OSCIL:
One-Dimensional Spring-Mass System Simulator
for Seismic Analysis
of High Temperature Gas Cooled Reactor Core

L. Lasker, Editor

Contributors

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January, 1976

MASTER

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BROOKHAVEN NATIONAL LABORATORY

OSCIL:

One-Dimensional Spring-Mass System Simulator for Seismic Analysis
of High Temperature Gas Cooled Reactor Core

January 1976

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PROGRAM OSCIL

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This is the first version of OSCIL. The code has been extensively tested using all the different options described in the following pages and it has been used many production runs with realistic data.

Due to the current interest in HTGR core safety studies, it is felt that it would be worthwhile to release the code in its present unpolished form. In the near future a fully self-explanatory version with detailed comment statements in each subroutine will be issued. A major execution time improvement in that version will be the replacement of the GEAR integration routine with one that handles banded Jacobians.

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Abstract

OSCIL is a program to predict the effects of seismic input on a HTGR core. The present model is a one-dimensional array of blocks with appropriate spring constants, inter-elemental and ground damping, and clearances. It can be used more generally for systems of moving masses separated by non-linear springs and dampers.

PROGRAM OSCIL

PART I

Code Description: General

Present code handles one-dimensional wall-spring-mass configuration for up to 70 masses. More than 70 masses can be accommodated by increasing the dimensions of the appropriate arrays. Plans are being made to expand OSCIL to two and three dimensional versions.

The code determines the time evolution of the system of masses depicted in Figure 1.

Fig. 1

XOL, XOR are the driving outside walls.

M(1), M(NM) are the reflector blocks.

M(2), ..., M(NM-1) are the internal blocks.

SP(1), SP(NM+1) are the reflector springs.

SP(2), ..., SP(NM) are springs which simulate the material properties of the blocks.

C(1), ..., C(NM) spring dampers.

CW(1), ..., CW(NM) ground dampers.

A1(1), ..., A1(NM) initial clearances.

The simplest set of coupled differential equations describing this system are:

$$M_1 \ddot{x}_1 + K_1 (x_1 - x_{OL}) + C_1 (\dot{x}_1 - \dot{x}_{OL}) + K_2 (x_1 - x_2) + C_2 (\dot{x}_1 - \dot{x}_2) + CW(1) (\dot{x}_1 - \dot{x}_{OL}) = 0 .$$

$$M_i \ddot{x}_i + K_i (x_i - x_{i-1}) + C_i (\dot{x}_i - \dot{x}_{i-1}) + K_{i+1} (x_i - x_{i+1}) + C_{i+1} (\dot{x}_i - \dot{x}_{i+1}) + CW(i) (\dot{x}_i - \dot{x}_{OL}) = 0 .$$

$$2 \leq i \leq NM - 1$$

$$M_{NM} \ddot{x}_{NM} + K_{NM} (x_{NM} - x_{NM-1}) + C_{NM} (\dot{x}_{NM} - \dot{x}_{NM-1}) + K_{NM+1} (x_{NM} - x_{OR}) + C_{NM+1} (\dot{x}_{NM} - \dot{x}_{OR}) + CW(NM) (\dot{x}_{NM} - \dot{x}_{OL}) = 0 .$$

where the K_i and C_i are non-linear functions of the displacements $(x_i - x_{i-1})$, as described in the Input Section.

The integration scheme used was the GEAR package written by A.C. Hindmarsh (5). This package automatically varies the time integration step and order of integration. The reasons for using it are described in detail in the section on the numerical methods.

Some Features of OSCIL

1). The execution time for a 70 mass example is an order of magnitude larger than that for a 9 mass system, viz. 3000 cpu secs vs. 250 cpu. secs. At present it is uncertain whether this is caused by the many multiple collisions with consequent short integration steps, or due to the fact that in the GEAR integration routine a $2n \times 2n$ ($n = \#$ of masses) matrix inversion takes place at each time step. Presently planning to replace GEAR with GEARB (7), which integrates systems of stiff ordinary differential equations with banded Jacobian. Since the Jacobian of OSCIL is banded with band width = 6, substantial time saving is expected.

2). OSCIL has a RESTART option so that a new run can begin where a previous one stopped.

3). Each major set of operations is completed in semi-independent modules. This makes it fairly simple to replace or modify any of these modules without affecting the remainder of the code. This is of particular concern in the sub-routines

- a) FORCE - which computes force on springs as functions of displacements
- b) SHOK - specifies nature of seismic oscillations of walls
- c) STORE - stores quantities to be plotted
- d) COEF - computes damping coefficients
- e) DIFFUN - called by GEAR, DIFFUN computes accelerations from displacements

The present options in FORCE, SHOK and STORE are described in the INPUT section. New options can easily be added. The output can be varied with calls to PRNMF (see Input Section) or modifications to PROUT.

4). Because it is believed that a visual presentation of the core motion will eventually be required, the techniques for generating computer movies using CALCOMP to display program solutions are being investigated. At present, simple but visually powerful plots are made of 1-dimensional systems.

