1) - \tau_{\eta\zeta}(i,j)}{h/\sqrt{2}} \quad \text{(A-1b)}$$

where

U and V are the displacements in the η and ζ directions, respectively;

σ_η and σ_ζ are the normal stresses and $\tau_{\eta\zeta}$ is the shear stress;

ρ is the mass density of the soil;

h is the grid size; and

the dots indicate time derivatives.

B. QUADRATURE EQUATIONS

$$U^t = U^{t-\Delta t} + (\Delta t)\dot{U}^{t-\Delta t} + \frac{(\Delta t)^2}{6}\left[2\ddot{U}^{t-\Delta t} + \ddot{U}^t\right] \quad \text{(A-2a)}$$

$$V^t = V^{t-\Delta t} + (\Delta t)\dot{V}^{t-\Delta t} + \frac{(\Delta t)^2}{6}\left[2\ddot{V}^{t-\Delta t} + \ddot{V}^t\right] \quad \text{(A-2b)}$$

$$\dot{U}^t = \dot{U}^{t-\Delta t} + \frac{\Delta t}{2}\left[\ddot{U}^{t-\Delta t} + \ddot{U}^t\right] \quad \text{(A-2c)}$$

$$\dot{V}^t = \dot{V}^{t-\Delta t} + \frac{\Delta t}{2}\left[\ddot{V}^{t-\Delta t} + \ddot{V}^t\right] \quad \text{(A-2d)}$$

where

Δt is the time increment, and superscript $(t-\Delta t)$ indicates the variables of the previous load increment.

C. DRUCKER-PRAGER YIELD CRITERION

The criterion states that if the yield function, f, as defined below is less than zero, the stress point is elastic, and if f is equal to or greater than zero, the stress point has yielded.

$$\text{Yield function} = f = \alpha I + \sqrt{J} - k \tag{A-3}$$

where

$$I = \sigma_\eta + \sigma_\zeta + \sigma_\xi \tag{A-4}$$

$$J = \frac{1}{6}\left[(\sigma_\eta - \sigma_\zeta)^2 + (\sigma_\zeta - \sigma_\xi)^2 + (\sigma_\xi - \sigma_\eta)^2 + 6\tau_{\eta\zeta}^{\;2}\right] \tag{A-5}$$

$$\sigma_\xi = \nu(\sigma_\eta + \sigma_\zeta) \tag{A-6}$$

$$\alpha_1 = \frac{2\sin\phi}{\sqrt{3}\,(3-\sin\phi)} \tag{A-7}$$

$$k = \frac{6\,c\cos\phi}{\sqrt{3}\,(3-\sin\phi)} = \text{yield stress in shear} \tag{A-8}$$

c = cohesion

ϕ = friction angle

D. INCREMENTAL STRAIN-DISPLACEMENT RELATIONS

$$\Delta\epsilon_\eta(i,j) = \frac{\Delta U(i,j) - \Delta U(i-1,j-1)}{h/\sqrt{2}} \tag{A-9a}$$

$$\Delta\epsilon_\zeta(i,j) = \frac{\Delta V(i-1,j) - \Delta V(i,j-1)}{h/\sqrt{2}} \tag{A-9b}$$

$$\Delta\epsilon_\xi(i,j) = 0 \tag{A-9c}$$

$$\Delta\gamma_{\eta\zeta}(i,j) = \frac{\Delta U(i-1,j) - \Delta U(i,j-1)}{2h/\sqrt{2}} + \frac{\Delta V(i,j) - \Delta V(i-1,j-1)}{2h/\sqrt{2}} \tag{A-9d}$$

where

$\Delta\epsilon_\eta$, $\Delta\epsilon_\zeta$, and $\Delta\epsilon_\xi$ are the normal strain increments,

$\Delta\gamma_{\eta\zeta}$ is the shear strain increment, and

$$\Delta U = U^{t} - U^{t-\Delta t} \tag{A-10a}$$

$$\Delta V = V^{t} - V^{t-\Delta t} \tag{A-10b}$$

E. INCREMENTAL STRESS-STRAIN RELATIONS

$$\Delta\sigma_{\eta} = \lambda\Delta\epsilon + 2G\Delta\epsilon_{\eta} - \beta Q\left(\frac{\sigma_{\eta}}{2\sqrt{J}} + B\right)\left(\frac{\Delta W}{2\sqrt{J}} + B\Delta\epsilon\right) \tag{A-11a}$$

$$\Delta\sigma_{\zeta} = \lambda\Delta\epsilon + 2G\Delta\epsilon_{\zeta} - \beta Q\left(\frac{\sigma_{\zeta}}{2\sqrt{J}} + B\right)\left(\frac{\Delta W}{2\sqrt{J}} + B\Delta\epsilon)\right) \tag{A-11b}$$

$$\Delta\tau_{\eta\zeta} = 2G\Delta\gamma_{\eta\zeta} - \beta Q\left(\frac{\tau_{\eta\zeta}}{2\sqrt{J}}\right)\left(\frac{\Delta W}{2\sqrt{J}} + B\Delta\epsilon\right) \tag{A-11c}$$

where

$$\Delta\epsilon = \Delta\epsilon_{\eta} + \Delta\epsilon_{\zeta} \tag{A-12}$$

$$B = \frac{1+\nu}{1-2\nu}\ \alpha - \frac{I}{6\sqrt{J}} \tag{A-13}$$

$$Q = \frac{4G}{1 + \frac{6(1+\nu)\alpha^{2}}{1-2\nu}} \tag{A-14}$$

λ = Lame's constant in Hooke's law = $\frac{E\nu}{(1+\nu)(1-2\nu)}$

G = Modulus of rigidity = $\frac{E}{2(1+\nu)}$

ΔW = Increment work done

$$= \sigma_{\eta}\Delta\epsilon_{\eta} + \sigma_{\zeta}\Delta\epsilon_{\zeta} + \tau_{\eta\zeta}\Delta\gamma_{\eta\zeta} \tag{A-15}$$

and

$$\beta = \begin{cases} 1 \text{ if } f \geq 0 \text{ and } \Delta W > 0 \text{ (loading)} \\ 0 \text{ if } f \geq 0 \text{ and } \Delta W < 0 \text{ (unloading) or } f < 0 \text{ (elastic)} \end{cases}$$

Then the stresses at time t are:

$$\sigma_{\eta}^{t} = \sigma_{\eta}^{t-\Delta t} + \Delta\sigma_{\eta}^{t} \tag{A-16a}$$

$$\sigma_{\zeta}^{t} = \sigma_{\zeta}^{t-\Delta t} + \Delta\sigma_{\zeta}^{t} \tag{A-16b}$$

$$\tau_{\eta\zeta}^{t} = \tau_{\eta\zeta}^{t-\Delta t} + \Delta\tau_{\eta\zeta}^{t} \tag{A-16c}$$

F. STRESS CORRECTION EQUATIONS FOR PERFECTLY PLASTIC YIELDING

$$\sigma'_{\eta} = (1-\eta_c)\,\sigma_{\eta} + \eta_c\left[(1+6\alpha_1^{2})\frac{I}{3} - 2\alpha k\right] \tag{A-17a}$$

$$\sigma'_{\zeta} = (1-\eta_c)\,\sigma_{\zeta} + \eta_c\left[(1+6\alpha_1^{2})\frac{I}{3} - 2\alpha k\right] \tag{A-17b}$$

$$\tau'_{\eta\zeta} = (1-\eta_c)\,\tau_{\eta\zeta} \tag{A-17c}$$

where

$$\eta_c = \frac{J - (k - \alpha_1 I)^2}{2J + 12\alpha^2\,(k - \alpha_1 I)^2} \tag{A-18}$$

and

σ'_{η}, σ'_{ζ}, and $\tau'_{\eta\zeta}$ are the corrected stresses.

