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REPORT NO. 1237
JANUARY 1964

A MACHINE PROGRAM FOR
COMPUTING NONLINEAR VISCOELASTIC WAVE
PROPAGATION IN SOILS

Millicent M. Beck

RDT & E Project No. 1M010501A006
BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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Millicent M. Beck

Computing Laboratory

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REPORT NO. 1237

Millicent M. Beck/ilm
Aberdeen Proving Ground, Md.
January 1964

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COMPUTING NONLINEAR VISCOELASTIC WAVE PROPAGATION IN SOILS

ABSTRACT

A numerical method and its machine program for calculating nonlinear viscoelastic wave propagation in soils are described. Solutions give particle velocity, stress and strain as functions of time and distance from the stress source.

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TABLE OF SYMBOLS

Superscript

i ith iteration.

Subscripts

m index identifying the negative wave path characteristics (maximum value M).

n index identifying the positive wave path characteristics (maximum value N).

0 initial state.

German

a, b coefficients in the viscoelastic law (Equation II-4).

$\sqrt{\frac{\rho b}{a}}$

E Young's modulus.

$f(\epsilon), \sigma(\sigma)$ functions in the law defining the static stress - strain curve of a material (Equations II-5 and II-3).

$F \frac{1}{a} [g(\sigma) - f(\epsilon)]$

H, K parameters in the static stress-strain law.

m integer identifying the negative wave path characteristics.

n integer identifying the positive wave path characteristics.

R, S static constants of a material.

t time.

Δt time increment.

v material velocity.

x Lagrangian distance.

TABLE OF SYMBOLS (Cont'd)

Greek

α	parameters in the static stress-strain law (Equation II-5).
β	
δ	criterion for convergence.
ϵ	strain.
ρ	density of material.
σ	stress.
σ_0	initial stress.

I. INTRODUCTION

This report is primarily a reference to the BRLESC (Ballistic Research Laboratories' Electronic Scientific Computer) computational procedure used at the Ballistic Research Laboratories to solve a system of nonlinear differential equations describing the viscoelastic propagation of stress waves in soils.

Studies of this nature have been pursued in the past. Seismic forces and their associated motion have been measured under known conditions to check theoretical development^{1,2,3*}. Simulation techniques have been used for the longer duration pulses produced by nuclear explosions. Measurements in the free field have shown that more consideration should be given to the phenomena occurring after the first stress peak. In order to evaluate theory on the diffraction of stress waves around an enclosure, a simple structure has been buried in a soil filled shock tube. The techniques are being improved for measurements of the required parameters associated with stress propagation.

When a nuclear device is detonated in air near the ground, a large area of the ground under the point of detonation is loaded nearly simultaneously. Under such loading, a uniform or horizontally layered half space would experience motion nearly perpendicular to the surface. Plane wave theory can be used to predict with sufficient accuracy the ground parameters near the surface which is close to the point under the detonation.

Since in the high stress region, we cannot use available linear elastic theory, nonlinear stress-strain assumptions must be made. Mercado^{4,5,6} assumed a nonlinear viscoelastic theory (time dependent) which has been shown to be present under some extreme conditions. The quantitative importance of time dependency has not yet been established for the phenomena of interest here, and this effect may not be of major concern for many materials.

This work is a theoretical phase of the contract on propagation of underground shock waves contracted to Rensselaer Polytechnic Institute by the Terminal Ballistic Laboratory at Ballistic Research Laboratories.

Information obtained from such stress-wave studies are required for free field predictions and will be useful in the development of techniques for destroying or protecting underground structures from nuclear blast.

*

Superscript numbers denote references listed at the end of this report.

II. THEORY

The theory discussed here is that of Mercado^{4,5,6} which is based on Malvern's theory^{7,8} for stress propagation in strain-rate sensitive materials.

An analytical representation of the stress-strain curve is obtained by fitting an empirical formula suggested by Osgood⁹ of the form (Reference 4, Equation 2)

$$(II-1) \quad \epsilon = \frac{\sigma}{E} + R\left(\frac{\sigma}{E}\right)^S$$

to the static data. In the above equation ϵ = strain, σ = stress, E = Young's modulus and R and S are static constants of a material. With this law, the basic constitutive equation defining the material (Reference 4, Equation 10) takes the form

$$(II-2) \quad \sigma_t - \frac{b}{a} \epsilon_t = \frac{1}{a} \left[\epsilon - g(\sigma) \right],$$

where t represents time, a and b are coefficients in the viscoelastic law, and we choose

$$(II-3) \quad g(\sigma) = \frac{\sigma}{E} + K\left(\frac{\sigma}{E}\right)^H,$$

where H, K are parameters in the stress-strain law. Mercado states that there is no experimental data known from which the dynamic constants a and b may be directly determined¹⁰. It is known from theory that $b/a \geq E$, therefore, b/a is arbitrarily chosen. The lowest order approximation to the dynamic stress-strain law is obtained by truncating the time-wise expansions of σ and ϵ after the first derivative, giving

$$(II-4) \quad g(\sigma) + a \sigma_t = f(\epsilon) + b \epsilon_t,$$

where we arbitrarily choose

$$(II-5) \quad f(\epsilon) = \epsilon \frac{1 + \beta \epsilon}{1 + \alpha \epsilon},$$

α and β being parameters in the stress-strain law.

The dynamic behavior of materials is obtained by simultaneous solution of the dynamic stress-strain law and the laws for the conservation of mass and momentum.

For a first approximation to the dynamic behavior of soils, we use the stress-strain law (II-4), the equation for the conservation of mass

$$(II-6) \quad \epsilon_t = v_x,$$

and the equation for conservation of momentum

$$(II-7) \quad \sigma_x = \rho v_t.$$

Here x is Lagrangian distance, v is material velocity, and ρ is density. Linear combinations of Equations II-4, II-6 and II-7 give the following set of characteristic equations. Along $\frac{dx}{dt} = 0$ (particle path),

$$(II-8) \quad \begin{aligned} d\sigma - \frac{b}{a} d\epsilon &= -\frac{1}{a} \left[g(\sigma) - f(\epsilon) \right] dt; \\ &= -F(\sigma, \epsilon) dt \end{aligned}$$

and along $\frac{dx}{dt} = \frac{b}{ac}$ (positive characteristic),

where

$$c \equiv \sqrt{\frac{\rho b}{a}}$$

and

$$F \equiv \frac{1}{a} \left[g(\sigma) - f(\epsilon) \right]$$

$$(II-9) \quad \begin{aligned} d\sigma - c dv &= -\frac{1}{a} \left[g(\sigma) - f(\epsilon) \right] dt \\ &= -F(\sigma, \epsilon) dt; \end{aligned}$$

and along $\frac{dx}{dt} = -\frac{b}{ac}$ (negative characteristic),

$$(II-10) \quad \begin{aligned} d\sigma + c dv &= -\frac{1}{a} \left[g(\sigma) - f(\epsilon) \right] dt \\ &= -F(\sigma, \epsilon) dt. \end{aligned}$$

These equations are supplemented by the jump conditions for a discontinuous wave propagating into a stationary medium in which $\sigma = 0$, $\epsilon = 0$ and $v = 0$. By replacing σ , ϵ , and v respectively in (II-4), (II-6), (II-7) by $\sigma H(\xi)$, $\epsilon H(\xi)$, and $v H(\xi)$, where $H(\xi) = 0$ for $\xi < 0$ and $H(\xi) = 1$ for $\xi > 0$ and $\frac{dH(\xi)}{d\xi} = \text{Dirac } \delta$, we integrate the results with respect to ξ from $-\xi$ to $+\xi$, and letting $\xi \rightarrow 0$ we obtain the jump relationship

$$(II-11) \quad \sigma = -cv = \frac{b}{a} \epsilon.$$

These equations represent the conservation of mass and momentum across a discontinuity moving into an undisturbed medium with the velocity

$$(II-12) \quad \frac{dx}{dt} = \frac{b}{ac},$$

which is also a positive characteristic.

III. NUMERICAL FORMULATION

To compute the stress, strain, and particle velocity behind the wave front, we integrate the conservation equations using the known values along the wave front and the initial and boundary values.

The characteristic curves are used as the coordinate system to extend the solution into the domain of disturbance.

Using a grid of characteristics in the t, x plane (Figure 1) σ , ϵ , and v are evaluated at each point (m, n) .

Along the wave front ($m = 0$), (II-9) and (II-11) hold. Differentiating Equation II-11 with respect to t and substituting into Equation II-9, we obtain

$$(III-1) \quad \frac{d\sigma}{dt} = \frac{1}{2a} g(\sigma) - f(\epsilon) = -\frac{1}{2} F(\sigma, \epsilon).$$

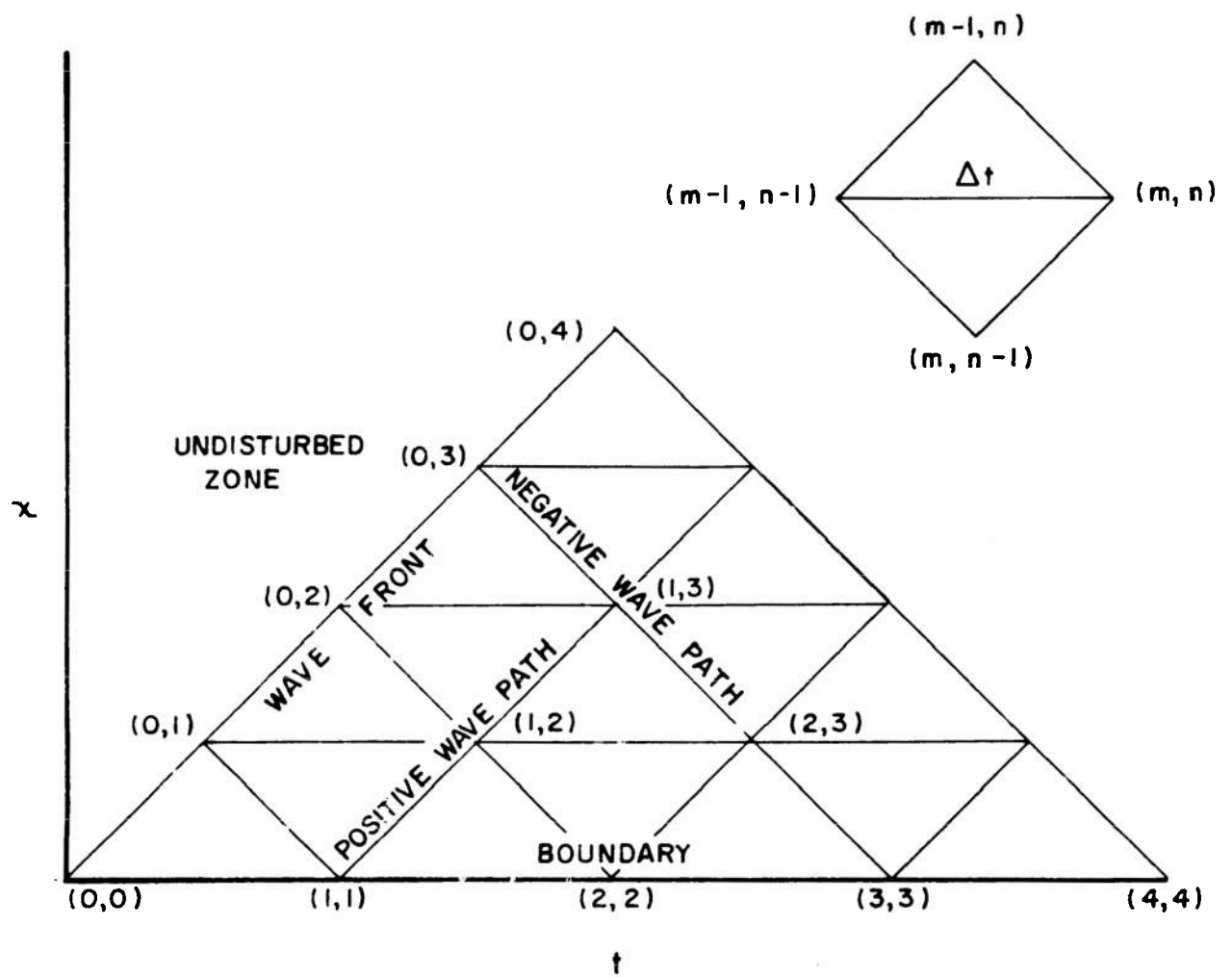


FIGURE 1.