5). Any number of input sets can be read in simultaneously. A separate run will be made for each set and execution will stop when an end-of-file is encountered.

USAGE

Input

Card 1

Variables: TITLE.

Format: 8A10.

Card 2

Variables: NFUN, NM, NTIME.

Format: 3I10.

Description:

NFUN is used in subroutine SHOK to determine the nature of the forcing function of the outside walls XOL, XOR.

NFUN = 1 Step function $XOL = XOR = A$, $DIXL = DIXR = 0$.

NFUN = 2 Forcing function sinusoidal in-phase

$$XOL = XOR = A \cdot \sin(B \cdot \text{DELT}).$$

$$DIXL = DIXR = A \cdot B \cdot \cos(B \cdot \text{DELT}).$$

NFUN = 3 Forcing function sinusoidal out-of-phase.

$$XOL - XOR = A \cdot \sin(B \cdot \text{DELT})$$

$$DIXL = -DIXR = A \cdot B \cdot \cos(B \cdot \text{DELT}).$$

NFUN = 4 This is a special option used for the situation depicted in Fig. 2.

Fig. 2.

The wall remains stationary and the spring is of cubic type i.e., $NGAP(1) = 3$ (see card 5' with a predetermined driving force $F = A \cos(\omega t)$). The equation describing this system is given by

$$\ddot{x} = [A \cos(\omega t) - K(1,1) * x^3 - 1000*x]/M.$$

This option is useful for testing integrated solutions of non-linear spring equations, as these solutions can be determined analytically, and the solutions are not unique. (See section "Testing of Program".)

N.B. $NFUN = 4$ can only be used with a single mass, single spring and $NGAP(1) = 3$.

$A, \omega = BINT$ are given on card 3 as for $NFUN = 2$ or 3. Other forcing functions can be added to OSCIL by including them in SHOK and using corresponding new $NFUN$ options.

NM is the number of masses.

$NTIME$ If $NFUN = 2$ or 3, $NTIME$ is # of passes to be made, each time incrementing the first angular velocity $BINT$ by FRQ .

Card 3

Variables: $A, BINT, FRQ, ALPHAI, NSTEP, IWAVE$

Format: 4F10.2, 2I10

Description:

A Amplitude of oscillation

$BINT$ For $NFUN = 2$ or 3 - initial value of ω for each pass

FRQ Increment of $BINT$ for each pass if $NTIME \geq 2$

$ALPHAI$ Slope for linear increase (decrease) of frequency (angular velocity) with time according to

$$\omega = \omega_0 + ALPHAI * t$$

where

$$\omega_0 = BINT \text{ if } IWAVE = 0$$

$$\omega_0 = BINT * 2\pi \text{ if } IWAVE = 1$$

- NSTEP = 1 All mass and wall displacements plotted relative to origin, i.e.,
origin considered to be equilibrium position for all walls and masses
- 2 This option can only be used if all the springs have gaps, and all
springs between the masses have equal gaps.

For the plotting routine the equilibrium positions of the masses are separated by the gap size = A1(I) and the equilibrium positions of the walls are separated from the outer masses by A2(1), where A2(1) is the length of the outer springs plus gap size.

The use of this option leads to a clear pictorial representation of the relative motions of the linear array of masses. With this option, no two trajectories (mass or wall) should cross for a realistic run.

If NFUN = 2 or 3

IWAVE = 0 BINT is initial angular vel ω_0
IWAVE = 1 BINT is initial frequency.

Card 4

Variables: NSTART, NIN, NCOF, NOR, UMU.

Format: I7, 3I1, E10.2.

Description:

NSTART = 0 Start from scratch at $T = 0$.

= N This is used to restart a run from $T_0 * N * (10 * PRI)$ where PRI is the print interval.

To use this option, the previous run must have functioned for

$T \geq T_0$ and since the results are stored in a file REST, this file must have been saved.

NIN The value of NIN determines how the input data for each mass and spring is to be read in the following cards. (See below.)

NIN = 1 Requires separate data for each mass, each spring and the initial displacement.

NIN = 2 This can only be used if the two outer masses and springs are equal, the second and next to last springs are equal, and all the inner springs and masses are equal. A smaller input deck is needed and this option is usually used in conjunction with NSTEP = 2.

NCOF = 1 The ground dampers $CW \equiv 0$ and the value of spring dampers C are the values read in Card 5.

NCOF = 2 CW and C are computed in subroutine COEF according to:

$$C(I) = .02 * \sqrt{M(I) * K(I,2)} \quad \text{For } I = 1, NM.$$

$$C(I) = .02 * \frac{M(I-1) + M(I)}{2} * K(I,2)$$

$$CW(I) = M(I) * \frac{1544 * \mu}{\pi * \omega * \Sigma (\text{gaps})}$$

If different formulas are desired, COEF can be easily modified.

NOR = 1 Both walls and all masses are plotted on one graph.

NOR = 2 Two graphs are plotted.

Graph 1. Displacement of XOL and the two left most masses.

Graph 2. Displacements of the six center masses.

UMU Value of coefficient of friction for NCOF = 2.