APPENDIX II

FORTRAN IV SOURCE LISTINGS

```
                                                  CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE       1
      OVERLAY (FMOV,0,0)
      PROGRAM MHVSP (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE8,TAPE9,
     1TAPE10)
C  FRED K. BOGNER -- U D RESEARCH INSTITUTE
C  PROGRAM FOR BRAKED- WHEEL SINKAGE PREDICTION
C  MAIN PROGRAM FOR CALLING THE FIVE OVERLAID SUBROUTINES.
      COMMON/DUMMY/ VD(47,27), UD(47,27),
     1              SX(47,27), SY(47,27), SXY(47,27),
     2              UT(47,27),UDT(47,27),UDDT(47,27), UI(47,27),
     3              VT(47,27),VDT(47,27),VDDT(47,27), VI(47,27),
     4             SXT(47,27),SYT(47,27),SXYT(47,27),YIT(47,27)
      COMMON/CRDAT/ TITLE(4),RHO,E,PHI,TD,FPL,PKP,H,CT
      COMMON/SDAT/ TM,DT,N,M,N1,M1,SI,SIK,CO1,HH,DTT,AL,GG,PO,C,
     1             CO3,P,AP,AAP,LPP,SQR2,WOT,IR,IEN,BETA,
     2             NIN,LS,KT,NTO,KU,KN,PCU(21),PIN(20)
      COMMON/CONTR/LB,LEN,ILI,ILP,IEI,IE,JLI,JLL,NT1,NT2,NT3,NTO,NTI,
     1             NIT,NOT,NLO(20),ICV,CONV
      CALL OVERLAY (4LFMOV,1,0)
      CALL OVERLAY (4LFMOV,2,0)
      CALL OVERLAY (4LFMOV,3,0)
      CALL OVERLAY (4LFMOV,4,0)
      CALL OVERLAY (4LFMOV,5,0)
      STOP 666
      END
```

```
      PROGRAM     MMVSP                                    CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE      2

      SYMBOLIC REFERENCE MAP

 ENTRY POINTS
  5150  MMVSP

 VARIABLES       SN  TYPE              RELOCATION
    22  AAP          REAL                  SDAT          13  AL          REAL                  SDAT
    21  AP           REAL                  SDAT          30  BETA        REAL                  SDAT
    16  C            REAL                  SDAT          44  CONV        REAL                  CONTR
    10  CO1          REAL                  SDAT          17  CO3         REAL                  SDAT
    13  CT           REAL                  CRDAT          1  DT          REAL                  SDAT
    12  DTT          REAL                  SDAT           5  E           REAL                  CRDAT
    10  FPL          REAL                  CRDAT         14  GG          REAL                  SDAT
    12  H            REAL                  CRDAT         11  HH          REAL                  SDAT
    26  IB           INTEGER               SDAT          43  ICV         INTEGER               CONTR
     5  IE           INTEGER               CONTR          4  IEI         INTEGER               CONTR
    27  IEN          INTEGER               SDAT           2  ILI         INTEGER               CONTR
     3  ILP          INTEGER               CONTR          6  JLI         INTEGER               CONTR
     7  JLL          INTEGER               CONTR         36  KN          INTEGER               SDAT
    33  KT           INTEGER               SDAT          35  KU          INTEGER               SDAT
     0  LA           INTEGER               CONTR          1  LEN         INTEGER               CONTR
    23  LPP          INTEGER               SDAT          32  LS          INTEGER               SDAT
     3  M            INTEGER               SDAT           5  M1          INTEGER               SDAT
     2  N            INTEGER               SDAT          31  NIN         INTEGER               SDAT
    15  NIT          INTEGER               CONTR         17  NLO         INTEGER     ARRAY     CONTR
    16  NOT          INTEGER               CONTR         34  NTD         INTEGER               SDAT
    14  NTI          INTEGER               CONTR         13  NTO         INTEGER               CONTR
    10  NT1          INTEGER               CONTR         11  NT2         INTEGER               CONTR
    12  NT3          INTEGER               CONTR          4  N1          INTEGER               SDAT
    20  P            REAL                  SDAT          37  PCU         REAL        ARRAY     SDAT
     6  PHI          REAL                  CRDAT         64  PIN         REAL        ARRAY     SDAT
    11  PKP          REAL                  CRDAT         15  PO          REAL                  SDAT
     4  RHO          REAL                  CRDAT          6  SI          REAL                  SDAT
     7  SIK          REAL                  SDAT          24  SOR2        REAL                  SDAT
  4752  SX           REAL      ARRAY       DUMMY      40161  SXT         REAL        ARRAY     DUMMY
 11724  SXY          REAL      ARRAY       DUMMY      45133  SXYT        REAL        ARRAY     DUMMY
  7337  SY           REAL      ARRAY       DUMMY      42546  SYT         REAL        ARRAY     DUMMY
     7  TD           REAL                  CRDAT          0  TITLE       REAL        ARRAY     CRDAT
     0  TM           REAL                  SDAT        2365  UD          REAL        ARRAY     DUMMY
 21263  UDDT         REAL      ARRAY       DUMMY      16676  UDT         REAL        ARRAY     DUMMY
 23650  UI           REAL      ARRAY       DUMMY      14311  UT          REAL        ARRAY     DUMMY
     0  VD           REAL      ARRAY       DUMMY      33207  VDDT        REAL        ARRAY     DUMMY
 30672  VDT          REAL      ARRAY       DUMMY      35574  VI          REAL        ARRAY     DUMMY
 26235  VT           REAL      ARRAY       DUMMY         25  WOT         REAL                  SDAT
 47520  YIT          REAL      ARRAY       DUMMY

 FILE NAMES          MODE
     0  INPUT                    1023  OUTPUT                  4114  TAPE10                         0  TAPE5
  1023  TAPE6                    2046  TAPE8                   3071  TAPE9

 EXTERNALS            TYPE    ARGS
        OVERLA4                  3

 COMMON BLOCKS    LENGTH
        DUMMY      21573
        CRDAT         12
        SDAT          72
        CONTR         37
```

```
      PROGRAM     MMVSP                          CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE      3

  STATISTICS
    PROGRAM LENGTH      75B       61
     BUFFER LENGTH    5137B     2655
     COMMON LENGTH   52276B    21694
```

```
                                            CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.     PAGE      1
                 OVERLAY (1,0)
                 PROGRAM PRDAT
                 CALL SRDAT
                 END
```

```
        PROGRAM     PRDAT                              CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.     PAGE      2

        SYMBOLIC REFERENCE MAP

    ENTRY POINTS
        2  PRDAT

    EXTERNALS          TYPE    ARGS
        SRDAT                   0

    STATISTICS
      PROGRAM LENGTH      7B        7
```

```
      SUBROUTINE SRDAT
C  THIS SUBROUTINE READS IN PARAMETER DATA
      COMMON/CRDAT/ TITLE(4),RHO,E,PHI,TD,FPL,PKP,H,CT
      COMMON/SDAT/ TM,DT,N,M,N1,M1,SI,SIK,CO1,HH,DTT,AL,GG,PO,C,
     1             CO3,P,AP,AAP,LPP,SQR2,WOT,IB,IEN,BETA,
     2             NIN,LS,KT,NTD,KU,KN,PCU(21),PIN(20)
      COMMON/CONTR/LB,LEN,ILI,ILP,IEI,IE,JLI,JLL,NT1,NT2,NT3,NTO,NTI,
     1             NIT,NOT,NLO(20),ICV,CONV
C  READ IN TITLE OF THE RUN.
      READ (5,129)  TITLE
C READ IN DATA - FIRST  READ CONSISTS OF SOIL PARAMETERS
C               SECOND READ CONSISTS OF LOAD PARAMETERS
C               THIRD  READ CONSISTS OF COMPUTATIONAL PARAMETERS
C               FOURTH READ CONSISTS OF LOAD CURVE
      READ (5,100) RHO,PO,E,C,PHI
      READ (5,101) TD,FPL,PKP,WOT,IB,IEN,BETA
      READ (5,102) H,DT,M,N
      READ (5,140)  (PCU(I),I=1,21)
C READ IN THE VALUE OF THE COHESION OF THE TAPE DATA WHICH IS USED FOR
C  CONVERSION.
      READ (5,140) CT
C READ IN TAPE NUMBERS OF THE TAPE SETUP ON UNIT 9 AND 10,RESPECTIVELY
      READ (5,141) NIT,NOT
C READ IN STARTING LOAD INCREMENT NUMBER AND ENDING LOAD INCREMENT
C NUMBER, AND OTHER CONTROL INDICES
      READ (5,141) LB,LEN,ILI,IEI,JLI,NT1,NT2,NT3,LPP,NTI,NTO,ICV
      RETURN
  100 FORMAT(F8.1,F6.2,3F8.1)
  101 FORMAT (2F10.3,F10.2,E10.2,2I5,F10.4)
  102 FORMAT (F8.3,E12.6,2I5)
  129 FORMAT (4A10)
  140 FORMAT (5F11.2)
  141 FORMAT (1X,16I5)
      END
```

```
        SUBROUTINE  SRDAT                              CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE       2

        SYMBOLIC REFERENCE MAP

ENTRY POINTS
    1   SRDAT

VARIABLES      SN  TYPE              RELOCATION
   22   AAP        REAL                   SDAT         13   AL         REAL                SDAT
   21   AP         REAL                   SDAT         30   BETA       REAL                SDAT