In difference form this equation becomes (see Figure 2)

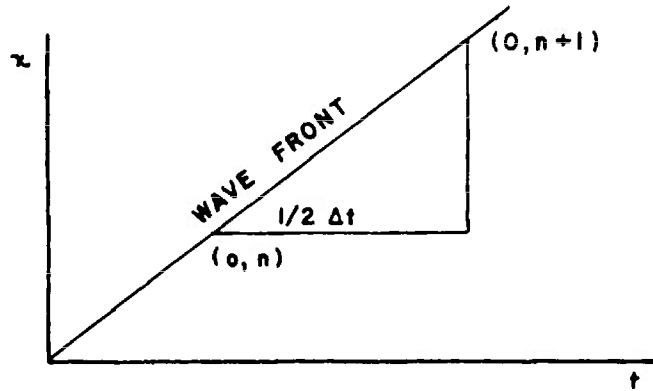


FIGURE 2.

$$(III-2) \quad \frac{\sigma_{o,n+1} - \sigma_{o,n}}{\frac{1}{2} \Delta t} = - \frac{F^{(i-1)}(\sigma_{o,n+1}, \epsilon_{o,n+1}) + F(\sigma_{o,n}, \epsilon_{o,n})}{4}$$

or

$$(III-3) \quad \sigma_{o,n+1}^{(i)} = \sigma_{o,n} - \frac{\Delta t}{8} f^{(i-1)}(\sigma_{o,n+1}, \epsilon_{o,n+1}) + F(\sigma_{o,n}, \epsilon_{o,n}).$$

With this value of σ at $(o,n+1)$, we have ϵ and v from (II-11).

$$(III-4) \quad \epsilon_{o,n+1}^{(i)} = \frac{a}{b} \sigma_{o,n+1}^{(i)},$$

$$(III-5) \quad v_{o,n+1}^{(i)} = -\frac{1}{c} \sigma_{o,n+1}^{(i)}.$$

Initially,

$$\sigma_{o,o} = \sigma_o, \quad \epsilon_{o,o} = \frac{a}{b} \sigma_o$$

and

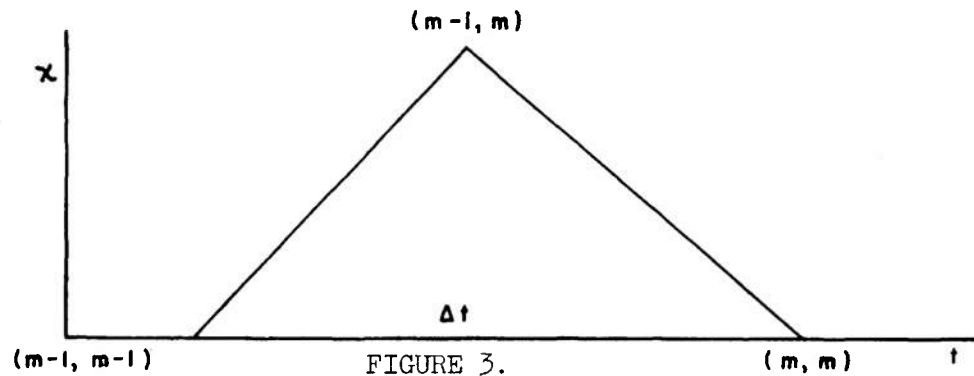
$$v_{o,o} = -\frac{1}{c} \sigma_o.$$

The set (III-3), (III-4), (III-5) are iterated over i at each point $(0, n)$, until, for some arbitrarily small positive number δ ,

$$(III-6) \quad \left| \frac{\sigma^{(i)} - \sigma^{(i-1)}}{\sigma^{(i-1)}} \right| < \delta,$$

n is then increased to some maximum value. Thus, the $m = 0$ characteristic is obtained.

For the $m = 1$ characteristic, the first point to be computed is the boundary point on the line $x = 0$. On this line we assume some constant value σ_0 for the stress. Then the general boundary point (m, m) (see Figure 3), we compute as follows:



The time and Lagrange distance are obtained from

$$(III-7) \quad t_{m,m} = t_{m-1,m-1} + \Delta t,$$

$$(III-8) \quad x_{m,m} = 0.$$

The stress is the specified value

$$(III-9) \quad \sigma_{m,m} = \sigma_0.$$

Let

$$(III-10) \quad \epsilon_{m,m}^{(0)} = \frac{\epsilon_{m-1,m-1} + \epsilon_{m-1,m}}{2},$$

$$(III-11) \quad v_{m,m}^{(0)} = \frac{v_{m-1,m-1} + v_{m-1,m}}{2}.$$

The difference form of (II-8) gives for the strain

$$(III-12) \quad \epsilon_{m,m}^{(i)} = \epsilon_{m-1,m-1} + \frac{a\Delta t}{b} \frac{f(\sigma_0, \epsilon_{m-1,m-1}) + F(\sigma_0, \epsilon_{m,m}^{(i-1)})}{2},$$

and the difference form of (II-9) in which $d\sigma = 0$ gives for the velocity

$$(III-13) \quad v_{m,m}^{(i)} = v_{m-1,m} - \frac{1}{c} (\sigma_o - \sigma_{m-1,m}) - \frac{\Delta t}{2c} \frac{F(\sigma_{m-1,m}, \epsilon_{m-1,m}) + F(\sigma_o, \epsilon_{m,m}^{(i-1)})}{2}.$$

This process is repeated until for some i , the convergence test

$$(III-14) \quad \left| \frac{\phi_{m,m}^{(i)} - \phi_{m,m}^{(i-1)}}{\phi_{m,m}^{(i-1)}} \right| < \delta$$

is satisfied, where $\phi = \epsilon$ and v , and where if the denominator is zero, this convergence test is bypassed.

With this boundary point computed, we progress up along the positive characteristic. Each point along this characteristic, say point (m,n) (see Figure 4), we compute as follows.

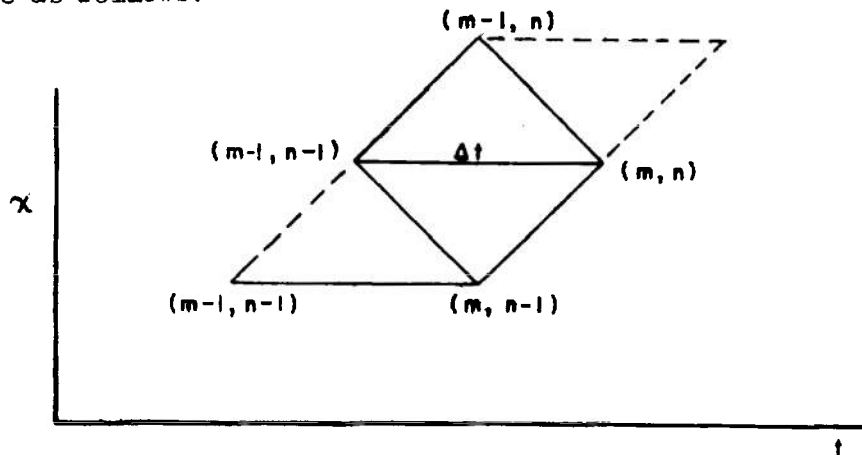


FIGURE 4.

The time and Lagrange distance are obtained from

$$(III-15) \quad t_{m,n} = t_{m,n-1} + \frac{\Delta t}{2},$$

$$(III-16) \quad x_{m,n} = x_{m,n-1} + \frac{b}{ac} \left(\frac{\Delta t}{2} \right).$$

Let

$$(III-17) \quad \sigma_{m,n}^{(0)} = \frac{\sigma_{m-1,n} + \sigma_{m,n-1}}{2},$$

$$(III-18) \quad \epsilon_{m,n}^{(0)} = \frac{\epsilon_{m-1,n} + \epsilon_{m,n-1}}{2},$$

$$(III-19) \quad v_{m,n}^{(0)} = \frac{v_{m-1,n} + v_{m,n-1}}{2},$$

The difference forms of (II-8), (II-9), and (II-10) solved simultaneously give

$$(III-20) \quad \begin{aligned} \sigma_{m,n}^{(i)} = & \frac{\sigma_{m,n-1} + \sigma_{m-1,n}}{2} - \frac{c}{2}(v_{m,n-1} - v_{m-1,n}) \\ & - \frac{\Delta t}{4} \left[\frac{F(\sigma_{m,n-1}, \epsilon_{m,n-1}) + F(\sigma_{m,n}^{(i-1)}, \epsilon_{m,n}^{(i-1)})}{2} \right. \\ & \left. + \frac{F(\sigma_{m-1,n}, \epsilon_{m-1,n}) + F(\sigma_{m,n}^{(i-1)}, \epsilon_{m,n}^{(i-1)})}{2} \right], \end{aligned}$$

$$(III-21) \quad \epsilon_{m,n}^{(i)} = \epsilon_{m-1,n-1} + \frac{b(\sigma_{m,n}^{(i)} - \sigma_{m-1,n-1})}{a} + \frac{\Delta t}{B} \frac{F(\sigma_{m-1,n-1}, \epsilon_{m-1,n-1}) + F(\sigma_{m,n}^{(i-1)}, \epsilon_{m,n}^{(i-1)})}{2},$$

$$(III-22) \quad v_{m,n}^{(i)} = v_{m,n-1} + \frac{\sigma_{m,n}^{(i)} - \sigma_{m,n-1}}{c} + \frac{\Delta t}{2c} \frac{F(\sigma_{m,n-1}, \epsilon_{m,n-1}) + F(\sigma_{m,n}^{(i-1)}, \epsilon_{m,n}^{(i-1)})}{2}.$$

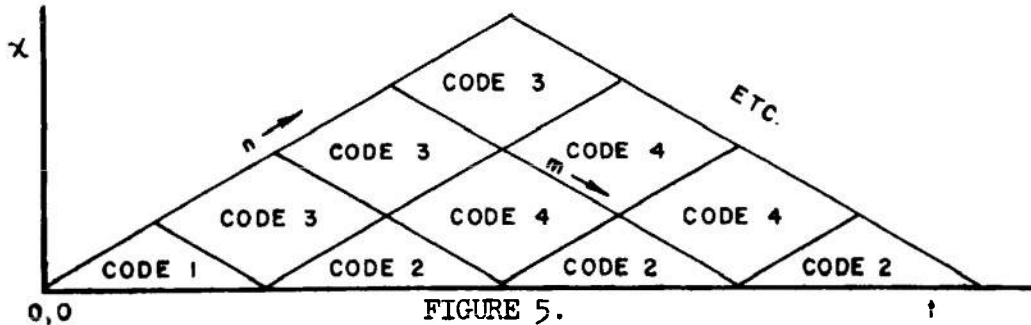
This process is repeated for each i until the convergence criterion

$$(III-23) \quad \left[\frac{\phi_{m,n}^{(i)} - \phi_{m,n}^{(i-1)}}{\phi_{m,n}^{(i-1)}} \right] < \delta$$

is satisfied for $\phi = \sigma, \epsilon$, and v .