Cards 5i

Different sets of cards are used to describe masses and springs depending on value of NIN.

NIN = 1

Cards 5a-5d

Variable: (5a) PM(I)

(5b) XINT(I)

I = 1, NM .

(5c) DLXINT(I)

(5d) D2XINT(I) .

Format: 12F 6.2.

Description:

PM(I) Value of I'th mass.

XINT(I) Initial displacement from equilibrium of I'th mass.

DLXINT(I) Initial velocity of I'th mass.

D2XINT(I) Initial acceleration of I'th mass.

Cards 5I: I = 1, NSPR NSPR = NM + 1

This is actually NM + 1 cards, one for each spring.

Variable: NGAP(I), K(I,1), K(I,2), A1(I), C(I), A2(I).

Format: 110, 5E10.2.

Description:

NGAP(I) determines the nature of the non-linearity of the I'th spring in SUBROUTINE FORCE. Other optional functions can be added to FORCE.

The spring retarding forces on the masses are computed in FORCE. This routine considers the masses to be solid bodies which cannot pass one another.

Fig. 3.

L is the distance between the equilibrium positions of masses I and $I - 1$.
 For the bodies not to pass one another need $DIF(I) = X(I) - X(I-1) \geq -L$.
 Thus it is necessary for the retarding force $\rightarrow \infty$ as $X(I) - X(I-1) \rightarrow -L$.
 In the program this is done by setting $A2(I) = -L + \epsilon$ where $\epsilon > 0$ is small and $FORCE \sim 10^9$ for $X(I) - X(I-1) < A2(I)$ or $FORCE \sim \text{Exponential}$.
 The present options for the retarding force are

Fig. 4

a) $NGAP = 1$

Force = 2-slope linear.

Fig. 5

For $DIF(I) < A2(I)$ $F(I) = 10^9 * (DIF(I) - A2(I)) + K(I,1) * A2(I)$
 $A2(I) \leq DIF(I) \leq A1(I)$ $F(I) = K(I,1) * DIF(I)$.
 $A1(I) < DIF(I)$ $F(I) = K(I,2) * (DIF(I) - A1(I)) - K(I,1) * A1(I)$
Note: $A2(I) < 0$ and must be read in as negative value.

b) $NGAP = 2$

Springs with gaps.

Fig. 6

$DIF(I) < A2(I)$ $F(I) = 10^9 * [DIF(I) - A2(I)] + K(2,I) * (A2(I) - A1(I))$
 $A2(I) \leq DIF(I) \leq A1(I)$ $F(I) = K(I,2) * (DIF(I) - A1(I))$
 $A1(I) < DIF(I)$ $F(I) = K(I,1) * DIF(I)$.

Note: $A2(I) < 0$, $A1(I) < 0$ and must be negative on data card.

For these options, for $DIF(I) < A2(I)$ an alternative exponential form for $F(I)$ can be used viz:

$$F(I) = K(I,2) * (1 - \exp(A2(I) - DIF(I))) + \text{other term}$$

The exponential function $= K * (1 - e^{A2 - DIF(I)})$ is taken so that for

$$|A2 - DIF(I)| < \delta, \delta \text{ small}$$

$$K * (1 - e^{A2 - DIF(I)}) \approx K * (DIF(I) - A2(I)) .$$

and $F(I) \approx K(I,2) * (DIF(I) - A1(I))$

i.e. it approximates the linear part for

$$A2(I) \leq DIF(I) \leq A1(I) .$$

However the steep slope seems more realistic.

c) NGAP = 3

Retarding force cubic

Fig. 7

$$F(I) = K(I,1) * [DIF(I)]^3 .$$

C(I) - These are damping coefficients to be used if NCOF = 1.

NIN = 2.

Card 5a

Variable: PM(1), PM(2).

Format: 2 F 6.2.

Description:

PM(1) - Value of 2 outer masses.

PM(2) - Value of all the inner masses.

Here the initial displacements, velocities and accelerations are all taken to be zero if NSTART = 0.

Cards 5b - 5d

Variable: NGAP(I), K(I,1), K(I,2), A1(I), C(I), A2(I).

Three cards, one for each I = 1, 2, 3.

Format: I10, 5E10.2.

Description:

For a description of the variables, see the description for NIN = 1.

I = 1 are the values for the 2 outer springs.

I = 2 values for second and next to last springs.

I = 3 values for all the other inner springs.

Card 6

Variables: PRI, FINTIM, TINT, METH, ERR.

Format: 3E10.2, I10, E10.2.

Description:

PRI - Print interval of results. (seconds). At present displacements of XOL and first three masses are printed, as well as velocities of first three masses. Also the time, frequency (for NFUN = 2 or 3), and present integration step size are printed. If different variables are desired, this can be done with a call to PRNTP (PRI, FINTIM, DONE, A, B, C, D, E, F, G, O, P, Q) where values of the alphabetic characters are the variables to be printed.

FINTIM - Computations end at FINTIM.

TINT - Initial time step.

METH - Method to be used in GEAR integration package. Presently using
METH = 22 as no PERDERV has been written yet.