   16   C          REAL                   SDAT         44   CONV       REAL                CONTR
   10   CO1        REAL                   SDAT         17   CO3        REAL                SDAT
   13   CT         REAL                   CRDAT         1   DT         REAL                SDAT
   12   DTT        REAL                   SDAT          5   E          REAL                CRDAT
   10   FPL        REAL                   CRDAT        14   GG         REAL                SDAT
   12   H          REAL                   CRDAT        11   HH         REAL                SDAT
  155   I          INTEGER                             26   IB         INTEGER             SDAT
   43   ICV        INTEGER                CONTR         5   IE         INTEGER             CONTR
    4   IEI        INTEGER                CONTR        27   IEN        INTEGER             SDAT
    2   ILI        INTEGER                CONTR         3   ILP        INTEGER             CONTR
    6   JLT        INTEGER                CONTR         7   JLL        INTEGER             CONTR
   36   KN         INTEGER                SDAT         33   KT         INTEGER             SDAT
   35   KU         INTEGER                SDAT          0   LB         INTEGER             CONTR
    1   LEN        INTEGER                CONTR        23   LPP        INTEGER             SDAT
   32   LS         INTEGER                SDAT          3   M          INTEGER             SDAT
    5   M1         INTEGER                SDAT          2   N          INTEGER             SDAT
   31   NIN        INTEGER                SDAT         15   NIT        INTEGER             CONTR
   17   NLO        INTEGER      ARRAY     CONTR        16   NOT        INTEGER             CONTR
   34   NTD        INTEGER                SDAT         14   NTI        INTEGER             CONTR
   13   NTO        INTEGER                CONTR        10   NT1        INTEGER             CONTR
   11   NT2        INTEGER                CONTR        12   NT3        INTEGER             CONTR
    4   N1         INTEGER                SDAT         20   P          REAL                SDAT
   37   PCU        REAL         ARRAY     SDAT          6   PHI        REAL                CRDAT
   64   PIN        REAL         ARRAY     SDAT         11   PKP        REAL                CRDAT
   15   PO         REAL                   SDAT          4   RHO        REAL                CRDAT
    6   SI         REAL                   SDAT          7   STK        REAL                SDAT
   24   SOR2       REAL                   SDAT          7   TD         REAL                CRDAT
    0   TITLE      REAL         ARRAY     CRDAT         0   TM         REAL                SDAT
   25   WOT        REAL                   SDAT

FILE NAMES         MODE
        TAPE5       FMT

STATEMENT LABELS
  135   100       FMT                    140   101       FMT                  144   102       FMT
  147   129       FMT                    151   140       FMT                  153   141       FMT

COMMON BLOCKS    LENGTH
        CRDAT        12
        SDAT         72
        CONTR        37

STATISTICS
  PROGRAM LENGTH      1568      110
   COMMON LENGTH      1719      121
```

```
                                        CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE      1
              OVERLAY (2,0)
              PROGRAM PDAT1
              CALL SDAT1
              END
```

```
        PROGRAM     PDAT1                              CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.     PAGE     2

        SYMBOLIC REFERENCE MAP

   ENTRY POINTS
       2  PDAT1

   EXTERNALS          TYPE    ARGS
        SDAT1                   0

   STATISTICS
     PROGRAM LENGTH      78        7
```

```
      SUBROUTINE SDAT1
C  THIS SUBROUTINE MAKES PRELIMINARY CALCULATIONS ON THE
C  PARAMETERS AND PRINTS OUT FOR REFERENCE.
      COMMON/CRDAT/ TITLE(4),RHO,E,PHI,TD,FPL,PKP,H,CT
      COMMON/SDAT/ TM,DT,N,M,N1,M1,SI,SIK,C01,HH,DTT,AL,GG,PO,C,
     1             C03,P,AP,AAP,LPP,SQR2,WOT,IB,IEN,BETA,
     2             NIN,LS,KT,NTD,KU,KN,PCU(21),PIN(20)
      COMMON/CONTR/LB,LEN,ILI,ILP,IEI,IE,JLI,JLL,NT1,NT2,NT3,NTO,NTI,
     1             NIT,NOT,NLO(20),ICV,CONV
C  WRITE TITLE OF THE RUN.
      WRITE (6,144)  TITLE
C CALCULATE OTHER SOIL PARAMETERS AND PRINT THEM OUT FOR REFERENCE
      N1=N-1
      M1=M-1
      G=144.*E/(1.+PO)/2.
      C2=SQRT(G*32.2/RHO)
      C1=C2*(2.*(1.-PO)/(1.-2.*PO))**0.5
      AL=2.*PO*G/(1.-2.*PO)
      WRITE (6,103)
      WRITE (6,104) RHO,PO,E,G,C2,C1
      WRITE (6,105) C,PHI
      PHI=PHI*3.1415927/180.
      CC=(3.-SIN(PHI))*3.**0.5
      AP=2.*SIN(PHI)/CC
      AAP=AP*AP
      YS=6.*C*COS(PHI)/CC
      WRITE (6,106) AP,YS
      WRITE (6,111)
      WRITE (6,113) TD,FPL,PKP,IB,IEN,BETA
      WRITE (6,107)
      WRITE (6,108) H,DT,M,N,WOT
      WRITE (6,109)
      WRITE (6,110) FPL,TD,YS
C NON-DIMENSIONALIZING ALL PARAMETERS AND CALCULATE SOME CONSTANTS THAT
C WILL BE USED IN THE LATER LOOPS
      AL=AL/YS
      G=G/YS
      GG=2.*G
      H=H/FPL
      SQR2=SQRT(2.)
      HH=H*SQR2
      FPL=FPL/12.
      DTT=DT/TD
      C01=YS*TD*TD*32.2/(RHO*FPL*FPL)
      C03= AP*(1.+PO)/(1.-2.*PO)
      P=GG/(0.5+3.*C03*AP)
      DTG=DTT*GG
      DTP=DTT*P
      WRITE (6,115)
      NIN=0.025/DTT+0.001
      FNIN=NIN
      NTD=40*NIN
      TTD=0.
      NO=0
      FP=PKP/10000.
```

```
      PC=PCU(1)
      DO 163 J=1,20
      TTD=TTD+0.025
      NQ=NQ+NIN
      JJ=J+1
      PI=(PCU(JJ)-PC)*FP/FNIN
      PC=PCU(JJ)
      PCM=PC*FP
      PIN(J)=PI/YS
      PCU(JJ)=PCM/YS
  163 WRITE (6,116)  J,TTD,PC,PCM,PI,PCU(JJ),PIN(J),NQ
C  CALCULATE THE PRINT CONTROL INDICES, THE TIME OF THE PULSE, AND THE
C  INITIAL APPLIED PRESSURE , SI, AND PRINT OUT FOR REFERENCE.
      ILP=LB+ILI-1
      IE=LB+IEI-1
      JLL=LB+JLI-1
      BL=LB-1
      TM=BL*DT
      TB=TM/TD/0.025+1.0
      KT=TB+0.001
      IF (KT.LT.41)  GO TO 170
      STK=0.
      SI=0.
      GO TO 171
  170 TK=KT
      KN=KT
      LS=KT*NIN
      KU=1
      IF (KT.LE.20)  GO TO 165
      KT=42-KT
      KU=-1
      KN=KT-1
  165 SIK=FLOAT(KU)*PIN(KN)
      KTU=KT+KU
      SI=(TB-TK)*(PCU(KTU)-PCU(KT))+PCU(KT)+SIK
  171 CONTINUE
      WRITE (6,117)
      WRITE (6,118)  LB,LEN,SI,SIK,TM
      WRITE (6,135) LB,LEN,ILI,IEI,JLI,NT1,NT2,NT3,LPP,NTI,NTO,ICV
C IF CONVERSION IS NEEDED, CALCULATE THE CONVERSION FACTOR FOR THE
C  STRESSES.
      IF (ICV.EQ.0) GO TO 159
      CONV=CT/C
  159 CONTINUE
      RETURN
  103 FORMAT(1H1,19X,15HSOIL PROPERTIES)
  104 FORMAT(23X,7HDENSITY,17X,5HRHO =,F10.1,10H LBS/CU-FT/
     1        23X,14HPOISSONS RATIO,11X,4HPO =,F10.2/
     2        23X,14HYOUNGS MODULUS,12X,3HE =,F10.1,4H PSI/
     3        23X,13HSHEAR MODULUS,13X,3HG =,F10.1,10H LBS/SQ-FT/
     4        23X,29HSHEAR WAVE VELOCITY       C2 =,F10.1,7H FT/SEC/
     5        23X,29HDILATATIONAL WAVE VEL.    C1 =,F10.1,7H FT/SEC//)
  105 FORMAT(23X,8HCOHESION,18X,3HC =,F10.1,10H LBS/SQ-FT/23X,14HFRICTIO
     1N ANGLE,10X,5HPHI =,F10.1,4H DEG//)
  106 FORMAT(23X,29HFOR YIELD CRITERIA    ALPHA =,E16.8/49X,3HK =,E16.8,
```

```
    110H LBS/SQ-FT//)
107 FORMAT(1H0,19X,24HCOMPUTATIONAL PARAMETERS)
108 FORMAT(23X,10HSPACE MESH,
   116X,3HH =,F10.4,3H IN/23X,29HBASIC TIME INCREMENT     DT =,
   2F10.7,4H SEC//23X,11HNUMBER OF I,15X,3HM =,I4/23X,11HNUMBER OF J,
   315X,3HN =,I4/23X,29HUNLOADING TOLERANCE      WOT =,1PE10.2//)
109 FORMAT(1H0,19X,50HCHARACTERISTIC PARAMETERS FOR NON-DIMENSIONALIZI
   1NG)
110 FORMAT (23X,36HLENGTH -- FOOTPRINT LENGTH    = FPL =,F10.2,3H IN/
   1          23X,36HTIME   -- TIME DUR. OF PULSE = TD  =,F10.5,4H SEC/
   2          23X,36HSTRESS -- SHEAR YIELD STRESS = K   =,F10.2,10H LBS/
   3SQ-FT///)
111 FORMAT (1H0,19X,15HLOAD PARAMETERS)
112 FORMAT (1H///)
113 FORMAT (23X,29HTIME DURATION OF PULSE   TD =,F10.3,4H SEC/
   1          23X,29HTIRE FOOTPRINT LENGTH   FPL =,F10.3,3H IN/
   2         23X,29HPEAK PRESSURE OF PULSE  PKP =,F10.1,10H LBS/SQ-FT/
   3         23X,29HLOAD BORDER INDEX-BEGIN  IB =,I10/
   4         23X,29HLOAD BORDER INDEX-END   IEN =,I10/
   5         23X,29HSHEAR-NORMAL RATIO     BETA =,F10.3//)
115 FORMAT (6X,99H AT DIMENSIONLESS    BASIC LOAD    DIMENSIONED
   1DIMENSIONED      DIMENSIONLESS      DIMENSIONLESS/105H   J        TIME
   2  T/TD              CURVE        LOAD CURVE    LOAD INCREMENT       LOAD
   3 CURVE      LOAD INCREMENT//)
116 FORMAT (1X,I3,F14.3,F18.1,F16.3,F16.5,1PE19.7,E18.7,I8)
117 FORMAT (1H1,18X,34HPARAMETERS FOR THIS PARTICULAR RUN)