IV. ORGANIZATION OF CALCULATION AND PROGRAM

For each m characteristic that we compute, we require values on the $m-1$ characteristic; therefore, the memory size limits the number of points that can be computed on each characteristic. In order not to limit the domain of computation, it was divided into zones. For this purpose, four codes are written, differing only in the input arrangements. These four codes can be used to cover the entire domain (Figure 5).



An option provides a choice on the number of computed points to be printed. On the boundaries of each code zone, however, values at all points are printed, since they may be the input data for subsequent zones. Code 1 would suffice to complete the computation if the memory were sufficiently large to accommodate all the points on any given characteristic.

The compiler language used is the FORAST¹¹.

CODE SYMBOLS

CODE NAME	DEFINITIONS
A	$\frac{1}{a}$
ALPHA	α
ANS	Printing frequency (1,2,3,etc.)
B	$\frac{b}{a}$
BEE	b
BEGIN	{ + no shock at wave front - shock at wave front
BETA	β
C	c
DELT	Δt
DELTA	δ
E	ϵ (strain)
EO	E (Young's modulus)
H	H
K	K
M	m
N	n
RHO	ρ
SIGMA	σ
SIGO	σ_0
T	t
V	v
X	x

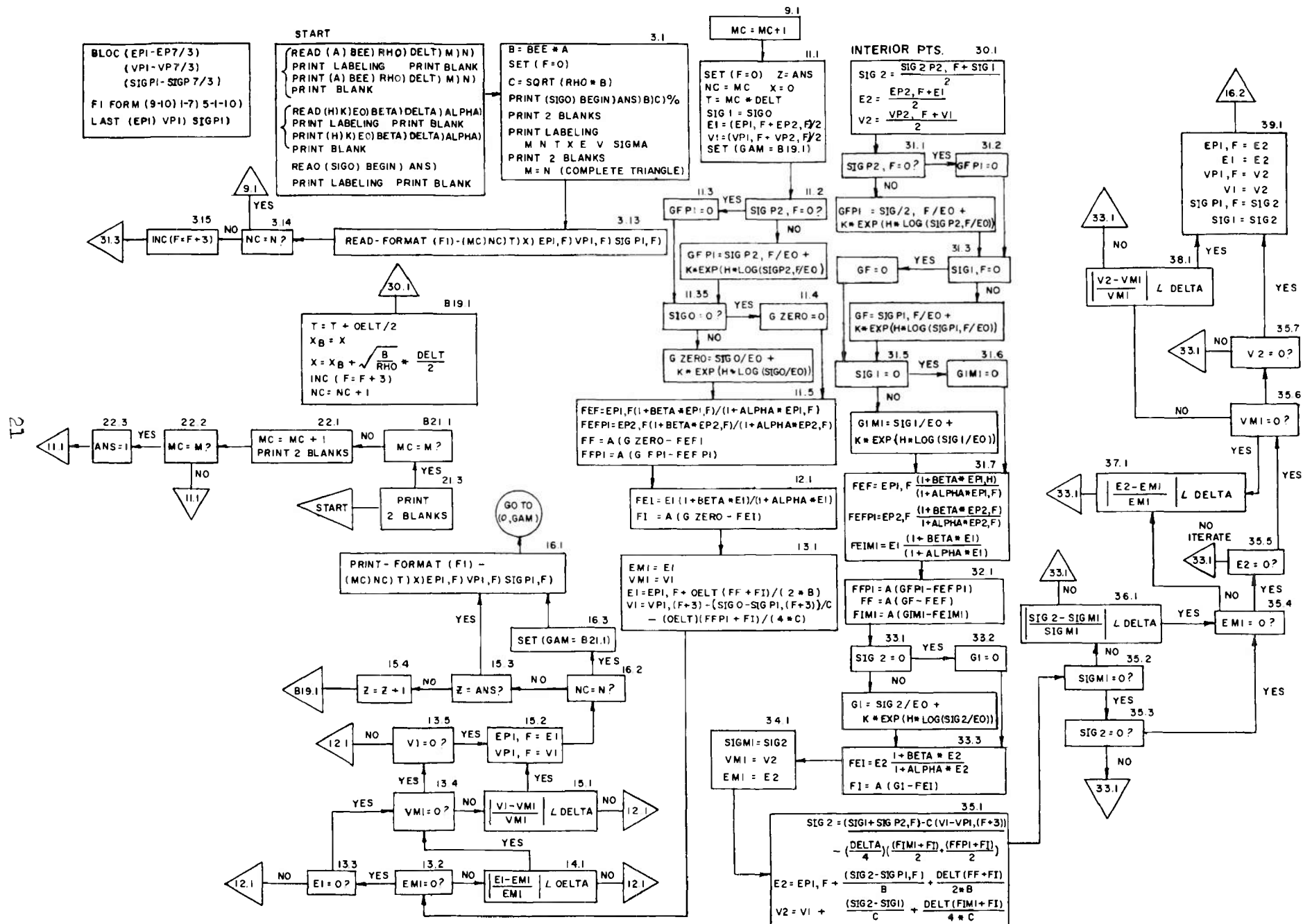
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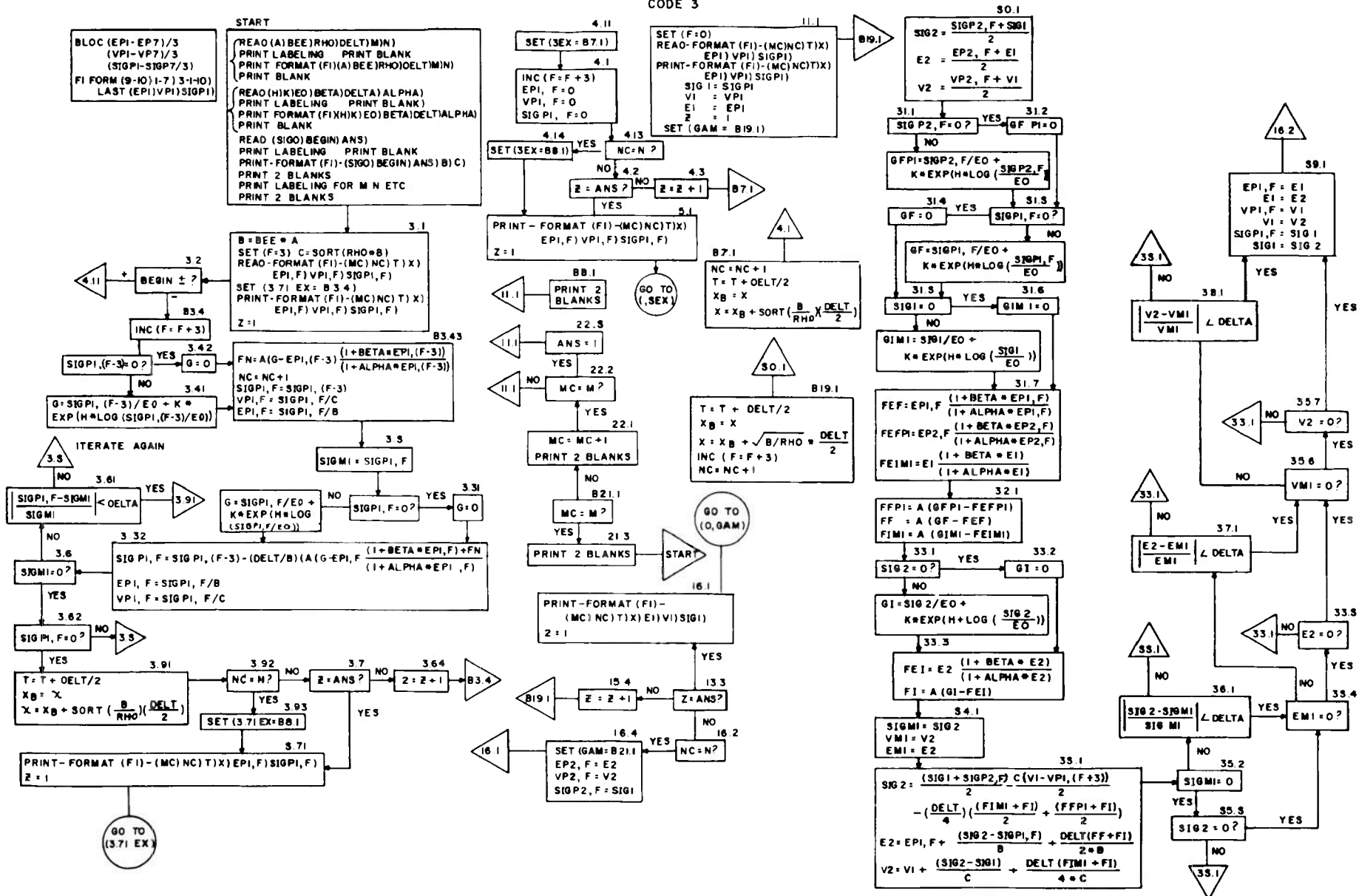
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CODE 2