ERR - Error tolerance for GEAR routine. Found results to be the same up to
4 decimal places for $ERR \leq 10^{-9}$.

For a more detailed explanation of TINT, METH and ERR, see the description
of the GEAR package.

Card 7

Variables: SCAL, CPT.

Format: 2E10.2.

Description:

SCAL - Scaling factor for graph. SCAL is the value of the tenth position from
the origin (i.e. where the first I occurs). It was decided that the
user should supply the scaling factor rather than have the scaling auto-
matic, as usually many variables with very different orders of magnitude
are plotted on the same graph. Thus, the scaling factor is chosen for
the variable of most interest in the run.

CPT - Maximum machine time (CPU time) in decimal seconds to be allowed for a
run. If this time is reached before the simulation time FINTIM, the run
is automatically ended and the results at this point are printed and
plotted.

USAGE

Input Deck - For a description of variables and how they should be used see the following section.

WORD	
COLUMN	1
FORMAT	8A10.
CARD	Descriptive title for problem.
SYMBOL	TITLE

Card 1
Problem title
Format 8A10.

WORD	
COLUMN	1 10 11 20 21 30
FORMAT	I10 I10 I10
CARD	
SYMBOL	NFUN NM NTIME

Card 2
Format 3I10
NM - # of masses
NTIME = # of runs
NFUN = Nature of
Forcing Function

WORD	
COLUMN	10 20 30 40 50 60
FORMAT	F10.2 F10.2 F10.2 F10.2 I10 I10
CARD	Factors describing Forcing Function and Nature of problem.
SYMBOL	A BINT FRQ ALPHAI NSTEP IWAVE

Card 3
Format 4F10.2, 2I10

WORD	
COLUMN	7 8 9 10 20
FORMAT	I7 I1 I1 I1 E10.2
CARD	Various options for restart and type at input following this card. UMU - coeft. of friction
SYMBOL	NSTART NIN NCOF NOR UMU

Card 4
Format I7, 3I1, E10.2
Input data options.

The following cards for NIN=1

WORD	This card only if NIN=1		
COLUMN	6	12	72
FORMAT	F6.2	F6.2	F6.2
CARD	Value of masses.		
SYMBOL	PM(1)	PM(2)	PM(12)

Card 5a. NIN=1
12 F 6.2
PM(I) I=1, NM

WORD	This card only if NIN=1		
COLUMN	6	12	72
FORMAT	F6.2	F6.2	F6.2
CARD	XINT - Initial positions.		
SYMBOL	XINT(1)	XINT(2)	XINT(12)

Card 5b. NIN=1
12 F 6.2
XINT(I) I=1, NM.

WORD	This card only if NIN=1		
COLUMN	6	12	72
FORMAT	F6.2	F6.2	F6.2
CARD	D1XINT - Initial velocities.		
SYMBOL	D1XINT(1)	D1XINT(2)	D1XINT(12)

Card 5c NIN=1
12 F 6.2
D1XINT(I) I=1, NM

WORD	This card only if NIN=1		
COLUMN	6	12	72
FORMAT	F6.2	F6.2	F6.2
CARD	D2XINT - Initial accelerations.		
SYMBOL	D2XINT(1)	D2XINT(2)	D2XINT(72)

Card 5d NIN=1
12 F 6.2
D2XINT(I) I=1, NM

WORD	These cards only if NIN=1, NSPR cards.					
COLUMN	10	20	30	40	50	60
FORMAT	I10	E10.2	E10.2	E10.2	E10.2	E10.2
CARD	Spring parameters for each spring I=1, NSPR.					
SYMBOL	NGAP(I)	K(I,1)	K(I,2)	A1(I)	C(I)	A2(I)

Card 5I NIN=1
I=1, NSPR
One card for each
spring
Format I10, 5E10.2

WORD	
COLUMN	
FORMAT	
CARD	
SYMBOL	

WORD	
COLUMN	
FORMAT	
CARD	
SYMBOL	

WORD	
COLUMN	
FORMAT	
CARD	
SYMBOL	

The following cards for NIN=2

WORD	This card only if NIN=2	
COLUMN	6	12
FORMAT	F6.2	F6.2
CARD	PM(1) - Outer Mass PM(2) - Inner Mass	
SYMBOL	PM(1)	PM(2)

Card 5a. NIN=2
Format 2F6.2
Symmetric problems

WORD	These cards only if NIN=2; Three cards I= 1,2,3					
COLUMN	10	20	30	40	50	60
FORMAT	I10	E10.2	E10.2	E10.2	E10.2	E10.2
CARD	Spring parameters for outer, next-to-outer, and inner springs.					
SYMBOL	NGAP(I)	K(I,1)	K(I,2)	A1(I)	C(I)	A2(I)

Cards 5b - 5d NIN=2
I=1,2,3
Format I10, 5E10.2

WORD	
COLUMN	
FORMAT	
CARD	
SYMBOL	

WORD	
COLUMN	
FORMAT	
CARD	
SYMBOL	

WORD					
COLUMN	10	20	30	40	50
FORMAT	E10.2	E10.2	E10.2	10	E10.2
CARD	Time parameters and GEAR package parameters.				
SYMBOL	PRI	FINTIM	TINT	METH	ERR

Card 6
Format
SE10.2, I10, E10.2
PRI - Print interval
FINTIM - Finish time
TINT
METH- Gear package
ERR Parameters.