118 FORMAT (23X,37HSTARTING LOAD INCREMENT NUMBER   LB =,I6/23X,37HEND
   1ING   LOAD INCREMENT NUMBER  LEN =,I6/23X,37HSTARTING SURFACE PRES
   2SURE          SI =,1PE17.7,16H (DIMENSIONLESS)/23X,37HPRESSURE (OR L
   3OAD) INCREMENT     SIK =,1PE17.7,16H (DIMENSIONLESS)/23X,13HSTARTIN
   4G TIME,20X,4HTM =,0PF12.7,4H SEC//)
135 FORMAT (1H0,18X,32HLAST DATA CARD OF THIS RUN IS---//
   225X,57HLB  LEN  ILI  IEI  JLI  NT1  NT2  NT3  LPP  NTI  NTO  ICV//
   322X,12I5)
144 FORMAT (1H1////1H0,47X,45HBRAKED-WHEEL VERTICAL LOAD SINKAGE PREDI
   1CTION//59X,4A10)
    END
```

```
          SUBROUTINE  SDAT1                                   CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE      4

          SYMBOLIC REFERENCE MAP

 ENTRY POINTS
     1   SDAT1

 VARIABLES      SN  TYPE           RELOCATION
    22  AAP         REAL                SDAT          13  AL          REAL                   SDAT
    21  AP          REAL                SDAT          30  BETA        REAL                   SDAT
  1033  BL          REAL                              16  C           REAL                   SDAT
  1016  CC          REAL                              44  CONV        REAL                   CONTR
    10  CO1         REAL                SDAT          17  CO3         REAL                   SDAT
    13  CT          REAL                CRDAT       1015  C1          REAL
  1014  C2          REAL                               1  DT          REAL                   SDAT
  1020  DTG         REAL                            1021  DTP         REAL
    12  DTT         REAL                SDAT           5  E           REAL                   CRDAT
  1022  FNIN        REAL                            1025  FP          REAL
    10  FPL         REAL                CRDAT       1013  G           REAL
    14  GG          REAL                SDAT          12  H           REAL                   CRDAT
    11  HH          REAL                SDAT          26  IB          INTEGER                SDAT
    43  ICV         INTEGER             CONTR          5  IE          INTEGER                CONTR
     4  IEI         INTEGER             CONTR         27  IEN         INTEGER                SDAT
     2  ILI         INTEGER             CONTR          3  ILP         INTEGER                CONTR
  1027  J           INTEGER                         1030  JJ          INTEGER
     6  JLI         INTEGER             CONTR          7  JLL         INTEGER                CONTR
    36  KN          INTEGER             SDAT          33  KT          INTEGER                SDAT
  1036  KTU         INTEGER                           35  KU          INTEGER                SDAT
     0  LB          INTEGER             CONTR          1  LEN         INTEGER                CONTR
    23  LPP         INTEGER             SDAT          32  LS          INTEGER                SDAT
     3  M           INTEGER             SDAT           5  M1          INTEGER                SDAT
     2  N           INTEGER             SDAT          31  NIN         INTEGER                SDAT
    15  NIT         INTEGER             CONTR         17  NLO         INTEGER    ARRAY       CONTR
    16  NOT         INTEGER             CONTR       1024  NO          INTEGER
    34  NTD         INTEGER             SDAT          14  NTI         INTEGER                CONTR
    13  NTO         INTEGER             CONTR         10  NT1         INTEGER                CONTR
    11  NT2         INTEGER             CONTR         12  NT3         INTEGER                CONTR
     4  N1          INTEGER             SDAT          20  P           REAL                   SDAT
  1026  PC          REAL                            1032  PCM         REAL
    37  PCU         REAL       ARRAY    SDAT           6  PHI         REAL                   CRDAT
  1031  PI          REAL                              64  PIN         REAL       ARRAY       SDAT
    11  PKP         REAL                CRDAT         15  PO          REAL                   SDAT
     4  RHO         REAL                CRDAT          6  SI          REAL                   SDAT
     7  SIK         REAL                SDAT          24  SQR2        REAL                   SDAT
  1034  TB          REAL                               7  TD          REAL                   CRDAT
     0  TITLE       REAL       ARRAY    CRDAT       1035  TK          REAL
     0  TM          REAL                SDAT        1023  TTD         REAL
    25  WOT         REAL                SDAT        1017  YS          REAL

 FILE NAMES        MODE
         TAPE6      FMT

 EXTERNALS          TYPE     ARGS
         COS        REAL       1 LIBRARY                 SIN         REAL         1 LIBRARY
         SQRT       REAL       1 LIBRARY

 INLINE FUNCTIONS   TYPE     ARGS
         FLOAT      REAL       1   INTRIN
```

```
      SUBROUTINE  SDAT1                                    CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE     5

STATEMENT LABELS
  435  103      FMT                         441  104      FMT                         475  105      FMT
  507  106      FMT                         520  107      FMT                         525  108      FMT
  551  109      FMT                         561  110      FMT                         604  111      FMT
  610  112      FMT  NO REFS                612  113      FMT                         647  115      FMT
  676  116      FMT                         704  117      FMT                         712  118      FMT
  747  135      FMT                         764  144      FMT                         433  159
    0  163                                  342  165                                  327  170
  353  171

COMMON BLOCKS   LENGTH
      CRDAT         12
      SDAT          72
      CONTR         37

STATISTICS
  PROGRAM LENGTH   10379     543
   COMMON LENGTH    1718     121
```

```
                                   CDC 6600 FTN V3.0-279B OPT=1  12/27/71   13.34.46.      PAGE       1

                OVERLAY (3,0)
                PROGRAM PDAT2
                CALL SDAT2, RETURNS (99)
                GO TO 100
             99 STOP 777
            100 CONTINUE
                END
```

```
        PROGRAM     PDAT2                                        CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.    PAGE      2
        SYMBOLIC REFERENCE MAP

  ENTRY POINTS
      2   PDAT2

  EXTERNALS             TYPE    ARGS
          SDAT2                   0

  STATEMENT LABELS
      6   99                                  10   100

  STATISTICS
    PROGRAM LENGTH       16B         14
```

```
      SUBROUTINE SDAT2, RETURNS(MR)
C  THIS SUBROUTINE CONTINUES SUBROUTINE SDAT1 AND ZEROES ARRAYS OR
C  READS DATA FROM TAPE.
      COMMON/DUMMY/ VD(47,27), UD(47,27),
     1              SX(47,27), SY(47,27), SXY(47,27),
     2              UT(47,27),UDT(47,27),UDDT(47,27), UI(47,27),
     3              VT(47,27),VDT(47,27),VDDT(47,27), VI(47,27),
     4             SXT(47,27),SYT(47,27),SXYT(47,27),YIT(47,27)
      COMMON/SDAT/ TM,DT,N,M,N1,M1,SI,SIK,CO1,HH,DTT,AL,GG,PO,C,
     1             CO3,P,AP,AAP,LPP,SQR2,WOT,IB,IEN,BETA,
     2             NIN,LS,KT,NTD,KU,KN,PCU(21),PIN(20)
      COMMON/CONTR/LB,LEN,ILI,ILP,IEI,IE,JLI,JLL,NT1,NT2,NT3,NTO,NTI,
     1             NIT,NOT,NLO(20),ICV,CONV
      IF (LB.NE.1)  GO TO 164
C IF THIS IS THE VERY FIRST RUN, ALL STRESSES AND DISPLACEMENTS ARE
C FIRST SET EQUAL TO ZERO, AND THE YIELD INDICATING MATRIX IS SET TO BE
C ELASTIC
      DO 7 J=1,N
      DO 7 I=1,M
        UD(I,J)=0.
        VD(I,J)=0.
        UT(I,J)=0.
        VT(I,J)=0.
       UDT(I,J)=0.
       VDT(I,J)=0.
      UDDT(I,J)=0.
      VDDT(I,J)=0.
        UI(I,J)=0.
        VI(I,J)=0.
        SX(I,J)=0.
        SY(I,J)=0.
       SXY(I,J)=0.
        SXT(I,J)=0.
        SYT(I,J)=0.
       SXYT(I,J)=0.
    7  YIT(I,J)=-1.
      RETURN
C REARRANGE DESIGNATION OF UNIT OF TAPES DEPENDING ON  NTI  AND  NTO
  164 IF (NTI.EQ.9) GO TO 173
      ILL=NIT
      NIT=NOT
      NOT=ILL
  173 WRITE (6,138) NIT
C IF THIS IS A CONTINUATION RUN, THE STRESSES, DISPLACEMENTS, AND
C     YIELD INDICATING TABLE OF THE PRECEDING RUN ARE READ IN FROM INPUT
C     TAPE. DATA READ IN, IF NO REDUNDANCY OCCURRED, ARE SAVED IN DISK
C     UNIT 8 FOR TRANSFER TO OUTPUT TAPE.
      DO 162 I=1,NT1
      READ (NTI) UT,UDT,UDDT,UI,VT,VDT,VDDT,VI,SXT,SYT,SXYT,YIT
      ILL=SYT(1,1)
      WRITE (6,139)  ILL
      IF (I.NE.NT2)  GO TO 162