PROGRAM FOR CODE I AND INPUT PARAMETERS WITH
BOUNDARY DATA FOR A SPECIAL CASE

PROB	TF-033 GROUND SHOCK STUDIES CODE 1	1
	BLOC(EPI-EP7/3)VP1-VP7/3)SIGPI-SIGP7/3)%	2
F1	FORM(9-10)1-7)5-1-10)%	3
	LAST(EP1)VP1)SIGP1)%	5
START	READ(A)BEE)RHO)DELT)M)N)%	6
	PRINT-FORMAT(F1)-	7
CONT	< A BEE RHO DELT >	8
CONT<	M N >% ENTER(PRINTB)%	9
	PRINT-FORMAT(F1)-(A)BEE)RHO)DELT)M)N)%ENTER(PRINTB)%	10
	READ(H)K)EO)BETA)DELTA)ALPHA)%	11
	PRINT-FORMAT(F1)-	12
CONT	< H K EO BETA >	13
CONT<	DELTA ALPHA >%ENTER(PRINTB)%	14
	PRINT-FORMAT(F1)-(H)K)EO)BETA)DELTA)ALPHA)%ENTER(PRINTB)%	15
	READ(SIGO)BEGIN)ANS)%	16
	PRINT-FORMAT(F1)-	17
CONT	< SIGO BEGIN ANS B C >%	18
	ENTER(PRINTB)%	19
2.1	IF(N<M)GOTO(2.2)%	20
3.1	B=BEE*A% T=0%X=0%	21
	Z=ANS%	22
	SET(F=0)%C=SQRT(RHO*B)%MC=0%NC=0%	23
	PRINT-FORMAT(F1)-(SIGO)BEGIN)ANS)B)C)%	24
	ENTER(PRINTB)% ENTER(PRINTB)%	25
	PRINT-FORMAT(F1)-	26
CONT	< M N T X E >	27
CONT<	V SIGMA >%	28
	ENTER(PRINTB)%ENTER(PRINTB)%	29
3.2	IF(BEGIN)IS+GOTO(4.11)%	30
3.3	SIGP1,F=SIGO%EP1,F=SIGO/B%VP1,F=-SIGO/C%	31
	Z=1% SET(3.71EX=B3.4)%	32
	PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%	33
B3.4	INC(F=F+3)%	34
	IF(SIGP1,(F-3)=0)GOTO(3.42)%	35
3.41	G=SIGP1,(F-3)	36
CONT	/EO+K*EXP(H*LOG(SIGP1,(F-3)/EO))%GOTO(3.43)%	37
3.42	G=0%	38
3.43	FN=A(G-EP1,(F-3)(1+BETA*EP1,(F-3))/(1+ALPHA*EP1,(F-3)))%	39
	NC=NC+1%SIGP1,F=SIGP1,(F-3)%	40
	VP1,F=-SIGP1,F/C%EP1,F=SIGP1,F/B%	41
3.5	SIGM1=SIGP1,F%	42
	IF(SIGP1,F=0)GOTO(3.51)%	43
	G=SIGP1,F/EO+K*EXP(H*LOG(SIGP1,F /EO))%GOTO(3.52)%	44
3.51	G=0%	45
3.52	SIGP1,F=SIGP1,(F-3)-(DELT/8)(A(G-EP1,F(1+BETA*EP1,F)/	46
CONT	(1+ALPHA*EP1,F))+FN)%	47
	EP1,F=SIGP1,F/B%VP1,F=-SIGP1,F/C%	48
3.6	IF(SIGM1=0)GOTO(3.62)%	49
3.61	IF-ABS((SIGP1,F-SIGM1)/SIGM1<DELTA)GOTO(3.91)%GOTO(3.5)%	50
3.62	IF(SIGP1,F=0)GOTO(3.91)%GOTO(3.5)%	51
3.71	PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%	52
	Z=1% GOTO(3.71EX)%	53
3.91	T=T+DELT/2%X=X=X+SQRT(B/RHO)*DELT/2%	54
3.92	IF(NC=N)WITHIN(.005)GOTO(3.93)%	55

3.7	IF(Z=ANS)WITHIN(.005)GOTO(3.71)%	56
3.64	Z=Z+1% GOTO(B3.4)%	57
3.93	SET(3.71EX=B8.1)%GOTO(3.71)%	58
4.11	SET(5EX=B7.1)%	59
4.1	EP1,F=0%VP1,F=0%SIGP1,F=0%	60
4.13	IF(NC=N)WITHIN(.005)GOTO(4.14)%	61
4.2	IF(Z=ANS)WITHIN(.005)GOTO(5.1)%	62
4.3	Z=Z+1% GOTO(B7.1)%	63
4.14	SET(5EX=B8.1)%	64
5.1	PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%	65
	Z=1% GOTO(,5EX)%	66
B7.1	INC(F=F+3)%NC=NC+1%T=T+DELT/2%X=X+SQRT(B/RHO)*DELT/2%	67
	GOTO(4.1)%	68
B8.1	ENTER(PRINTB)%ENTER(PRINTB)%	69
9.1	MC=1%	70
11.1	SET(F=0)% NC=MC%X=0%T=MC*DELT%	71
	Z=ANS% SET(GAM=B19.1)%	72
	SIG1=SIG0%E1=(EP1,F+EP2,F)/2%V1=(VP1,F+VP2,F)/2%	73
11.2	IF(SIGP2,F =0)GOTO(11.3)%	74
	GFP1=SIGP2,F/E0+K*EXP(H*LOG(SIGP2,F/E0))%GOTO(11.35)%	75
11.3	GFP1=0%	76
11.35	IF(SIG0 =0)GOTO(11.4)%	77
	GZERO=SIG0/E0+K*EXP(H*LOG(SIG0/E0))%GOTO(11.5)%	78
11.4	GZERO=0%	79
11.5	FEF=EP1,F(1+BETA*EP1,F)/(1+ALPHA*EP1,F)%	80
	FEFP1=EP2,F(1+BETA*EP2,F)/(1+ALPHA*EP2,F)%	81
	FF=A(GZERO-FEF)%	82
	FFP1=A(GFP1-FEFP1)%	83
12.1	FEI=E1(1+BETA*E1)/(1+ALPHA*E1)%	84
	FI=A(GZERO-FEI)%	85
13.1	EM1=E1%VM1=V1%	86
	E1=EP1,F+DELT(FF+FI)/(2*B)%	87
	V1=VP1,(F+3)-(SIG0-SIGP1,(F+3))/C-(DELT)(FFP1+FI)/(4*C)%	88
13.2	IF(EM1=0)GOTO(13.3)%	89
14.1	IF-ABS((E1-EM1)/EM1<DELTA)GOTO(13.4)%GOTO(12.1)%	90
13.3	IF(E1=0)GOTO(13.4)%GOTO(12.1)%	91
13.4	IF(VM1=0)GOTO(13.5)%	92
15.1	IF-ABS((V1-VM1)/VM1<DELTA)GOTO(15.2)%GOTO(12.1)%	93
13.5	IF(V1=0)GOTO(15.2)%GOTO(12.1)%	94
15.2	EP1,F=E1%VP1,F=V1%	95
16.2	IF(NC=N)GOTO(16.3)%	96
15.3	IF(Z=ANS)WITHIN(.005)GOTO(16.1)%	97
15.4	Z=Z+1% GOTO(B19.1)%	98
16.1	PRINT-FORMAT(F1)-(MC)NC)T)X)E1)V1)SIG1)%	99
	Z=1% GOTO(C,GAM)%	100
16.3	SET(GAM=821.1)% GOTO(16.1)%	101
B19.1	INC(F=F+3)%NC=NC+1%	102
	T=T+DELT/2%X=X+SQRT(B/RHO)*DELT/2%GOTO(30.1)%	103
B21.1	IF(MC=M)WITHIN(.005)GOTO(21.3)%	104
22.1	MC=MC+1% ENTER(PRINTB)% ENTER(PRINTB)%	105
22.2	IF(MC=M)WITHIN(.005)GOTO(22.3)% GOTO(11.1)%	106
22.3	ANS=1% GOTO(11.1)%	107
21.3	ENTER(PRINTB)% ENTER(PRINTB)% GOTO(START)%	108
30.1	SIG2=(SIGP2,F+SIG1)/2%E2=(EP2,F+E1)/2%	109
	V2=(VP2,F+V1)/2%	110
31.1	IF(SIGP2,F =0)GOTO(31.2)%	111
	GFP1=SIGP2,F/E0+K*EXP(H*LOG(SIGP2,F/E0))%GOTO(31.3)%	112
31.2	GFP1=0%	113

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31.3      IF(SIGP1,F  =0)GOTO(31.4)%                                114
          GF=SIGP1,F/E0+K*EXP(H*LOG(SIGP1,F/E0))%GOTO(31.5)%      115
31.4      GF=0%                                                    116
31.5      IF(SIG1  =0)GOTO(31.6)%                                117
          GIM1=SIG1/E0+K*EXP(H*LOG(SIG1/E0))%GOTO(31.7)%          118
31.6      GIM1=0%                                                  119
31.7      FEF=EP1,F (1+BETA*EP1,F)/(1+ALPHA*EP1,F)%              120
          FEFPI=EP2,F (1+BETA*EP2,F)/(1+ALPHA*EP2,F)%            121
          FEIM1=E1 (1+BETA*E1)/(1+ALPHA*E1)%                      122
32.1      FFP1=A(GFP1-FEFP1)%  FF=A(GF-FEF)%                     123
          FIM1=A(GIM1-FEIM1)%                                      124
33.1      IF(SIG2  =0)GOTO(33.2)%                                125
          GI=SIG2/E0+K*EXP(H*LOG(SIG2/E0))%GOTO(33.3)%           126
33.2      GI=0%                                                    127
33.3      FEI=E2(1+BETA*E2)/(1+ALPHA*E2)%                          128
          FI=A(GI-FEI)%                                           129
34.1      SIGM1=SIG2%VM1=V2%EM1=E2%                               130
35.1      SIG2=(SIG1+SIGP2,F)/2-C(V1-VP1,(F+3))/2                 131
          CONT-(DELT/4)((FIM1+FI)/2+(FFP1+FI)/2)%                 132
          E2=EP1,F+(SIG2-SIGP1,F)/B+DELT(FF+FI)/(2*B)%           133
          V2=V1+(SIG2-SIG1)/C+DELT(FIM1+FI)/(4*C)%               134
35.2      IF(SIGM1=0)GOTO(35.3)%                                  135
36.1      IF-ABS((SIG2-SIGM1)/SIGM1<DELTA)GOTO(35.4)%GOTO(33.1)% 136
35.3      IF(SIG2=0)GOTO(35.4)%GOTO(33.1)%                       137
35.4      IF(EM1=0)GOTO(35.5)%                                    138
37.1      IF-ABS((E2-EM1)/EM1<DELTA)GOTO(35.6)%GOTO(33.1)%       139
35.5      IF(E2=0)GOTO(35.6)%GOTO(33.1)%                         140
35.6      IF(VM1=0)GOTO(35.7)%                                    141
38.1      IF-ABS((V2-VM1)/VM1<DELTA)GOTO(39.1)%GOTO(33.1)%       142
35.7      IF(V2=0)GOTO(39.1)%GOTO(33.1)%                         143
39.1      EP1,F=E2%E1=E2% VP1,F=V2%V1=V2%                       144
          SIGP1,F=SIG2%SIG1=SIG2%GOTO(16.2)%                     145
2.2      PRINT<  N      IS      LESS      THAN      M      >%    146
          ENTER(PRINTB)% ENTER(PRINTB)%  GOTO(START)%             147
          END GOTO(START)%                                         148