WORD		
COLUMN	10	20
FORMAT	E10.2	E10.2
CARD	SCAL - Scale for graph CPT - Max execution time allowed for problem.	
SYMBOL	SCAL	CPT

Card 7
Format 2E10.2

WORD	
COLUMN	
FORMAT	
CARD	
SYMBOL	

WORD	
COLUMN	
FORMAT	
CARD	
SYMBOL	

Numerical Integration Technique - Methods of C.W. GEAR

Very little mention is made of the nature of the numerical methods used in the reports of other core seismic analysis codes ^{(1), (2), (3)}. However, there should be concern about the convergence and the stability of the solutions of the type of differential equation that arise in this analysis.

Since the system of equations have rapidly varying terms and widely varying time constants, they fall into the class of stiff differential equations, which need particular methods of solution as developed by GEAR ⁽⁴⁾ over the last few years. OSCIL uses a GEAR package written by A.C. Hindmarsh ⁽⁵⁾.

In the model the springs used to simulate collisions between blocks is depicted by the graph below

Fig. 8

As in GEAR (4) the system of equations with K_1 as in the above figure are stiff for two reasons:

- i) The high stiffness constants $O[K] \sim 10^6 - 10^7$ of the blocks imply a very small time constant and small integration step h . Must have $O[h] \sim 10^{-12} - 10^{-15}$ sec when the blocks are in contact to maintain a relative error $\leq 10^{-7}$ at a particular time step. But the time constants corresponding to the seismic oscillations $O[1/\omega] \sim 1$ sec.

ii) Since there are gaps between the blocks, the forces (and hence the accelerations $\ddot{x}_i$) on the blocks have discontinuous first derivatives. This means that the equations are stiff around A1 even if the springs are soft.

The property of stiffness is local; the equations are stiff for some regions of t and not in others. For this system of equations the time constants are widely varying. Most conventional methods for solving ODE's require incremental values of t commensurate with $\min \tau_i$ (where τ_i are the time constants associated with the system, and obtained from the eigenvalues of the Jacobian). $\min \tau_i$ is small for large K_i , while the size $|T - t_0|$ of the problem range is commensurate with the period of the forcing function $\sim$ secs. As a result, the problem cannot be run to completion in a reasonable number of steps using conventional methods.

In the GEAR package the step size and order of integration are automatically varied to maintain optimum efficiency within an error tolerance set by the user. It iterates at each step until an equilibrium solution is found (within error tolerance).

To test the reliability of any given calculation, the user increases or decreases the error tolerance rather than the step size as in other methods of numerical integration. It was found that for $K \sim 3 \times 10^7$ the solutions are constant for an error tolerance $\leq 10^{-9}$ for any number of masses.

For a detailed explanation of these terms and features, see (6). The use of GEAR is described in (5), attached with this report.

Program Description:

The subroutines of OSCIL - RDIN, COEF, CLEAN, RESTART, ~~RDIN~~, DRIVE, DIFFUN, FORCE, PRNTF, PROUT, STORE, PLOTV plus the subroutines of DRIVE are programmed in a fairly well-structured manner.

Diagram (1)

Overall structure of OSCIL. A downward sloping line from one box to another indicates that the lower routine is called by the upper one.

Subroutine Functions

- 1) CLEAN - Initializes at start of run
- 2) COEF - Evaluates damping coefficients - See description of input
- 3) RDIN - Reads in data
- 4) PROUT - Prints some results
- 5) PRNTE - Prints results and increases print interval
- 6) RESTART - Reads tapes for restarting
- 7) STORE - Stores displacements for use in PLOTV
- 8) PLOTV - Plots displacements of masses
- 9) DRIVE - Integrates system of differential equations
- 10) DIFFUN - Sets up equations for given time T
- 11) SHOK - Describes forcing function of walls
- 12) FORCE - Determines forces on springs

Diagram (2)

Macroscopic flow chart of OSCIL showing main features. For flow chart of DRIVE, see (5).

Sample Input

Seven mass symmetric problem. The input deck for this problem is given below using both the option NIN = 1 and NIN = 2.

A: NIN = 1

Card						
1.	SEVEN MASS CORE MODEL					
2.	2	7	1			
3.	1.0	11.4	0.0	0.0	2	0
4.	0121	.16				
5a.	10.67	26.55	26.55	26.55	26.55	10.67
5b.						
5c.						
5d.						
5e.	2	0.0	20000.	-0.14	35.0	-1.14
5f.	2	0.0	37000000.	-0.645	35.0	-10000.
5g.	2	0.0	37000000.	-0.645	35.0	-10000.
5h.	2	0.0	37000000.	-0.645	35.0	-10000.
5i.	2	0.0	37000000.	-0.645	35.0	-10000.
5j.	2	0.0	37000000.	-0.645	35.0	-10000.
5k.	2	0.0	37000000.	-0.645	35.0	-10000.
5l.	2	0.0	20000.	-0.14	35.0	-1.14
6.	.01	5.	1.E-11	22	1.E-8	
7.	1.	400.				