      WRITE (8 ) UT,UDT,UDDT,UI,VT,VDT,VDDT,VI,SXT,SYT,SXYT,YIT
  162 CONTINUE
C READ FROM DISK UNIT 8 THE DESIRE STARTING STRESSES AND DISPLACEMENTS
```

```
C FOR THE CONTINUATION RUN.
      IF (NT2.EQ.0)  GO TO 175
      REWIND 8
  174 READ (8   ) UT,UDT,UDDT,UI,VT,VDT,VDDT,VI,SXT,SYT,SXYT,YIT
      ILL=SYT(1,1)
  175 IF (ILL.NE.(LB-1))  RETURN MR
      REWIND NTI
      NT1=0
C EQUATE THE CURRENT DISPLACEMENTS AND STRESSES WITH THE PREVIOUSLY
C  SAVED DISPLACEMENTS AND STRESSES. MAKE STRESS CONVERSION IF THE TAPE
C  DATA IS NORMALIZED DIFFERENTLY.
      DO 8 J=1,N
      DO 8 I=1,M
      UD(I,J)=UDT(I,J)
      VD(I,J)=VDT(I,J)
    9 IF (ICV.EQ.0) GO TO 176
       SXYT(I,J)=SXYT(I,J)*CONV
        SYT(I,J)= SYT(I,J)*CONV
        SXT(I,J)= SXT(I,J)*CONV
  176   SX(I,J)= SXT(I,J)
        SY(I,J)= SYT(I,J)
       SXY(I,J)=SXYT(I,J)
    8 CONTINUE
      NT2=0
      REWIND 8
      RETURN
  138 FORMAT (1H0,18X,11HTAPE NUMBER,I6,54H  CONTAINS THE RESULTS OF LOA
     1D INCREMENT NUMBER  ILL =//)
  139 FORMAT (23X,I5)
      END
```

```
          SYMBOLIC REFERENCE MAP

 ENTRY POINTS
      2  SDAT2

 VARIABLES      SN  TYPE             RELOCATION
     22  AAP        REAL                 SDAT            13  AL         REAL                 SDAT
     21  AP         REAL                 SDAT            30  BETA       REAL                 SDAT
     16  C          REAL                 SDAT            44  CONV       REAL                 CONTR
     10  CO1        REAL                 SDAT            17  CO3        REAL                 SDAT
      1  DT         REAL                 SDAT            12  DTT        REAL                 SDAT
     14  GG         REAL                 SDAT            11  HH         REAL                 SDAT
    276  I          INTEGER                              26  IB         INTEGER              SDAT
     43  ICV        INTEGER              CONTR            5  IE         INTEGER              CONTR
      4  IEI        INTEGER              CONTR           27  IEN        INTEGER              SDAT
      2  ILI        INTEGER              CONTR          277  ILL        INTEGER
      3  ILP        INTEGER              CONTR          275  J          INTEGER
      6  JLI        INTEGER              CONTR            7  JLL        INTEGER              CONTR
     36  KN         INTEGER              SDAT            33  KT         INTEGER              SDAT
     35  KU         INTEGER              SDAT             0  LB         INTEGER              CONTR
      1  LEN        INTEGER              CONTR           23  LPP        INTEGER              SDAT
     32  LS         INTEGER              SDAT             3  M          INTEGER              SDAT
      0  MR         RETURNS                               5  M1         INTEGER              SDAT
      2  N          INTEGER              SDAT            31  NIN        INTEGER              SDAT
     15  NIT        INTEGER              CONTR           17  NLO        INTEGER      ARRAY   CONTR
     16  NOT        INTEGER              CONTR           34  NTD        INTEGER              SDAT
     14  NTI        INTEGER              CONTR           13  NTO        INTEGER              CONTR
     10  NT1        INTEGER              CONTR           11  NT2        INTEGER              CONTR
     12  NT3        INTEGER              CONTR            4  N1         INTEGER              SDAT
     20  P          REAL                 SDAT            37  PCU        REAL         ARRAY   SDAT
     64  PIN        REAL         ARRAY   SDAT            15  PO         REAL                 SDAT
      6  SI         REAL                 SDAT             7  SIK        REAL                 SDAT
     24  SDP2       REAL                 SDAT          4752  SX         REAL         ARRAY   DUMMY
  40161  SXT        REAL         ARRAY   DUMMY        11724  SXY        REAL         ARRAY   DUMMY
  45133  SXYT       REAL         ARRAY   DUMMY         7337  SY         REAL         ARRAY   DUMMY
  42546  SYT        REAL         ARRAY   DUMMY            0  TM         REAL                 SDAT
   2365  UD         REAL         ARRAY   DUMMY        21263  UDOT       REAL         ARRAY   DUMMY
  16676  UDT        REAL         ARRAY   DUMMY        23650  UI         REAL         ARRAY   DUMMY
  14311  UT         REAL         ARRAY   DUMMY            0  VD         REAL         ARRAY   DUMMY
  33207  VDDT       REAL         ARRAY   DUMMY        30622  VDT        REAL         ARRAY   DUMMY
  35574  VI         REAL         ARRAY   DUMMY        26235  VT         REAL         ARRAY   DUMMY
     25  WOT        REAL                 SDAT         47520  YIT        REAL         ARRAY   DUMMY

 FILE NAMES         MODE
        TAPE6        FMT                 TAPE8      UNFMT

 STATEMENT LABELS
      0  7                                   0  8                                   0  9           INACTIVE
    257  138        FMT                    271  139         FMT                   150  162
     34  164                                42  173                                 0  174           INACTIVE
    214  175                               243  176

 COMMON BLOCKS    LENGTH
        DUMMY      21573
        SDAT          72
        CONTR         37
```

```
         SUBROUTINE  SDAT2                                    CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE      4
  STATISTICS
    PROGRAM LENGTH     300B      192
     COMMON LENGTH   52262B    21682
```

```
                                          CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.       PAGE     1
                    OVERLAY (4,0)
                    PROGRAM PCALC
                    CALL SCALC
                    END
```

```
           PROGRAM     PCALC                                      CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE      2

           SYMBOLIC REFERENCE MAP

       ENTRY POINTS
           2  PCALC

       EXTERNALS          TYPE    ARGS
              SCALC                 0

       STATISTICS
         PROGRAM LENGTH      7B        7
```

```
      SUBROUTINE SCALC
C  THIS SUBROUTINE DOES THE MAIN CALCULATIONS OF THE ITERATIONS, PRINTS
C  OUT NEEDED RESULTS, AND SAVES RESULTS ON TAPES.
      COMMON/DUMMY/  VD(47,27),  UD(47,27),
     1               SX(47,27),  SY(47,27),  SXY(47,27),
     2               UT(47,27),UDT(47,27),UDDT(47,27),  UI(47,27),
     3               VT(47,27),VDT(47,27),VDDT(47,27),  VI(47,27),
     4              SXT(47,27),SYT(47,27),SXYT(47,27),YIT(47,27)
      COMMON/SDAT/  TM,DT,N,M,N1,M1,SI,SIK,C01,HH,DTT,AL,GG,PO,C,
     1              C03,P,AP,AAP,LPP,SOP2,WOT,IB,IEN,BETA,
     2              NIN,LS,KT,NTD,KU,KN,PCU(21),PIN(20)
      COMMON/CONTR/LB,LEN,ILI,ILP,IEI,IE,JLI,JLL,NT1,NT2,NT3,NTO,NTI,
     1              NIT,NOT,NLO(20),ICV,CONV
C THE FOLLOWING DATA STATEMENTS SUPPLY THE VARIABLE FORMATS.
      LOGICAL  FRNT,LAST
      SJF(V1,V2,V3,V4)=SQRT(((V1-V2)**2+(V2-V3)**2+(V3-V1)**2)/6.+V4*V4)
C STARTING POINT OF MOST OUTER LOOP, FOR CALCULATION OF EACH LOAD
C  INCREMENTS.
      UPL=-1.
      IY=0
  169 DO 250  ILL=LB,LEN
      LPT=0
      TM=TM+DT
C  SET APPLIED SURFACE STRESSES AT THE FICTITIOUS STRESS POINTS
      IB1=IB+1
      DO 4  I=IB1,IEN
       SX(I,1)=SI*(0.5+BETA)
       SY(I,1)=SI*(0.5-BETA)
    4 SXY(I,1)=SI/2.
C STARTING POINT OF THE ITERATION LOOP.
      JA=1
      IT=0
    6 IT=IT+1
      LAST=JA.EQ.2
      DFU=0.
      DFV=0.
C STARTING POINT FOR THE LOOP INCREMENTING EACH ROW GOING DOWNWARD
      DO 83  J=1,N1
      JP=J+1
      DO 83   I=2,M1
      IP=I+1
C CALCULATE, AT EACH MASS POINT, THE ACCELERATIONS FROM THE DYNAMIC
C EQUATIONS OF MOTION.
    9 UDD=C01*(SX(IP,JP)-SX(I,J)+SXY(I,JP)-SXY(IP,J))/HH
      VDD=C01*(SY(I,JP)-SY(IP,J)+SXY(IP,JP)-SXY(I,J))/HH
C CALCULATE THE DISPLACEMENTS AND VELOCITIES AT TIME   T   FROM THE
C QUADRATURE EQUATIONS.
   10 UB     =UT(I,J)+DTT*UDT(I,J)+DTT*DTT*(UDDT(I,J)*2.+UDD)/6.
      VB     =VT(I,J)+DTT*VDT(I,J)+DTT*DTT*(VDDT(I,J)*2.+VDD)/6.
      UDB     =UDT(I,J)+DTT*(UDDT(I,J)+UDD)/2.
      VDB     =VDT(I,J)+DTT*(VDDT(I,J)+VDD)/2.
      IF (IT.NE.1)  GO TO 12
      UD(I,J)=UDB
      VD(I,J)=VDB
      GO TO 14
```

```
C AVERAGE WITH THE DISPLACEMENTS FROM THE PRECEDING ITERATION
   12 U=UT(I,J)+UI(I,J)
      V=VT(I,J)+VI(I,J)
      UB=(UB+U)/2.
      VB=(VB+V)/2.
      UD(I,J)=(UDB+UD(I,J))/2.
      VD(I,J)=(VDB+VD(I,J))/2.
C  10 CALCULATE THE DISPLACEMENT INCREMENTS
   14 UI(I,J)=UB-UT(I,J)
      VI(I,J)=VB-VT(I,J)