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CASE 1 10X10 DOMAIN INPUT PARAMETERS

A	BEE	RHO	DELT	M	N
90388944	07 23896900-02	15000000-03	20000000-03	10000000 02	10000000 02
H	K	EO	BETA	DELTA	ALPHA
22200000	01 68600000 04	21400000 05	00000000 00	10000000-08	00000000 00
SIG0	BEGIN	ANS			
50000000	02-50000000 00	10000000 01			

CASE 2 3X3 ZONE INPUT PARAMETERS

A	BEE	RHO	DELT	M	N
90388944	07 23896900-02	15000000-03	20000000-03	30000000 01	30000000 01
H	K	EO	BETA	DELTA	ALPHA
22200000	01 68600000 04	21400000 05	00000000 00	10000000-08	00000000 00
SIG0	BEGIN	ANS			
50000000	02-50000000 00	10000000 01			

PROGRAM FOR CODE 2 AND INPUT PARAMETERS WITH
BOUNDARY DATA FOR A SPECIAL CASE

	PROB TF-033 GROUND SHOCK STUDIES CODE2	1
	BLOC(EP1-EP7/3)VP1-VP7/3)SIGP1-SIGP7/3)%	2
F1	FORM(9-10)1-7)5-1-10)%	3
	LAST(EP1)VP1)SIGP1)%	5
START	READ(A)BEE)RHO)DELT)M)N)%	6
	PRINT-FORMAT(F1)-	7
	CONT < A BEE RHO DELT >	8
	CONT< M N >% ENTER(PRINTB)%	9
	PRINT-FORMAT(F1)-(A)BEE)RHO)DELT)M)N)%ENTER(PRINTB)%	10
	READ(H)K)EO)BETA)DELTA)ALPHA)%	11
	PRINT-FORMAT(F1)-	12
	CONT < H K EO BETA >	13
	CONT<DELTA ALPHA >%ENTER(PRINTB)%	14
	PRINT-FORMAT(F1)-(H)K)EO)BETA)DELTA)ALPHA)%ENTER(PRINTB)%	15
	READ(SIGO)BEGIN)ANS)%	16
	PRINT-FORMAT(F1)-	17
	CONT < SIGO BEGIN ANS B C >%	18
	ENTER(PRINTB)%	19
3.1	B=BEE*A%	20
	SET(F=0)%C=SQRT(RHO*B)%	21
	PRINT-FORMAT(F1)-(SIGO)BEGIN)ANS)B)C)%	22
	ENTER(PRINTB)% ENTER(PRINTB)%	23
	PRINT-FORMAT(F1)-	24
	CONT < M N T X E >	25
	CONT < V SIGMA >%	26
	ENTER(PRINTB)%ENTER(PRINTB)% M=N%	27
3.13	READ-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%	28
3.14	IF(NC=N)WITHIN(.005)GOTO(9.1)%	29
3.15	INC(F=F+3)% GOTO(3.13)%	30
9.1	MC=MC+1%	31
11.1	SET(F=0)% NC=MC%X=0%T=MC*DELT%	32
	Z=ANS% SET(GAM=819.1)%	33
	SIG1=SIGO%E1=(EP1,F+EP2,F)/2%V1=(VP1,F+VP2,F)/2%	34
11.2	IF(SIGP2,F =0)GOTO(11.3)%	35
	GFP1=SIGP2,F/EO+K*EXP(H*LOG(SIGP2,F/EO))%GOTO(11.35)%	36
11.3	GFP1=0%	37
11.35	IF(SIGO =0)GOTO(11.4)%	38
	GZERO=SIGO/EO+K*EXP(H*LOG(SIGO/EO))%GOTO(11.5)%	39
11.4	GZERO=0%	40
11.5	FEF=EP1,F(1+BETA*EP1,F)/(1+ALPHA*EP1,F)%	41
	FEFP1=EP2,F(1+BETA*EP2,F)/(1+ALPHA*EP2,F)%	42
	FF=A(GZERO-FEF)%	43
	FFP1=A(GFP1-FEFP1)%	44
12.1	FEI=E1(1+BETA*E1)/(1+ALPHA*E1)%	45
	FI=A(GZERO-FEI)%	46
13.1	EM1=E1%VM1=V1%	47
	E1=EP1,F+DELT(FF+FI)/(2*B)%	48
	V1=VP1,(F+3)-(SIGO-SIGP1,(F+3))/C-(DELT)(FFP1+FI)/(4*C)%	49
13.2	IF(EM1=0)GOTO(13.3)%	50
14.1	IF-ABS((E1-EM1)/EM1<DELTA)GOTO(13.4)%GOTO(12.1)%	51
13.3	IF(E1=0)GOTO(13.4)%GOTO(12.1)%	52
13.4	IF(VM1=0)GOTO(13.5)%GOTO(15.1)%	53
15.1	IF-ABS((V1-VM1)/VM1<DELTA)GOTO(15.2)%GOTO(12.1)%	54
13.5	IF(V1=0)GOTO(15.2)%GOTO(12.1)%	55

15.2	EP1,F=E1%VP1,F=V1%	56
16.2	IF(NC=N)WITHIN(.005)GOTO(16.3)%	57
15.3	IF(Z=ANS)WITHIN(.005)GOTO(16.1)%	58
15.4	Z=Z+1% GOTO(B19.1)%	59
16.1	PRINT-FORMAT(F1)-(MC)NC)T)X)E1)V1)SIG1)%	60
	Z=1% GOTO(0,GAM)%	61
16.3	SET(GAM=B21.1)% GOTO(16.1)%	62
B19.1	INC(F=F+3)%NC=NC+1%	63
	T=T+DELT/2%X=X=X+SQRT(R/RHO)*DELT/2%GOTO(30.1)%	64
B21.1	IF(MC=M)WITHIN(.005)GOTO(21.3)% MC=MC+1% ENTER(PRINTB)%	65
	ENTER(PRINTB)% IF(MC=M)WITHIN(.005)GOTO(22.3)% GOTO(11.1)%	66
21.3	ENTER(PRINTB)% ENTER(PRINTB)% GOTO(START)%	67
22.3	ANS=1% GOTO(11.1)%	68
30.1	SIG2=(SIGP2,F+SIG1)/2%E2=(EP2,F+E1)/2%	69
	V2=(VP2,F+V1)/2%	70
31.1	IF(SIGP2,F=0)GOTO(31.2)%	71
	GFP1=SIGP2,F/E0+K*EXP(H*LOG(SIGP2,F/E0))%GOTO(31.3)%	72
31.2	GFP1=0%	73
31.3	IF(SIGP1,F=0)GOTO(31.4)%	74
	GF=SIGP1,F/E0+K*EXP(H*LOG(SIGP1,F/E0))%GOTO(31.5)%	75
31.4	GF=0%	76
31.5	IF(SIG1=0)GOTO(31.6)%	77
	GIM1=SIG1/E0+K*EXP(H*LOG(SIG1/E0))%GOTO(31.7)%	78
31.6	GIM1=0%	79
31.7	FEF=EP1,F (1+BETA*EP1,F)/(1+ALPHA*EP1,F)%	80
	FEFP1=EP2,F (1+BETA*EP2,F)/(1+ALPHA*EP2,F)%	81
	FEIM1=E1 (1+BETA*F1)/(1+ALPHA*E1)%	82
32.1	FFP1=A(GFP1-FEFP1)% FF=A(GF-FEF)%	83
	FIM1=A(GIM1-FEIM1)%	84
33.1	IF(SIG2=0)GOTO(33.2)%	85
	GI=SIG2/E0+K*EXP(H*LOG(SIG2/E0))%GOTO(33.3)%	86
33.2	GI=0%	87
33.3	FEI=E2(1+BETA*E2)/(1+ALPHA*E2)%	88
	FI=A(GI-FEI)%	89
34.1	SIGM1=SIG2%VM1=V2%EM1=E2%	90
35.1	SIG2=(SIG1+SIGP2,F)/2-C(V1-VP1,(F+3))/2	91
	CONT-(DELT/4)((FIM1+FI)/2+(FFP1+F1)/2)%	92
	E2=EP1,F+(SIG2-SIGP1,F)/B+DELT(FF+F1)/(2*B)%	93
	V2=V1+(SIG2-SIG1)/C+DELT(FIM1+F1)/(4*C)%	94
35.2	IF(SIGM1=0)GOTO(35.3)%	95
36.1	IF-ABS((SIG2-SIGM1)/SIGM1<DELTA)GOTO(35.4)%GOTO(33.1)%	96
35.3	IF(SIG2=0)GOTO(35.4)%GOTO(33.1)%	97
35.4	IF(EM1=0)GOTO(35.5)%	98
37.1	IF-ABS((E2-EM1)/EM1<DELTA)GOTO(35.6)%GOTO(33.1)%	99
35.5	IF(E2=0)GOTO(35.6)%GOTO(33.1)%	100
35.6	IF(VM1=0)GOTO(35.7)%	101
38.1	IF-ABS((V2-VM1)/VM1<DELTA)GOTO(39.1)%GOTO(33.1)%	102
35.7	IF(V2=0)GOTO(39.1)%GOTO(33.1)%	103
39.1	EP1,F=E2%E1=E2% VP1,F=V2%V1=V2%	104
	SIGP1,F=SIG2%SIG1=SIG2%GOTO(16.2)%	105
	END GOTO(START)%	106

CASE 1

INPUT PARAMETERS

A	BEE	RHO	DELT	M	N
90388944	07 23896900-02	15000000-03	20000000-03	40000000	01 70000000 01

H	K	EO	BETA	DELTA	ALPHA
22200000 01	68600000 04	21400000 05	00000000 00	10000000-08	00000000 00
SIG0	BEGIN	ANS			
50000000 02-50000000 00	10000000 01				

INPUT BOUNDARY DATA ON M=3 CHARACTERISTIC

M	N	T	X	E	V	SIGMA
300000 01	300000 01	600000-03	000000 00	451328-02-383640 02	500000 02	
300000 01	400000 01	700000-03	120000 01	412734-02-359208 02	477472 02	
300000 01	500000 01	800000-03	240001 01	379712-02-337303 02	456285 02	
300000 01	600000 01	900000-03	360001 01	351191-02-317622 02	436460 02	
300000 01	700000 01	100000-02	480002 01	326356-02-299895 02	417963 02	

CASE 2

INPUT PARAMETERS

A	BEE	RHO	DELT	M	N
90388944 07	23896900-02	15000000-03	20000000-03	80000000 01	10000000 02
H	K	EO	BETA	DELTA	ALPHA
22200000 01	68600000 04	21400000 05	00000000 00	10000000-08	00000000 00
SIG0	BEGIN	ANS			
50000000 02-50000000 00	10000000 01				

INPUT BOUNDARY DATA ON M=7 CHARACTERISTIC

700000 01	700000 01	140000-02	000000 00	670435-02-459084 02	500000 02
700000 01	800000 01	150000-02	120000 01	623943-02-438848 02	487296 02
700000 01	900000 01	160000-02	240001 01	582185-02-419527 02	474410 02
700000 01	100000 02	170000-02	360001 01	544555-02-401182 02	461515 02