B: NIN = 2

Card						
1.	SEVEN MASS CORE MODEL					
2.	2	7	1			
3.	1.0	11.4	0.0	0.0	2	0
4.	0221	.16				
5a.	10.67	26.55	26.55			
5b.	2	0.0	20000.	-0.14	35.0	-1.14
5c.	2	0.0	37000000.	-0.645	35.0	-10000.
5d.	2	0.0	37000000.	-0.645	35.0	-10000.
6.	.01	5.	1.E-11	22	1.E-8	
7.	1.	400.				

~~SENSITIVE IV-PULSE FUNCTION PARAMETERS~~

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~~THIS IS A SPYING~~

[illegible]

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99	99
100	100

1.	26,078	2.	26,988	3.	26,991	4.	26,992	5.	26,994
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~~SECRET~~

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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PART II

Testing of OSCIL

Model Description

To evaluate the effects of seismic response, the following quantities must be known.

(1) Material properties - the modulus of elasticity, poisson's ratio, density and yield strength applicable to the fuel elements, the top, bottom and side reflector elements, the support posts and blocks, the borinated shields and the dowels.

(2) Geometric conditions - dimensions of all reflector elements, support blocks and posts, borinated shield, spring packs and dowels; the operational clearances between all elements including the dowel pin and hole clearances.

(3) The scaling method used in three dimensions as applied to the various blocks, clearances, springs and posts; the forcing function characteristics; the test fixture structural and dynamic characteristics.

An analytical evaluation of the seismic response information presented in the HTGR Nuclear Training Manual has been made. In particular, Section 5 of the Manual is concerned with the Core Seismic Program. A figure in the Manual shows the core motion characteristics in response to an input of 3.5 Hz. The core is pictured as consisting of three masses with clearances between each. Springs are located at the outside ends of the segmented core masses. The central mass represents the core while the two outer masses represent the reflector blocks. The springs represent the spring packs.

One of the cores looked at was composed of 3944 blocks arranged in 493 vertical stacks. Reflector blocks are arranged around the outside circumference

of the core stacks. Radial springs are located between a borinated shield and the outer shell of the structure. The borinated shield is adjacent to the outside surface of the reflector blocks. The model represented in the HTGR Manual and shown in Figure 9 shows a single layer through a typical cross section of the core.

It was decided that the information presented in the HTGR Manual could be evaluated analytically. To do this a mathematical model representing a single layer of elements was considered. This is shown in Figure 1. The core structure is represented by a series of masses $m_1, m_2, \dots, m_i, \dots, m_n$. The elastic properties between adjacent masses are indicated by K_i . The elements designated by K_1 and K_{n+1} represent the elastic constants of the reflector blocks when in contact with the spring packs and borinated shield. The elements designated by K_2 to K_n represent the elastic properties of adjacent fuel elements when in contact. For the initial model, general damping is assumed to occur whenever there is a relative velocity between adjacent masses. Clearances between adjacent masses are given by A_i . Motional inputs to the system are provided by XOL on the left and XOR on the right.

The equations of motion for the system in Figure 1 are given on p. 2.

OSCIL was written to describe the motion of the general, in-line, n degree of freedom system.

CORE MOTION CHARACTERISTICS

FIGURE 9

3 MASS SYSTEM

WHERE :

ELASTIC - DAMPER SYMBOL

FIGURE 10

"N" MASS SYSTEM

FIGURE 11

Test Cases

Initially several simple cases were considered. In particular, two and three degree of freedom systems were investigated for harmonic inputs at either end. The inputs were either in phase or out of phase with each other. These cases were investigated since some response characteristics could be predicted. These known solutions were used to check out the accuracy of the computer program.

Six cases were solved and the results examined to check out the program. Specifically, the program was tested to determine whether the introduction of non-linearity into some of the parameters could be properly processed. These parameters include the clearances, the non-linearities, the damping and the inputs. The six cases, and the range of the parameters used in each, are shown in Figures 12a through 12f. For all of these, a simple sinusoidal forcing function of unit amplitude ($A=1$) and adjustable frequency (B) was used. In the general program, the inputs may be independently specified. However, for the test cases to be presented the inputs are of equal magnitude and either in phase or 180 degrees out of phase with each other.

Case 1, Figure 12a, was a simple, undamped, linear, two degree of freedom system with symmetrical inputs at either end. Equal masses and springs were used. Because of symmetry, the response should be equivalent to that of a single degree of freedom system. This occurs if both masses respond with equal displacement so that the relative motion ($X_1 - X_2$) is zero. A typical output from the computer for Case I is shown in Table I. This shows the values of displacements X_1 and X_2 , the frequency B , the inputs X_0 and the velocities of each mass. The range of the frequency (B) was varied from zero to a value of

10 rad/sec. This range of inputs covers the resonance characteristics of the system. The printout is in intervals of 0.5 rad/sec. As expected, the listed values of X_1 and X_2 in Table I are identical.