      IF (JA.NE.2)  GO TO 16
      UDDT(I,J)=UDD
      VDDT(I,J)=VDD
   16 IF (ABS(UB).LT.1.0E-20.OR.ABS(VB).LT.1.0E-20)  GO TO 83
   17 IF (IT.LE.2) GO TO 20
C CALCULATE THE PERCENT CONVERGENCE OF THE VERTICAL DISPLACEMENT
C BETWEEN THIS AND THE PRECEDING ITERATION.  LOCATE THE LARGEST PERCENT
C AND SAVE IF FOR LATER REFERENCE.
      IF (ABS(U).LT.1.0E-40.OR.ABS(V).LT.1.0E-40)  GO TO 20
      DU=ABS(UB/U-1.)
      DV=ABS(VB/V-1.)
      IF (DU.LE.DFU) GO TO 18
      DFU=DU
      ILU=ILL
      ITU=IT
      IU=I
      JU=J
   18 IF (DV.LE.DFV) GO TO 20
      DFV=DV
      ILV=ILL
      ITV=IT
      IV=I
      JV=J
C CALCULATE THE STRESSES OF THE TWO STRESS POINTS BELOW THE MASS POINT.
C  INDEX IC INDICATES WHICH STRESS POINT IS BEING CONSIDERED.
C      IC=1  IS THE ONE ON THE RIGHT
C      IC=2  IS THE ONE ON THE LEFT
   20 IC=1
      K=IP
      L=JP
   22 KM=K-1
      IF (KM.EQ.0)  KM=M
      LM=L-1
      FRNT=IC.EQ.1.AND.K.NE.MK
C SAVE THE STRESSES OF THE PRECEDING ITERATION.
       SXS= SX(K,L)
       SYS= SY(K,L)
      SXYS=SXY(K,L)
      YITS=YIT(K,L)
C CALCULATE THE STRAIN INCREMENTS.
       EX=(UI(K,L)-UI(KM,LM))/HH
       EY=(VI(KM,L)-VI(K,LM))/HH
      EXY=(UI(KM,L)-UI(K,LM)+VI(K,L)-VI(KM,LM))/HH/2.
      EE=AL*(EX+EY)
C CHECK THE YIELD INDICATING TABLE TO DETERMINE WHICH STRES-STRAIN
```

```
C  RELATION TO USE.
      IF (YITS.GE.0..AND.YITS.LE.40000.) GO TO 35
C STRESS POINT IS ELASTIC.
       SX(K,L)= SXT(K,L)+GG*EX+EE
       SY(K,L)= SYT(K,L)+GG*EY+EE
      SXY(K,L)=SXYT(K,L)+GG*EXY
      GO TO 50
C  35 STRESS POINT IS PLASTIC.
   35 UPL=-1.
      WO=SXS*EX+SYS*EY+SXYS*EXY
      SZS=PO*(SXS+SYS)
      SS=SXS+SYS+SZS
      SJ=SJF(SXS,SYS,SZS,SXYS)
      BE=CO3-SS/SJ/6.
      SJ2=SJ*2.
      WE=(WO/SJ2+BE*EE/AL)*P
       SX(K,L)= SXT(K,L)+GG*EX+EE-(SXS/SJ2+BE)*WE
       SY(K,L)= SYT(K,L)+GG*EY+EE-(SYS/SJ2+BE)*WE
      SXY(K,L)=SXYT(K,L)+GG*EXY-SXYS*WE/SJ2
C  50 CHECK IF THE STRESS POINT HAS YIELDED.  THIS IS DONE ONLY FOR THE
C     FINAL ITERATION.  JA INDEX CONTROLS THE ENTRY.
   50 IF (.NOT.LAST)  GO TO 64
C CALCULATE THE YIELD FUNCTION
      SS=SX(K,L)+SY(K,L)
      SZZ=PO*SS
      SS=SS+SZZ
      SJ=SJF(SX(K,L),SY(K,L),SZZ,SXY(K,L))
      FC=AP*SS+SJ-1.
C CHECK IF THE YIELD FUNCTION IS GREATER THAN THE TOLERANCE ABOVE ZERO,
C AND MAKE THE APPROPRIATE CHANGE IN THE YIELD INDICATING TABLE
      IF (FC.GT.0.015) GO TO 55
      IF (YITS.LT.0.)  GO TO 53
      IF (FC.GT.-0.015) GO TO 55
   53 IF (FRNT)  GO TO 66
      YI=FC
      IF (FC.GT.0.)  YI=-10.-FC
      GO TO 64
C 55 STRESS POINT HAS YIELDED. CHANGE CONTROL INDEX TO SAVE DATA OF THIS
C    LOAD INCREMENT ON TAPE.  CHANGE THE FORMAT OF THE YIELD INDICATING
C    TABLE PRINT OUT.
   55 IF (FRNT)  GO TO 58
      IF (LPP.NE.1) GO TO 56
      LPP=2
C CHECK FOR UNLOADING
   56 WO=SX(K,L)*EX+SY(K,L)*EY+SXY(K,L)*EXY
      IF (WO.LT.-WOT) GO TO 57
      IF (WO.GT.WOT.OR.YITS.LT.40000.) GO TO 58
   57 UPL=1.
C CALCULATE THE STRESS CORRECTION FACTOR.
   58 SSP=(1.-AP*SS)**2
      SJS=SJ*SJ
      PH=(SJS-SSP)/(2.*SJS+12.*AAP*SSP)
      PAK=PH*((1.+6.*AAP)*SS/3.-2.*AP)
      RAT=1.-PH
      FCJ=AINT(10000.*FC)
```

```
      IF (FC.LT.0.) FCJ=20000.-FCJ
      YI=FCJ+RAT
      IF (UPL.GT.0.)  YI=YI+40000.
      IY=1
C STRESS CORRECTION IS MADE BY THE FOLLOWING STATEMENTS ONLY IF THE
C YIELD FUNCTION IS GREATER THAN A TOLERANCE.
      IF (FC.LT.0.020) GO TO 64
      YI=YI+30000.
       SX(K,L)= SX(K,L)*RAT+PAK
       SY(K,L)= SY(K,L)*RAT+PAK
      SXY(K,L)=SXY(K,L)*RAT
   64 IF (FRNT)  GO TO 66
      IF (LAST)  YIT(K,L)=YI
      IF (IC.EQ.2)  GO TO 83
   66 K=I
      IC=2
      GO TO 22
   83 CONTINUE
      IF (IT.LE.2) GO TO 6
      WRITE (6,143)  DFU,ILU,ITU,IU,JU,DFV,ILV,ITV,IV,JV
      IF (LAST)  GO TO 85
C CHECK IF THE CONVERGENCE IS GOOD ENOUGH.  RETURN TO CALCULATE ANOTHER
C ITERATION IF NOT ACCURATE ENOUGH.
      IF ((DFU.GT.0.002.OR.DFV.GT.0.002).AND.IT.LT.7) GO TO 6
C IF ACCURATE ENOUGH, ADJUST  JA  INDEX AND CALCULATE FINAL ITERATION.
      JA=2
      GO TO 6
C THE FOLLOWING LOOP SAVES ALL THE DISPLACEMENTS AND STRESSES FOR THE
C CALCULATION OF THE NEXT TIME INCREMENT.
C WITHIN THIS LOOP, THE VERTICAL DISPLACEMENTS AND STRESSES ARE ALSO
C CALCULATED FROM THE DIAGONAL DISPLAEMENTS AND STRESSES.
   85 DO 90 J=1,N
      DO 90 I=1,M
         UT(I,J)=  UT(I,J)+UI(I,J)
         VT(I,J)=  VT(I,J)+VI(I,J)
   87   UDT(I,J)=  UD(I,J)
        VDT(I,J)=  VD(I,J)
   89   SXT(I,J)=  SX(I,J)
        SYT(I,J)=  SY(I,J)
       SXYT(I,J)= SXY(I,J)
   90 CONTINUE
C IF THE END OF A LINEAR SEGMENT OF THE LOAD CURVE IS REACHED,  SIK  IS
C CHANGED TO THE APPLIED PRESSURE INCREMENT OF THE NEXT LINEAR SEGMENT.
      IF (ILL.LT.LS) GO TO 182
      IF (ILL.GE.NTD)  GO TO 179
      LS=LS+NIN
      KT=KT+KU
      IF (KT.NE.21)  GO TO 178
      KN=21
      KU=-1
  178 KN=KN+KU
      SIK=FLOAT(KU)*PIN(KN)
      SI=PCU(KT)
      GO TO 182
C 179 IF END OF THE LOAD CURVE OCCURS,  THE SURFACE PRESSURE IS NO
```

```
C       LONGER INCREMENTED.
  179 SI=0.
      SIK=0.
  182 CONTINUE
      IF (LPP.LT.2)  GO TO  185
C THE STRESSES AND DISPLACEMENTS OF THE LOAD INCREMENT IN WHICH THE
C FIRST PLASTIC POINT OCCURS ARE SAVED ON THE OUTPUT TAPE.
      LPP=0
      WRITE (6,119)
      WRITE (6,143)   TM,ILL,IT
      LPT=1
      GO TO 245
  185 CONTINUE
  193 IF (ILL.LT.ILP) GO TO 250
C SAVE RESULTS ON MASS STORAGE FOR SUBROUTINE PROUT TO PRINT OUT LATER.
C SAVING IS DONE ONLY AT INCREMENTS OF ILI.
  245 NT2=NT2+1
      SXT(1,1)=TM
      SYT(1,1)=ILL
      SXYT(1,1)=IY
      WRITE (8   ) UT,UDT,UDDT,UI,VT,VDT,VDDT,VI,SXT,SYT,SXYT,YIT
      IF (LPT.EQ.1)   GO TO 185
      ILP=ILP+ILI
  250 CONTINUE
      REWIND 8
      RETURN
  119 FORMAT (3X,23HSTRESS POINT IS PLASTIC//)
  143 FORMAT (2X,2(E20.8,4I8))
      END
```

```
      SUBROUTINE  SCALC                                 CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.       PAGE      6

      SYMBOLIC REFERENCE MAP

ENTRY POINTS
    1  SCALC

VARIABLES    SN  TYPE         RELOCATION
   22  AAP      REAL              SDAT           13  AL       REAL               SDAT
   21  AP       REAL              SDAT         1150  BE       REAL
   30  BETA     REAL              SDAT           16  C        REAL               SDAT
   44  CONV     REAL              CONTR          10  CO1      REAL               SDAT
   17  CO3      REAL              SDAT         1077  DFU      REAL
 1100  DFV      REAL                              1  DT       REAL               SDAT
   12  DTT      REAL              SDAT         1114  DU       REAL
 1115  DV       REAL                           1143  EE       REAL
 1140  EX       REAL                           1142  EXY      REAL
 1141  EY       REAL                           1154  FC       REAL
 1163  FCJ      REAL                           1065  FRNT     LOGICAL
   14  GG       REAL              SDAT           11  HH       REAL               SDAT
 1074  I        INTEGER                          26  IB       INTEGER            SDAT
 1073  IB1      INTEGER                        1126  IC       INTEGER
   43  ICV      INTEGER           CONTR           5  IE       INTEGER            CONTR
    4  IEI      INTEGER           CONTR          27  IEN      INTEGER            SDAT
    2  ILI      INTEGER           CONTR        1071  ILL      INTEGER
    3  ILP      INTEGER           CONTR        1116  ILU      INTEGER
 1122  ILV      INTEGER                        1103  IP       INTEGER
 1076  IT       INTEGER                        1117  ITU      INTEGER
 1123  ITV      INTEGER                        1120  IU       INTEGER
 1124  IV       INTEGER                        1070  IY       INTEGER
 1101  J        INTEGER                        1075  JA       INTEGER
    6  JLI      INTEGER           CONTR           7  JLL      INTEGER            CONTR
 1102  JP       INTEGER                        1121  JU       INTEGER
 1125  JV       INTEGER                        1127  K        INTEGER
 1131  KM       INTEGER                          36  KN       INTEGER            SDAT
   33  KT       INTEGER           SDAT           35  KU       INTEGER            SDAT
 1130  L        INTEGER                        1066  LAST     LOGICAL
    0  LB       INTEGER           CONTR           1  LEN      INTEGER            CONTR
 1132  LM       INTEGER                          23  LPP      INTEGER            SDAT
 1072  LPT      INTEGER                          32  LS       INTEGER            SDAT