PROGRAM FOR CODE 3 AND INPUT PARAMETERS WITH
BOUNDARY DATA FOR A SPECIAL CASE

	PROB TF-033 GROUND SHOCK STUDIES	CODE 3	1
	BLOC(EP1-EP7/3)VP1-VP7/3)SIGP1-SIGP7/3)%		2
F1	FORM(9-10)1-7)5-1-10)%		3
	LAST(EP1)VP1)SIGP1)%		5
START	READ(A)BEE)RHO)DELT)M)N)%		6
	PRINT-FORMAT(F1)-		7
	CONT < A BEE RHO DELT >		8
	CONT< M N >% ENTER(PRINTB)%		9
	PRINT-FORMAT(F1)-(A)BEE)RHO)DELT)M)N)%ENTER(PRINTB)%		10
	READ(H)K)FO)BETA)DELTA)ALPHA)%		11
	PRINT-FORMAT(F1)-		12
	CONT < H K EO BETA >		13
	CONT<DELTA ALPHA >%ENTER(PRINTB)%		14
	PRINT-FORMAT(F1)-(H)K)EO)BETA)DELTA)ALPHA)%ENTER(PRINTB)%		15
	READ(SIGO)BEGIN)ANS)%		16
	PRINT-FORMAT(F1)-		17
	CONT < SIGO BEGIN ANS >% ENTER(PRINTB)%		18
	PRINT-FORMAT(F1)-(SIGO)BEGIN)ANS)%ENTER(PRINTB)%ENTER(PRINTB)%		19
	PRINT-FORMAT(F1)-		20
	CONT < M N T X E >		21
	CONT < V SIGMA >%		22
	ENTER(PRINTB)%ENTER(PRINTB)%		23
3.1	B=BEE*A%		24
	SET(F=3)%C=SQRT(RHO*B)%		25
	READ-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%		26
	PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%		27
	Z=1% SET(3.71EX=B3.4)%		28
3.2	IF(BEGIN)IS+GOTO(4.11)%		29
B3.4	INC(F=F+3)%		30
	IF(SIGP1,(F-3) =0)GOTO(3.42)%		31
3.41	G=SIGP1,(F-3)		32
	CONT /EO+K*EXP(H*LOG(SIGP1,(F-3)/EO))%GOTO(3.43)%		33
3.42	G=0%		34
3.43	FN=A(G-EP1,(F-3))(1+BETA*EP1,(F-3))/(1+ALPHA*EP1,(F-3))%		35
	NC=NC+1%SIGP1,F=SIGP1,(F-3)%		36
	VP1,F=-SIGP1,F/C%EP1,F=SIGP1,F/B%		37
3.5	SIGM1=SIGP1,F%		38
	IF(SIGP1,F =0)GOTO(3.51)%		39
	G=SIGP1,F/EO+K*EXP(H*LOG(SIGP1,F /EO))%GOTO(3.52)%		40
3.51	G=0%		41
3.52	SIGP1,F=SIGP1,(F-3)-(DELT/8)(A(G-EP1,F(1+BETA*EP1,F)/		42
	CONT(1+ALPHA*EP1,F))+FN)%		43
	EP1,F=SIGP1,F/B%VP1,F=-SIGP1,F/C%		44
3.6	IF(SIGM1=0)GOTO(3.62)%		45
3.61	IF-ABS((SIGP1,F-SIGM1)/SIGM1<DELTA)GOTO(3.91)%GOTO(3.5)%		46
3.62	IF(SIGP1,F=0)GOTO(3.91)%GOTO(3.5)%		47
3.91	T=T+DELT/2%X=X=X+SQRT(B/RHO)*DELT/2%		48
3.92	IF(NC=N)WITHIN(.005)GOTO(3.93)%		49
3.7	IF(Z=ANS)WITHIN(.005)GOTO(3.71)%		50
3.64	Z=Z+1% GOTO(B3.4)%		51
3.71	PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%		52
	Z=1% GOTO(,3.71EX)%		53
3.93	SET(3.71EX=B8.1)%GOTO(3.71)%		54
4.11	SET(5EX=B7.1)%		55

4.1	INC(F=F+3)%	56
	EP1,F=0%VP1,F=0%SIGP1,F=0%	57
4.13	IF(NC=N)WITHIN(.005)GOTO(4.14)%	58
4.2	IF(Z=ANS)WITHIN(.005)GOTO(5.1)%	59
4.3	Z=Z+1% GOTO(B7.1)%	60
4.14	SET(5EX=RR.1)%	61
5.1	PRINT-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%	62
	Z=1% GOTO(.5EX)%	63
B7.1	NC=NC+1%T=T+DELT/2%XB=X%X=XB+SQRT(B/RHO)*DELT/2%	64
	GOTO(4.11)%	65
B8.1	ENTER(PRINTB)%ENTER(PRINTB)% GOTO(11.1)%	66
11.1	SET(F=0)%	67
	READ-FORMAT(F1)-(MC)NC)T)X)EP1)VP1)SIGP1)%	68
	PRINT-FORMAT(F1)-(MC)NC)T)X)EP1)VP1)SIGP1)%	69
	SIG1=SIGP1% V1=VP1% E1=EP1% Z=1%	70
	SET(GAM=B19.1)%	71
B19.1	INC(F=F+3)%NC=NC+1%	72
	T=T+DELT/2%XB=X%X=XB+SQRT(B/RHO)*DELT/2%	73
30.1	SIG2=(SIGP2,F+SIG1)/2%E2=(EP2,F+E1)/2%	74
	V2=(VP2,F+V1)/2%	75
31.1	IF(SIGP2,F=0)GOTO(31.2)%	76
	GFP1=SIGP2,F/E0+K*EXP(H*LOG(SIGP2,F/E0))%GOTO(31.3)%	77
31.2	GFP1=0%	78
31.3	IF(SIGP1,F=0)GOTO(31.4)%	79
	GF=SIGP1,F/E0+K*EXP(H*LOG(SIGP1,F/E0))%GOTO(31.5)%	80
31.4	GF=0%	81
31.5	IF(SIG1=0)GOTO(31.6)%	82
	GIM1=SIG1/E0+K*EXP(H*LOG(SIG1/E0))%GOTO(31.7)%	83
31.6	GIM1=0%	84
31.7	FEF=EP1,F(1+BETA*EP1,F)/(1+ALPHA*EP1,F)%	85
	FEFP1=EP2,F(1+BETA*EP2,F)/(1+ALPHA*EP2,F)%	86
	FEIM1=E1(1+BETA*E1)/(1+ALPHA*E1)%	87
32.1	FFP1=A(GFP1-FEFP1)% FF=A(GF-FEF)%	88
	FIM1=A(GIM1-FEIM1)%	89
33.1	IF(SIG2=0)GOTO(33.2)%	90
	GI=SIG2/E0+K*EXP(H*LOG(SIG2/E0))%GOTO(33.3)%	91
33.2	GI=0%	92
33.3	FEI=E2(1+BETA*E2)/(1+ALPHA*E2)%	93
	FI=A(GI-FEI)%	94
34.1	SIGM1=SIG2%VM1=V2%EM1=E2%	95
35.1	SIG2=(SIG1+SIGP2,F)/2-C(V1-VP1,(F+3))/2	96
	CONT-(DELT/4)((FIM1+FI)/2+(FFP1+FI)/2)%	97
	E2=EP1,F+(SIG2-SIGP1,F)/B+DELT(FF+FI)/(2*B)%	98
	V2=V1+(SIG2-SIG1)/C+DELT(FIM1+FI)/(4*C)%	99
35.2	IF(SIGM1=0)GOTO(35.3)%	100
36.1	IF-ABS((SIG2-SIGM1)/SIGM1<DELTA)GOTO(35.4)%GOTO(33.1)%	101
35.4	IF(EM1=0)GOTO(35.5)%	102
37.1	IF-ABS((E2-EM1)/EM1<DELTA)GOTO(35.6)%GOTO(33.1)%	103
35.5	IF(E2=0)GOTO(35.6)%GOTO(33.1)%	104
35.6	IF(VM1=0)GOTO(35.7)%	105
38.1	IF-ABS((V2-VM1)/VM1<DELTA)GOTO(39.1)%GOTO(33.1)%	106
35.7	IF(V2=0)GOTO(39.1)%GOTO(33.1)%	107
35.3	IF(SIG2=0)GOTO(35.4)%GOTO(33.1)%	108
39.1	EP1,F=E1% E1=E2% VP1,F=V1% V1=V2%	109
	SIGP1,F=SIG1% SIG1=SIG2% GOTO(16.2)%	110
B21.1	IF(MC=M)WITHIN(.005)GOTO(21.3)%	111
22.1	MC=MC+1% ENTER(PRINTB)% ENTER(PRINTB)%	112
22.2	IF(MC=M)WITHIN(.005)GOTO(22.3)% GOTO(11.1)%	113

22.3	ANS=1% GOTO(11.1)%	114
21.3	ENTER(PRINTB)% ENTER(PRINTB)% GOTO(START)%	115
16.2	IF(NC=N)GOTO(16.3)%	116
15.3	IF(Z=ANS)WITHIN(.005)GOTO(16.1)%	117
15.4	Z=Z+1% GOTO(B19.1)%	118
16.1	PRINT-FORMAT(F1)-(MC)NC)T)X)E1)V1)SIG1)%	119
	Z=1% GOTO(0,GAM)%	120
16.3	SET(GAM=B21.1)% EP2,F=E2% VP2,F=V2% SIGP2,F=SIG2%	121
	GOTO(16.1)%	122
	END GOTO(START)%	123

INPUT PARAMETERS

A	BEE	RHO	DELT	M	N
90388944 07	23896900-02	15000000-03	20000000-03	30000000 01	10000000 02
H	K	EO	BETA	DELTA	ALPHA
22200000 01	68600000 04	21400000 05	00000000 00	10000000-08	00000000 00
SIG0	BEGIN	ANS			
50000000 02	-50000000 00	10000000 01			

INPUT BOUNDARY DATA ON N=3 CHARACTERISTIC

000000 00	300000 01	300000-03	360001 01	183368-02-220043 02	396079 02
100000 01	300000 01	400000-03	240001 01	260629-02-275758 02	438797 02
200000 01	300000 01	500000-03	120000 01	350227-02-330727 02	473202 02
300000 01	300000 01	600000-03	000000 00	451328-02-383640 02	500000 02