Case 2, shown in Figure 12b, depicts a linear, damped, spring-mass system. The damping was introduced only at the outer ends because the response for such a condition is known to be essentially equivalent to that of a one degree of freedom system. Figure 13 is a plot of the computer results for an input frequency of 6.0 rad/sec and a damping coefficient of 0.1256. Figure 13a shows the response for the first 10 seconds. The response has within it the initial conditions of zero displacement and zero velocity. Figure 13b shows an extended plot of the maximum values only. As can be seen from the figures the initial transient has diminished and the response is attaining its steady state level. This checks with the known response for these conditions.

Case 3, shown in Figure 12c, involves a damped, spring-mass system with a non-linear breakpoint. This case is introduced to establish the capability of the program to handle non-linear spring characteristics. For this case, the spring has a hard-soft breakpoint characteristic. K_{11} is the spring constant for small deflections while K_{12} is the spring constant for larger relative deflections. The breakpoint occurs at a relative displacement of 10. Springs K_1 and K_3 both have this non-linear characteristic. K_2 is a linear spring over the entire range.

Figure 14 shows a plot of the displacements X_1 and X_2 . Comparing these results with Figure 13a, the plot for an identical but linear system, the effects of the non-linear springs are readily identified. Beyond this the breakpoint is encountered which introduces the non-linearity and hence, as expected, the curves differ.

CASE 1 UNDAMPED LINEAR SPRING-MASS SYSTEM

FIGURE 12a

CASE 2 DAMPED LINEAR SPRING-MASS SYSTEM

FIGURE 12b

CASE 3 DAMPED SPRING-MASS SYSTEM WITH NONLINEAR BREAK-POINT

• FIGURE 12c

CASE 4 **DAMPED SPRING-MASS SYSTEM WITH**
NONLINEAR BREAK-POINT

FIGURE 12d

CASE 5 **DAMPED SPRING-MASS SYSTEM WITH CLEARANCE**

FIGURE 12e

CASE 6 DAMPED SPRING-MASS SYSTEM WITH CLEARANCE

FIGURE 12f

TABLE I

X ₁	X ₂	B	X ₀	X ₁	X ₂
2969E-05	2969E-05	5000E+00	5000E-02	8098E-03	8098E-03
2392E-04	2392E-04	5000E+00	1000E-01	3416E-02	3416E-02
1913E-03	1913E-03	5000E+00	1500E-01	7809E-02	7809E-02
3732E-03	3732E-03	5000E+00	2000E-01	1397E-01	1397E-01
5436E-03	5436E-03	5000E+00	3000E-01	3125E-01	3125E-01
1202E-02	1202E-02	5000E+00	4284E-01	4204E-01	4204E-01
1518E-02	1518E-02	5000E+00	3999E-01	5503E-01	5503E-01
2155E-02	2155E-02	5000E+00	4498E-01	7036E-01	7036E-01
2946E-02	2946E-02	5000E+00	5497E-01	8647E-01	8647E-01
3906E-02	3906E-02	5000E+00	5996E-01	1041E+00	1041E+00
5050E-02	5050E-02	5000E+00	6495E-01	1231E+00	1231E+00
5392E-02	5392E-02	5000E+00	6994E-01	1434E+00	1434E+00
7944E-02	7944E-02	5000E+00	7493E-01	1651E+00	1651E+00
9720E-02	9720E-02	5000E+00	7992E-01	1879E+00	1879E+00
1173E-01	1173E-01	5000E+00	8490E-01	2119E+00	2119E+00
1399E-01	1399E-01	5000E+00	8988E-01	2369E+00	2369E+00
1650E-01	1650E-01	5000E+00	9486E-01	2628E+00	2628E+00
1927E-01	1927E-01	5000E+00	9983E-01	2866E+00	2866E+00
2232E-01	2232E-01	5000E+00	1048E+00	3171E+00	3171E+00
2564E-01	2564E-01	5000E+00	1098E+00	3453E+00	3453E+00
2925E-01	2925E-01	5000E+00	1147E+00	3740E+00	3740E+00
3316E-01	3316E-01	5000E+00	1197E+00	4032E+00	4032E+00
3735E-01	3735E-01	5000E+00	1247E+00	4327E+00	4327E+00
4184E-01	4184E-01	5000E+00	1296E+00	4625E+00	4625E+00
4663E-01	4663E-01	5000E+00	1346E+00	4923E+00	4923E+00
5172E-01	5172E-01	5000E+00	1395E+00	5222E+00	5222E+00
5710E-01	5710E-01	5000E+00	1445E+00	5520E+00	5520E+00
6278E-01	6278E-01	5000E+00	1494E+00	5815E+00	5815E+00
6861E-01	6861E-01	5000E+00	1544E+00	6108E+00	6108E+00
7503E-01	7503E-01	5000E+00	1593E+00	6396E+00	6396E+00
8158E-01	8158E-01	5000E+00	1643E+00	6679E+00	6679E+00
8841E-01	8841E-01	5000E+00	1692E+00	6956E+00	6956E+00
9552E-01	9552E-01	5000E+00	1741E+00	7226E+00	7226E+00
1029E+00	1029E+00	5000E+00	1791E+00	7487E+00	7487E+00
1105E+00	1105E+00	5000E+00	1840E+00	7739E+00	7739E+00
1184E+00	1184E+00	5000E+00	1889E+00	7981E+00	7981E+00
1255E+00	1255E+00	5000E+00	1938E+00	8212E+00	8212E+00
1348E+00	1348E+00	5000E+00	1987E+00	8431E+00	8431E+00
1434E+00	1434E+00	5000E+00	2036E+00	8637E+00	8637E+00
1521E+00	1521E+00	5000E+00	2085E+00	8830E+00	8830E+00
1611E+00	1611E+00	5000E+00	2133E+00	9009E+00	9009E+00
1702E+00	1702E+00	5000E+00	2182E+00	9173E+00	9173E+00
1794E+00	1794E+00	5000E+00	2231E+00	9321E+00	9321E+00
1888E+00	1888E+00	5000E+00	2279E+00	9454E+00	9454E+00
1983E+00	1983E+00	5000E+00	2328E+00	9570E+00	9570E+00
2079E+00	2079E+00	5000E+00	2377E+00	9669E+00	9669E+00
2177E+00	2177E+00	5000E+00	2426E+00	9751E+00	9751E+00
2275E+00	2275E+00	5000E+00	2474E+00	9815E+00	9815E+00
2373E+00	2373E+00	5000E+00	2522E+00	9861E+00	9861E+00
2472E+00	2472E+00	5000E+00	2571E+00	9889E+00	9889E+00
2571E+00	2571E+00	5000E+00	2619E+00	9900E+00	9900E+00
2670E+00	2670E+00	5000E+00	2667E+00	9913E+00	9913E+00
2768E+00	2768E+00	5000E+00	2715E+00	9915E+00	9915E+00
2867E+00	2867E+00	5000E+00	2764E+00	9880E+00	9880E+00
2965E+00	2965E+00	5000E+00	2812E+00	9758E+00	9758E+00
3062E+00	3062E+00	5000E+00	2861E+00	9677E+00	9677E+00