    3  M        INTEGER           SDAT         1133  MK       INTEGER  *UNDEF
    5  M1       INTEGER           SDAT            2  N        INTEGER            SDAT
   31  NIN      INTEGER           SDAT           15  NIT      INTEGER            CONTR
   17  NLO      INTEGER   ARRAY   CONTR          16  NOT      INTEGER            CONTR
   34  NTD      INTEGER           SDAT           14  NTI      INTEGER            CONTR
   13  NTO      INTEGER           CONTR          10  NT1      INTEGER            CONTR
   11  NT2      INTEGER           CONTR          12  NT3      INTEGER            CONTR
    4  N1       INTEGER           SDAT           20  P        REAL               SDAT
 1161  PAK      REAL                             37  PCU      REAL      ARRAY    SDAT
 1160  PH       REAL                             64  PIN      REAL      ARRAY    SDAT
   15  PO       REAL              SDAT         1162  RAT      REAL
    6  SI       REAL              SDAT            7  SIK      REAL               SDAT
 1147  SJ       REAL                           1157  SJS      REAL
 1151  SJ2      REAL                             24  SQR2     REAL               SDAT
 1146  SS       REAL                           1156  SSP      REAL
 4752  SX       REAL      ARRAY   DUMMY        1134  SXS      REAL
40161  SXT      REAL      ARRAY   DUMMY       11724  SXY      REAL      ARRAY    DUMMY
 1136  SXYS     REAL                          45133  SXYT     REAL      ARRAY    DUMMY
```

```
       SUBROUTINE  SCALC                                  CDC 6600 FTN V3.0-2798 OPT=1  12/27/71  13.34.46.     PAGE       7

VARIABLES     SN  TYPE          RELOCATION
 7337  SY        REAL       ARRAY    DUMMY          1135  SYS        REAL
42546  SYT       REAL       ARRAY    DUMMY          1145  SZS        REAL
 1153  SZZ       REAL                                  0  TM         REAL                SDAT
 1112  U         REAL                               1106  UB         REAL
 2365  UD        REAL       ARRAY    DUMMY          1110  UDB        REAL
 1104  UDD       REAL                              21263  UDDT       REAL       ARRAY    DUMMY
15676  UDT       REAL       ARRAY    DUMMY         23650  UI         REAL       ARRAY    DUMMY
 1067  UPL       REAL                              14311  UT         REAL       ARRAY    DUMMY
 1113  V         REAL                               1107  VB         REAL
    0  VD        REAL       ARRAY    DUMMY          1111  VDB        REAL
 1105  VDD       REAL                              33207  VDDT       REAL       ARRAY    DUMMY
30622  VDT       REAL       ARRAY    DUMMY         35574  VI         REAL       ARRAY    DUMMY
26235  VT        REAL       ARRAY    DUMMY          1152  WE         REAL
 1144  WO        REAL                                 25  WOT        REAL                SDAT
 1155  YI        REAL                              47520  YIT        REAL       ARRAY    DUMMY
 1137  YITS      REAL

FILE NAMES        MODE
       TAPE6       FMT               TAPE8     UNFMT

EXTERNALS          TYPE   ARGS
       SQRT      REAL       1 LIBRARY

INLINE FUNCTIONS   TYPE   ARGS
       ABS       REAL       1  INTRIN                    AINT       REAL       1  INTRIN
       FLOAT     REAL       1  INTRIN                    SJF        REAL       4    SF

STATEMENT LABELS
    0  4                                    26  6                                    0  9           INACTIVE
    0  10          INACTIVE                136  12                                 164  14
  203  16                                    0  17          INACTIVE               237  18
  251  20                                  255  22                                 360  35
  441  50                                  471  53                                 500  55
  505  56                                  523  57                                 525  58
  600  64                                  611  66                                 614  83
  663  85                                    0  87          INACTIVE                 0  89           INACTIVE
    0  90                                 1031  119     FMT                       1036  143     FMT
    0  169         INACTIVE                722  178                                730  179
  732  182                                 754  185                                  0  193          INACTIVE
  757  245                                1024  250

COMMON BLOCKS   LENGTH
       DUMMY     21573
       SDAT         72
       CONTR        37

STATISTICS
  PROGRAM LENGTH   11648      628
   COMMON LENGTH  522628    21682
```

```
                                       CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.     PAGE      1
             OVERLAY (5,0)
             PROGRAM PPOUT
             CALL PROUT
             END
```

```
PROGRAM      PPOUT                                  CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE      2

             SYMBOLIC REFERENCE MAP

      ENTRY POINTS
          2  PPOUT

      EXTERNALS          TYPE    ARGS
             PROUT                  0

      STATISTICS
        PROGRAM LENGTH      7B        7
```

```
      SUBROUTINE PROUT
C  THIS SUBROUTINE IS FOR PRINTING OUT THE VERTICAL STRESSES AND
C  THIS SUBROUTINE IS FOR PRINTING OUT THE VERTICAL STRESSES, VERTICAL
C  DISPLACEMENTS, AND YIELD INDICATING TABLE IN THE REGION UNDER THE
C  LOADED AREA FOR MONITORING THE COMPUTER RUN.
      COMMON/DUMMY/ VD(47,27), UD(47,27),
     1              SX(47,27), SY(47,27), SXY(47,27),
     2              UT(47,27),UDT(47,27),UDDT(47,27), UI(47,27),
     3              VT(47,27),VDT(47,27),VDDT(47,27), VI(47,27),
     4             SXT(47,27),SYT(47,27),SXYT(47,27),YIT(47,27)
      COMMON/SDAT/ TM,DT,N,M,N1,M1,SI,SIK,CO1,HH,DTT,AL,GG,PO,C,
     1             CO3,P,AP,AAP,LPP,SQR2,WOT,IB,IEN,BETA,
     2             NIN,LS,KT,NTO,KU,KN,PCU(21),PIN(20)
      COMMON/CONTR/LB,LEN,ILI,ILP,IEI,IE,JLI,JLL,NT1,NT2,NT3,NTO,NTI,
     1             NIT,NOT,NLO(20),ICV,CONV
      DIMENSION     SZ(47,27),  W(47,27), SRZ(47,27),U(47,27)
      EQUIVALENCE  (SZ(1),SX(1)),(W(1),SY(1)),(SRZ(1),SXY(1)),(UD,U)
      DIMENSION  FMS(3),FMW(3),FMY(3)
      DATA FMS(1)/20H(1X,I2,12   F10.6)  /,
     1     FMW(1)/20H(1X,I2,12   F10.6)  /,
     2     FMY(1)/20H(1X,I2,12   F10.6)  /,
     3     FX5,FX4,FX3,FX2/6HF10.5),6HF10.4),6HF10.3),6HF10.2)/
     4    ,FX6/6HF10.6)/
      DO 240 K=1,NT2
      READ  (8   ) UT,UDT,UDDT,UI,VT,VDT,VDDT,VI,SXT,SYT,SXYT,YIT
       TM= SXT(1,1)
      ILL= SYT(1,1)
       IY=SXYT(1,1)
      IF (ILL.NE.JLL)  GO TO 5
C THE INDEX  JLL  CONTROLS THE SAVING OF THE RESULTS OF A PARTICULAR
C     LOAD INCREMENT ON THE OUTPUT TAPE FOR LATER REFERENCE.  THE
C     INTERVAL IS GIVEN BY  JLI.  THE RESULTS OF THE LAST LOAD INCREMENT
C     IS ALSO SAVED FOR THE CONTINUATION RUN.
      JLL=JLL+JLI
      NT1=NT1+1
      NLO(NT1)=ILL
      WRITE (NTO) UT,UDT,UDDT,UI,VT,VDT,VDDT,VI,SXT,SYT,SXYT,YIT
    5 CONTINUE
      IF (IY.EQ.1)  FMY(2)=FX3
      DO 30 J=1,N
      DO 30 I=1,M
          W(I,J)=(UT (I,J)+VT(I,J))*1.0E06/SQR2
          U(I,J)=(UT(I,J)-VT(I,J))*1.0E06/SQR2
      IF (J.NE.1)  GO TO 25
      IF (I.GT.IEN.OR.I.LE.IB)  GO TO 20
      SI=SXYT(IEN,1)*2.
      SZ(I,1)=SI*100.
      SRZ(I,1)=SI*BETA*100.
      GO TO 30
   20 SZ(I,1)=0.
      SRZ(I,1)=0.
      GO TO 30
   25 SZ(I,J)=((SXT(I,J)+SYT(I,J))/2.+SXYT(I,J))*100.
      SRZ(I,J)=(SXT(I,J)-SYT(I,J))/2.
   30 CONTINUE
```

```
          JT=0
C SELECTION OF FORMAT FOR THE PRINT OUT.
      IF (ABS(SZ(IEN,1)).LT.10. )  GO TO 209
      IF (ABS(SZ(IEN,1)).LT.100.)  GO TO 208
      FMS(2)=FX4
      GO TO 212
  208 FMS(2)=FX5
      GO TO 212
  209 FMS(2)=FX6
  212 IF (ABS(W(IB+1,1)).LT.  100.)  GO TO 218
      IF (ABS(W(IB+1,1)).LT.10000.)  GO TO 216
      FMW(2)=FX2
      GO TO 238
  216 FMW(2)=FX4
      GO TO 238
  218 FMW(2)=FX6
  238 CONTINUE
      JB=1
      JE=JB+11
  239 WRITE (6,125)  ILL,    TM,(J,J=JB,JE)
      WRITE (6,FMS)  (J,( SZ(I,J),I=JB,JE),J=1,N)
      WRITE (6,124)  ILL,    TM,(J,J=JB,JE)
      WRITE (6,FMS)  (J,(SRZ(I,J),I=JB,JE),J=1,N)
      WRITE (6,126)  ILL,    TM,(J,J=JB,JE)
      WRITE (6,FMW)  (J,(  W(I,J),I=JB,JE),J=1,N)
      WRITE(6,127) ILL,TM,(J,J=JB,JE)
      WRITE(6,FMW) (J,(U(I,J),I=JB,JE),J=1,N)
      WRITE (6,136)  ILL,    TM,(J,J=JB,JE)
      WRITE (6,FMY)  (J,(YIT(I,J),I=JB,JE),J=1,N)
      IF (JT.EQ.1)  GO TO 240
      JB=JB+12
      JE=JE+12
      IF (JE.GE.M)  JT=1
      GO TO 239