PROGRAM FOR CODE 4 AND INPUT PARAMETERS WITH
BOUNDARY DATA FOR A SPECIAL CASE

	PROR TF-033 GROUND SHOCK STUDIES	CODE 4	1
	BLOC(EP1-EP7/3)VP1-VP7/3)SIGP1-SIGP7/3)%		2
F1	FORM(9-10)1-7)5-1-10)%		3
	LAST(EP1)VP1)SIGP1)%		5
START	READ(A)BEE)RHO)DELT)M)N)%		6
	PRINT-FORMAT(F1)-		7
	CONT < A BEE RHO DELT >		8
	CONT< M N >% ENTER(PRINTB)%		9
	PRINT-FORMAT(F1)-(A)BEE)RHO)DELT)M)N)%ENTER(PRINTB)%		10
	READ(H)K)EO)BETA)DELTA)ALPHA)%		11
	PRINT-FORMAT(F1)-		12
	CONT < H K EO BETA >		13
	CONT<DELTA ALPHA >%ENTER(PRINTB)%		14
	PRINT-FORMAT(F1)-(H)K)EO)BETA)DELTA)ALPHA)%ENTER(PRINTB)%		15
	READ(SIGO)BEGIN)ANS)%		16
	PRINT-FORMAT(F1)-		17
	CONT < SIGO BEGIN ANS B C >%		18
	ENTER(PRINTB)%		19
	B=BEE*A% C=SQRT(RHO*B)%		20
	PRINT-FORMAT(F1)-(SIGO)BEGIN)ANS)B)C)%		21
	ENTER(PRINTB)% ENTER(PRINTB)%		22
	PRINT-FORMAT(F1)-		23
	CONT < M N T X E >		24
	CONT < V SIGMA >%		25
	ENTER(PRINTB)%ENTER(PRINTB)%		26
	SET(F=3)%		27
1.1	READ-FORMAT(F1)-(MC)NC)T)X)EP1,F)VP1,F)SIGP1,F)%		28
	IF(NC=N)WITHIN(.005)GOTO(11.1)% INC(F=F+3)% GOTO(1.1)%		29
11.1	SET(F=0)% READ-FORMAT(F1)-(MC)NC)T)X)EP1)VP1)SIGP1)%		30
	PRINT-FORMAT(F1)-(MC)NC)T)X)EP1)VP1)SIGP1)% SET(GAM=B19.1)%		31
	SIG1=SIGP1% V1=VP1% E1=EP1% Z=1% GOTO(B19.1)%		32
B19.1	INC(F=F+3)%NC=NC+1%		33
	T=1+DELT/2%X=X=XB+SQRT(B/RHO)*DELT/2%GOTO(30.1)%		34
16.2	IF(NC=N)WITHIN(.005)GOTO(16.3)%		35
15.3	IF(Z=ANS)WITHIN(.005)GOTO(16.1)%		36
15.4	Z=Z+1% GOTO(B19.1)%		37
16.1	PRINT-FORMAT(F1)-(MC)NC)T)X)E1)V1)SIG1)%		38
	Z=1% GOTO(0,GAM)%		39
16.3	SET(GAM=B21.1)% EP2,F=E2% VP2,F=V2% SIGP2,F=SIG2% GOTO(16.1)%		40
B21.1	IF(MC=M)WITHIN(.005)GOTO(21.3)%		41
22.1	MC=MC+1% ENTER(PRINTB)% ENTER(PRINTB)%		42
22.2	IF(MC=M)WITHIN(.005)GOTO(22.3)% GOTO(11.1)%		43
22.3	ANS=1% GOTO(11.1)%		44
21.3	ENTER(PRINTB)% ENTER(PRINTB)% GOTO(START)%		45
30.1	SIG2=(SIGP2,F+SIG1)/2%E2=(EP2,F+E1)/2%		46
	V2=(VP2,F+V1)/2%		47
31.1	IF(SIGP2,F =0)GOTO(31.2)%		48
	GFPI=SIGP2,F/EO+K*EXP(H*LOG(SIGP2,F/EO))%GOTO(31.3)%		49
31.2	GFPI=0%		50
31.3	IF(SIGP1,F =0)GOTO(31.4)%		51
	GF=SIGP1,F/EO+K*EXP(H*LOG(SIGP1,F/EO))%GOTO(31.5)%		52
31.4	GF=0%		53
31.5	IF(SIG1 =0)GOTO(31.6)%		54
	GIMI=SIG1/EO+K*EXP(H*LOG(SIG1/EO))%GOTO(31.7)%		55

31.6	GIM1=0%	56
31.7	FEF=EP1,F (1+BETA*EP1,F)/(1+ALPHA*EP1,F)%	57
	FEFP1=EP2,F (1+BETA*EP2,F)/(1+ALPHA*EP2,F)%	58
	FEIM1=E1 (1+BETA*E1)/(1+ALPHA*E1)%	59
32.1	FFP1=A(GFP1-FEFP1)% FF=A(GF-FEF)%	60
	FIM1=A(GIM1-FEIM1)%	61
33.1	IF(SIG2=0)GOTO(33.2)%	62
	G1=SIG2/E0+k*EXP(H*LOG(SIG2/E0))%GOTO(33.3)%	63
33.2	GI=0%	64
33.3	FE1=E2(1+BETA*E2)/(1+ALPHA*E2)%	65
	FI=A(GI-FE1)%	66
34.1	SIGM1=SIG2%VM1=V2%EM1=E2%	67
35.1	SIG2=(SIG1+SIGP2,F)/2-C(V1-VP1,(F+3))/2	68
	CONT-(DELT/4)((FIM1+FI)/2+(FFP1+FI)/2)%	69
	E2=EP1,F+(SIG2-SIGP1,F)/B+DELT(FF+FI)/(2*B)%	70
	V2=V1+(SIG2-SIG1)/C+DELT(FIM1+FI)/(4*C)%	71
35.2	IF(SIGM1=0)GOTO(35.3)%GOTO(36.1)%	72
35.3	IF(SIG2=0)GOTO(35.4)%GOTO(33.1)%	73
35.4	IF(EM1=0)GOTO(35.5)%GOTO(37.1)%	74
35.5	IF(E2=0)GOTO(35.6)%GOTO(33.1)%	75
36.1	IF-ABS((SIG2-SIGM1)/SIGM1<DELTA)GOTO(35.4)%GOTO(33.1)%	76
37.1	IF-ABS((E2-EM1)/EM1<DELTA)GOTO(35.6)%GOTO(33.1)%	77
35.6	IF(VM1=0)GOTO(35.7)%GOTO(38.1)%	78
35.7	IF(V2=0)GOTO(39.1)%GOTO(33.1)%	79
38.1	IF-ABS((V2-VM1)/VM1<DELTA)GOTO(39.1)%GOTO(33.1)%	80
39.1	EP1,F=E1%E1=E2% VP1,F=V1%V1=V2%	81
	SIGP1,F=SIG1%SIG1=SIG2%GOTO(16.2)%	82
	END GOTO(START)%	83

INPUT PARAMETERS

A	BEE	RHO	DELT	M	N
90388944 07	23896900-02	15000000-03	20000000-03	70000000 01	10000000 02
H	K	E0	BETA	DELTA	ALPHA
22200000 01	68600000 04	21400000 05	00000000 00	10000000-08	00000000 00
SIG0	BEGIN	ANS			
50000000 02	50000000 00	10000000 01			

INPUT BOUNDARY DATA ON M=3 CHARACTERISTIC

300000 01	700000 01	100000-02	480002 01	326356-02-249895 02	417963 02
300000 01	800000 01	110000-02	600002 01	304572-02-283882 02	400730 02
300000 01	900000 01	120000-02	720003 01	285339-02-269371 02	384683 02
300000 01	100000 02	130000-02	840003 01	268255-02-256182 02	369738 02

INPUT BOUNDARY DATA ON N=7 CHARACTERISTIC

400000 01	700000 01	110000-02	360001 01	402989-02-342221 02	444541 02
500000 01	700000 01	120000-02	240001 01	486855-02-383498 02	467066 02
600000 01	700000 01	130000-02	120000 01	576599-02-422768 02	485524 02
700000 01	700000 01	140000-02	000000 00	670435-02-459084 02	500000 02

V. RESULTS

An example is computed on a grid of maximum $m = \text{maximum } n = 10$, both by use of code 1 and by use of the set of codes 1,2,3,4 (Figure 6).

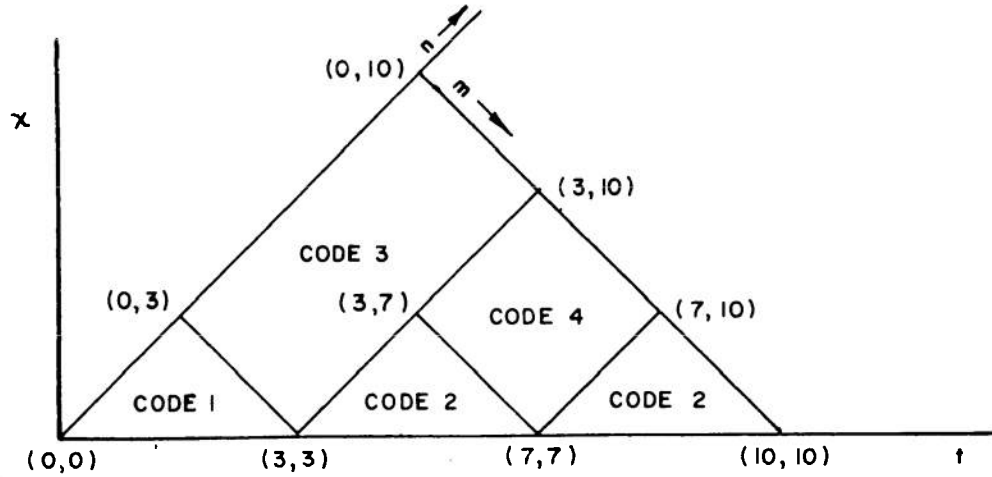


FIGURE 6

Code 1 uses data along the wave front and boundary; code 2 uses data along the smallest m of its zone and along the boundary; code 3 uses wave front data and data along the smallest n of its zone; code 4 uses data along the smallest m and smallest n of its zone.

COMPLETE 10X10 DOMAIN
USING CODE 1.

PROP TF-033 GROUND SHOCK STUDIES CODE 1

A	BEE	RHO	DELT	M	N	
903889	7 238969-02	150000-03	200000-03	100000	2 100000	2
H	K	EO	BETA	DELTA	ALPHA	
222000	1 686000	4 214000	5 000000	100000-08	000000	
SIG0	BEGIN	ANS	B	C		
500000	2-500000	100000	1 216002	5 180001	1	
M	N	T	X	E	V	SIGMA
000000	000000	000000	000000	231480-02-277777	2 500000	2
000000	100000	1 100000-03	120000	1 212557-02-255070	2 459127	2
000000	200000	1 200000-03	240001	1 196766-02-236121	2 425019	2
000000	300000	1 300000-03	360001	1 183368-02-220043	2 396079	2
000000	400000	1 400000-03	480002	1 171843-02-206212	2 371184	2
000000	500000	1 500000-03	600002	1 161813-02-194176	2 349518	2
000000	600000	1 600000-03	720003	1 152996-02-183596	2 330475	2
000000	700000	1 700000-03	840003	1 145180-02-174217	2 313591	2
000000	800000	1 800000-03	960003	1 138198-02-165838	2 298510	2
000000	900000	1 900000-03	108000	2 131920-02-158304	2 284949	2
000000	100000	2 100000-02	120000	2 126241-02-151490	2 272683	2
100000	1 100000	1 200000-03	000000	310978-02-321195	2 500000	2
100000	1 200000	1 300000-03	120000	1 283534-02-296726	2 467426	2
100000	1 300000	1 400000-03	240001	1 260629-02-275758	2 438797	2
100000	1 400000	1 500000-03	360001	1 241226-02-257606	2 413484	2
100000	1 500000	1 600000-03	480002	1 224580-02-241749	2 390970	2
100000	1 600000	1 700000-03	600002	1 210146-02-227784	2 370830	2
100000	1 700000	1 800000-03	720003	1 197511-02-215396	2 352719	2
100000	1 800000	1 900000-03	840003	1 186359-02-204333	2 336352	2
100000	1 900000	1 100000-02	960003	1 176445-02-194396	2 321493	2
100000	1 100000	2 110000-02	108000	2 167574-02-185421	2 307944	2
200000	1 200000	1 400000-03	000000	384089-02-355553	2 500000	2
200000	1 300000	1 500000-03	120000	1 350227-02-330727	2 473202	2
200000	1 400000	1 600000-03	240001	1 321642-02-308934	2 448734	2
200000	1 500000	1 700000-03	360001	1 297221-02-289697	2 426407	2
200000	1 600000	1 800000-03	480002	1 276141-02-272625	2 406019	2
200000	1 700000	1 900000-03	600002	1 257781-02-257395	2 387374	2
200000	1 800000	1 100000-02	720003	1 241662-02-243741	2 370287	2
200000	1 900000	1 110000-02	840003	1 227408-02-231441	2 354595	2
200000	1 100000	2 120000-02	960003	1 214723-02-220313	2 340149	2

300000	1	300000	1	600000-03	000000	451328-02-383640	2	500000	2
300000	1	400000	1	700000-03	120000	1 412734-02-359208	2	477472	2
300000	1	500000	1	800000-03	240001	1 379712-02-337303	2	456285	2
300000	1	600000	1	900000-03	360001	1 351191-02-317622	2	436460	2
300000	1	700000	1	100000-02	480002	1 326356-02-299895	2	417963	2
300000	1	800000	1	110000-02	600002	1 304572-02-283882	2	400730	2
300000	1	900000	1	120000-02	720003	1 285339-02-269371	2	384683	2
300000	1	100000	2	130000-02	840003	1 268255-02-256182	2	369738	2
400000	1	400000	1	800000-03	000000	513165-02-407119	2	500000	2
400000	1	500000	1	900000-03	120000	1 471185-02-383494	2	480766	2
400000	1	600000	1	100000-02	240001	1 434784-02-361917	2	462240	2
400000	1	700000	1	110000-02	360001	1 402989-02-342221	2	444541	2
400000	1	800000	1	120000-02	480002	1 375038-02-324235	2	427726	2
400000	1	900000	1	130000-02	600002	1 350325-02-307794	2	411809	2
400000	1	100000	2	140000-02	720003	1 328358-02-292743	2	396779	2
500000	1	500000	1	160000-02	000000	570034-02-427062	2	500000	2
500000	1	600000	1	110000-02	120000	1 525745-02-404472	2	483388	2
500000	1	700000	1	120000-02	240001	1 486855-02-383498	2	467066	2
500000	1	800000	1	130000-02	360001	1 452512-02-364077	2	451195	2
500000	1	900000	1	140000-02	480002	1 422033-02-346116	2	435879	2
500000	1	100000	2	150000-02	600002	1 394861-02-329516	2	421178	2
600000	1	600000	1	120000-02	000000	622336-02-444207	2	500000	2
600000	1	700000	1	130000-02	120000	1 576599-02-422768	2	485524	2
600000	1	800000	1	140000-02	240001	1 535965-02-402570	2	471057	2
600000	1	900000	1	150000-02	360001	1 499705-02-383620	2	456773	2
600000	1	100000	2	160000-02	480002	1 467227-02-365891	2	442798	2
700000	1	700000	1	140000-02	000000	670435-02-459084	2	500000	2
700000	1	800000	1	150000-02	120000	1 623943-02-438848	2	487296	2
700000	1	900000	1	160000-02	240001	1 582185-02-419527	2	474410	2
700000	1	100000	2	170000-02	360001	1 544555-02-401182	2	461515	2
800000	1	800000	1	160000-02	000000	714671-02-472089	2	500000	2
800000	1	900000	1	170000-02	120000	1 667977-02-453065	2	488786	2
800000	1	100000	2	180000-02	240001	1 625611-02-434677	2	477261	2
900000	1	900000	1	180000-02	000000	755354-02-483527	2	500000	2
900000	1	100000	2	190000-02	120000	1 708998-02-465697	2	490053	2
100000	2	100000	2	200000-02	000000	792768-02-493640	2	500000	2

COMPLETE 10X10 DOMAIN
USING CODES 1, 2, 3, 4.

PROC TF-033 GROUND SHOCK STUDIES CODE 1

A REE RHO DELT M N
903889 7 238969-02 150000-03 200000-03 300000 01 300000 01

H K EO BETA DELTA ALPHA
222000 1 686000 4 214000 5 000000 100000-08 000000

SIGO REGIN ANS B C

500000 2-500000 100000 1 216002 5 180001 1

M	N	I	X	E	V	SIGMA
000000	000000	000000	000000	231480-02-277777	2	500000
000000	100000	1	100000-03 120000	1 212557-02-255070	2	459127
000000	200000	1	200000-03 240001	1 196766-02-236121	2	425019
000000	300000	1	300000-03 360001	1 183368-02-220043	2	396079
100000	1	100000	1 200000-03 000000	310978-02-321195	2	500000
100000	1	200000	1 300000-03 120000	1 283534-02-296726	2	467426
100000	1	300000	1 400000-03 240001	1 260629-02-275758	2	438797
200000	1	200000	1 400000-03 000000	384089-02-355553	2	500000
200000	1	300000	1 500000-03 120000	1 350227-02-330727	2	473202
300000	1	300000	1 600000-03 000000	451328-02-383640	2	500000

PROB TF-033 GROUND SHOCK STUDIES CODE 2										
A		BEE		RHO		DELT		M	N	
903889	7	238969-02		150000-03		200000-03		400000	1 700000 1	
H		K		EO		BETA		DELTA	ALPHA	
222000	1	686000	4	214000	5	000000		100000-08	000000	
SIG0		BEGIN		ANS		B		C		
500000	2-500000			100000	1	216002	5	180001	1	
M		N		T		X		E	V	SIGMA
400000	1	400000	1	500000-03	000000			513165-02-407119	2	500000 2
400000	1	500000	1	900000-03	120000	1		471185-02-383494	2	480765 2
400000	1	600000	1	100000-02	240001	1		434784-02-361917	2	462240 2
400000	1	700000	1	110000-02	360001	1		402989-02-342221	2	444541 2
500000	1	500000	1	100000-02	000000			570035-02-427062	2	500000 2
500000	1	600000	1	110000-02	120000	1		525745-02-404472	2	483388 2
500000	1	700000	1	120000-02	240001	1		486855-02-383498	2	467066 2
600000	1	600000	1	120000-02	000000			622336-02-444207	2	500000 2
600000	1	700000	1	130000-02	120000	1		576599-02-422768	2	485524 2
700000	1	700000	1	140000-02	000000			670436-02-459083	2	500000 2

PROP TF-033 GROUND SHOCK STUDIES CODE 2

A	BEE	RHO	DELT	M	N		
903889	7 238969-02	150000-03	200000-03	800000	1 100000	2	
H	K	EO	BETA	DELTA	ALPHA		
222000	1 686000	4 214000	5 000000	100000-08	000000		
SIG0	BEGIN	ANS	B	C			
500000	2-500000	100000	1 216002	5 180001	1		
M	N	T	X	E	V	SIGMA	
800000	1 800000	1 160000-02	000000	714671-02-472089	2 500000	2	
800000	1 900000	1 170000-02	120000	1 667976-02-453065	2 488786	2	
800000	1 100000	2 180000-02	240001	1 625610-02-434677	2 477261	2	
900000	1 900000	1 180000-02	000000	755353-02-483527	2 500000	2	
900000	1 100000	2 190000-02	120000	1 708898-02-465697	2 490053	2	
100000	2 100000	2 200000-02	000000	792768-02-493640	2 500000	2	

PROF		TF-033	GROUND	SHOCK	STUDIES	CODE 3
A	REF	RMS	DELT	M	N	
903889	7	238969-02	150000-03	200000-03	300000	1 100000 2
H	K	EO	BETA	DELTA	ALPHA	
222000	1	686000	4	214000	5	000000 100000-08 000000
SIGN	BEGIN	ANS				
500000	2-500000	100000	1			
M	N	T	X	E	V	SIGMA
000000	300000	1	300000-03	360001	1	183368-02-220043 2 336079 2
000000	400000	1	400000-03	480001	1	171843-02-206213 2 371184 2
000000	500000	1	500000-03	600002	1	161813-02-194176 2 349519 2
000000	600000	1	600000-03	720002	1	152997-02-183597 2 330475 2
000000	700000	1	700000-03	840003	1	145180-02-174217 2 313592 2
000000	800000	1	800000-03	960003	1	138198-02-165839 2 298510 2
000000	900000	1	900000-03	108000	2	131920-02-158305 2 284949 2
000000	100000	2	100000-02	120000	2	126241-02-151490 2 272683 2
100000	1300000	1	400000-03	240001	1	260629-02-275758 2 438797 2
100000	1400000	1	500000-03	360001	1	241225-02-257606 2 413484 2
100000	1500000	1	600000-03	480002	1	224580-02-241749 2 390970 2
100000	1600000	1	700000-03	600002	1	210146-02-227784 2 370830 2
100000	1700000	1	800000-03	720003	1	197511-02-215396 2 352720 2
100000	1800000	1	900000-03	840003	1	186359-02-204333 2 336352 2
100000	1900000	1	100000-02	960004	1	176445-02-194396 2 321493 2
100000	1100000	2	110000-02	108000	2	167574-02-185421 2 307944 2
200000	1300000	1	500000-03	120000	1	350227-02-330727 2 473202 2
200000	1400000	1	600000-03	240000	1	321642-02-308934 2 448734 2
200000	1500000	1	700000-03	360001	1	297220-02-289697 2 426407 2
200000	1600000	1	800000-03	480001	1	276141-02-272625 2 406019 2
200000	1700000	1	900000-03	600002	1	257781-02-257395 2 387373 2
200000	1800000	1	100000-02	720002	1	241662-02-243741 2 370287 2
200000	1900000	1	110000-02	840003	1	227408-02-231441 2 354595 2
200000	1100000	2	120000-02	960003	1	214723-02-220313 2 340149 2
300000	1300000	1	600000-03	000000	451328-02-383640	2 500000 2
300000	1400000	1	700000-03	120000	1	412773-02-359208 2 477471 2
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