  240 CONTINUE
      NT2=NT1
      WRITE (6,138) NOT
      DO 205 I=1,NT1
  205 WRITE (6,139) NLO(I)
C THE RESULTS FROM THE INPUT TAPE SAVED IN UNIT 8 IS TRANSFFERRED TO THE
C OUTPUT TAPE BEHIND THE OUPUT OF THIS RUN.
      IF (NT3.EQ.0)  GO TO 199
      DO 210 I=1,NT3
      READ (NTI)  UT,UDT,UDDT,UI,VT,VDT,VDDT,VI,SXT,SYT,SXYT,YIT
      NT1=NT1+1
      ILL=SYT(1,1)
      WRITE (NTO) UT,UDT,UDDT,UI,VT,VDT,VDDT,VI,SXT,SYT,SXYT,YIT
      WRITE (6,139)  ILL
  210 CONTINUE
  199 NT3=NT1
      LEN=LEN+1
      ICV=0
      WRITE (6,137) LEN,ILI,IEI,JLI,NT1,NT2,NT3,LPP,NTO,NTI,ICV
   99 RETURN
  124 FORMAT (49H1SHEAR    STRESS DISTRIBUTION (SZ*100.)  AT ILL =,I5,
```

```
     1              8H, TIME =,F10.6,5H  SEC//1X,I9,11I10//)
 125 FORMAT (49H1VERTICAL STRESS DISTRIBUTION (SZ*100.)  AT ILL =,I5,
     1              8H, TIME =,F10.6,5H  SEC//1X,I9,11I10//)
 126 FORMAT (   58H1VERTICAL DISPLACEMENT DISTRIBUTION (W*10.0E 06)  AT
     1 ILL =,I5,              8H, TIME =,F10.6,5H  SEC//1X,I9,11I10//)
 127  FORMAT(55H1HORIZONTAL DISPLACEMENT DISTRIBUTION(U*1.0E06) AT ILL=
     1       I5,              8H, TIME =,F10.6,5H  SEC//1X,I9,11I10//)
 136 FORMAT (40H1YIELD INDICATING TABLE (YIT)    AT ILL =,I5,
     1   8H, TIME =,F10.6,5H  SEC//1X,I9,11I10//)
 137 FORMAT (1HD,3X,71HFOR CONTINUING RUN, ONLY NEED TO CHANGE THE LAST
     1 DATA CARD AS FOLLOWS--//
     211X,57HLR  LEN  ILI  IEI  JLI  NT1  NT2  NT3  LPP  NTI  NTO  ICV//
     38X,I5,5X,10I5)
 138 FORMAT (1H0,18X,11HTAPE NUMBER,I6,54H  CONTAINS THE RESULTS OF LOA
     1D INCREMENT NUMBER  ILL =//)
 139 FORMAT (23X,I5)
      END
```

```
       SUBROUTINE  PROUT                                          CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.      PAGE      4

       SYMBOLIC REFERENCE MAP

   ENTRY POINTS
        1  PROUT

   VARIABLES    SN  TYPE           RELOCATION
       22  AAP      REAL                   SDAT          13  AL       REAL                  SDAT
       21  AP       REAL                   SDAT          30  BETA     REAL                  SDAT
       16  C        REAL                   SDAT          44  CONV     REAL                  CONTR
       10  CO1      REAL                   SDAT          17  CO3      REAL                  SDAT
        1  DT       REAL                   SDAT          12  DTT      REAL                  SDAT
     1001  FMS      REAL        ARRAY                  1004  FMW      REAL       ARRAY
     1007  FMY      REAL        ARRAY                   635  FX2      REAL
      634  FX3      REAL                                633  FX4      REAL
      632  FX5      REAL                                636  FX6      REAL
       14  GG       REAL                   SDAT          11  HH       REAL                  SDAT
      775  I        INTEGER                              26  IB       INTEGER               SDAT
       43  ICV      INTEGER                CONTR          5  IE       INTEGER               CONTR
        4  IEI      INTEGER                CONTR         27  IEN      INTEGER               SDAT
        2  ILI      INTEGER                CONTR        772  ILL      INTEGER
        3  ILP      INTEGER                CONTR        773  IY       INTEGER
      774  J        INTEGER                             777  JB       INTEGER
     1000  JE       INTEGER                               6  JLI      INTEGER               CONTR
        7  JLL      INTEGER                CONTR        776  JT       INTEGER
      771  K        INTEGER                              36  KN       INTEGER               SDAT
       33  KT       INTEGER                SDAT          35  KU       INTEGER               SDAT
        0  LB       INTEGER                CONTR          1  LEN      INTEGER               CONTR
       23  LPP      INTEGER                SDAT          32  LS       INTEGER               SDAT
        3  M        INTEGER                SDAT           5  M1       INTEGER               SDAT
        2  N        INTEGER                SDAT          31  NIN      INTEGER               SDAT
       15  NIT      INTEGER                CONTR         17  NLO      INTEGER    ARRAY      CONTR
       16  NOT      INTEGER                CONTR         34  NTD      INTEGER               SDAT
       14  NTI      INTEGER                CONTR         13  NTO      INTEGER               CONTR
       10  NT1      INTEGER                CONTR         11  NT2      INTEGER               CONTR
       12  NT3      INTEGER                CONTR          4  N1       INTEGER               SDAT
       20  P        REAL                   SDAT          37  PCU      REAL       ARRAY      SDAT
       64  PIN      REAL        ARRAY      SDAT          15  PO       REAL                  SDAT
        6  SI       REAL                   SDAT           7  SIK      REAL                  SDAT
       24  SQR2     REAL                   SDAT       11724  SRZ      REAL       ARRAY      DUMMY
     4752  SX       REAL        ARRAY      DUMMY      40161  SXT      REAL       ARRAY      DUMMY
    11724  SXY      REAL        ARRAY      DUMMY      45133  SXYT     REAL       ARRAY      DUMMY
     7337  SY       REAL        ARRAY      DUMMY      42546  SYT      REAL       ARRAY      DUMMY
     4752  SZ       REAL        ARRAY      DUMMY          0  TM       REAL                  SDAT
     2365  U        REAL        ARRAY      DUMMY       2365  UD       REAL       ARRAY      DUMMY
    21263  UDOT     REAL        ARRAY      DUMMY      16676  UDT      REAL       ARRAY      DUMMY
    23650  UI       REAL        ARRAY      DUMMY      14311  UT       REAL       ARRAY      DUMMY
        0  VD       REAL        ARRAY      DUMMY      33207  VDDT     REAL       ARRAY      DUMMY
    30622  VDT      REAL        ARRAY      DUMMY      35574  VI       REAL       ARRAY      DUMMY
    26235  VT       REAL        ARRAY      DUMMY       7337  W        REAL       ARRAY      DUMMY
       25  WOT      REAL                   SDAT       47520  YIT      REAL       ARRAY      DUMMY

   FILE NAMES       MODE
           TAPE6     FMT                   TAPE8     UNFMT

   INLINE FUNCTIONS   TYPE     ARGS
           ABS        REAL       1  INTRIN
```

```
        SUBROUTINE  PROUT                                           CDC 6600 FTN V3.0-279B OPT=1  12/27/71  13.34.46.       PAGE     5

 STATEMENT LABELS
   104   5                                        141  20                                 143  25
   151   30                                         0  99           INACTIVE               637  124       FMT
   652   125      FMT                             665  126     FMT                         701  127       FMT
   714   136      FMT                             726  137     FMT                         747  138       FMT
   761   139      FMT                             574  199                                   0  205
   167   208                                      171  209                                   0  210
   173   212                                      204  216                                 206  218
   210   238                                      213  239                                 446  240

 COMMON BLOCKS    LENGTH
        DUMMY      21573
        SDAT          72
        CONTR         37

 STATISTICS
   PROGRAM LENGTH   10128      522
    COMMON LENGTH  522629    21682
```

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13. ABSTRACT

The design and utilization of military aircraft in forward area situations has required a continual investigation of those factors which define the aircraft flotation performance and operations capability on semi- and unprepared soil runways.

This report documents an analytical technique developed to predict the sinkage resulting from tire/wheel braking on a soil surface. A detailed description of the approach used is provided. Preparation of the computer program is explained including the instructions for input data. The results of several example cases are provided. And appendices are included for the governing equations, lumped parameter model developed and the Fortran IV source listings produced.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft Flotation; Lumped Parameter Iteration Method; Computer Program; Aircraft Tire Braking Effects on Soil Runways; CDC 6600 Computer Program; Braking; Drucker-Prager Yield Criterion; Soil Model; Soil Parameter; Soil Displacement						

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