FIGURE 13A

FIGURE 13B

FIGURE 14

Case 4, shown in Figure 12d, is similar to Case 3 except that it is a three degree of freedom system. Results for inphase inputs and response less than that which is necessary to reach the breakpoint as shown in Table II, reveal that X_3 is identical to X_1 , while X_2 is greater than either. This is as expected for a linear three degree of freedom system. After 4 seconds, which is in accordance with the time required for the breakpoint to be reached in the previous case, the values for X_3 differ from those of X_1 .

Results for out of phase inputs are given in Table III. Here it should be noted that the response agrees with linear theory. X_3 is equal but opposite to X_1 , and X_2 is essentially zero. The reason for this is that the displacements are small and the breakpoint is not reached. Thus the response should indeed remain linear.

Case 5, shown in Figure 12e, represents a damped, spring-mass system with clearances. The two external springs have a spring constant of zero until the relative displacement is equal to the clearance. At this point, the spring assumes a value of 39.478. The center spring is linear over the entire range. Computer results for the response are plotted in Figure 15. The effects of the non-linearity are identifiable by the double curvature in both the response curves for X_1 and X_2 . As depicted in the Figure, the double curvature for one variable occurs in the negative region while the double curvature for the other takes place in the positive region. The reason for this phenomena is due to the non-linear, non-symmetric spring constant employed for this problem. Neither K_1 nor K_3 can support tensile loads. Consequently, for relative in phase motion, when X_1 is in compression, K_3 is zero and vice versa. This leads to the symmetric-antisymmetric response depicted.

X ₁	X ₂	X ₃	X ₀	X ₀₂	TIME
9125E+00	0025E+00	9125E+00	9999E+00	9999E+00	3400E+01
7676E+11	7696E+01	7676E+01	9612E+00	9612E+00	3450E+01
5727E+01	6207E+01	5727E+01	9367E+00	9367E+00	3500E+01
7635E+01	0225E+01	7635E+01	6374E+00	6374E+00	3550E+01
0017E+01	0558E+01	0017E+01	3817E+00	3817E+00	3600E+01
9267E+01	1216E+02	9267E+01	9102E-01	9122E-01	3650E+01
966E+01	0633E+01	966E+01	0666E+00	2027E+00	3700E+01
7652E+01	0339E+01	7652E+01	4072E+00	4072E+00	3750E+01
5715E+01	6258E+01	5715E+01	7235E+00	7235E+00	3800E+01
3211E+01	3590E+01	3211E+01	0952E+00	0952E+00	3850E+01
3592E+01	0738E+00	3592E+01	0869E+00	0869E+00	3900E+01
2591E+01	2591E+01	2591E+01	0995E+00	0995E+00	3950E+01
5733E+01	5733E+01	5733E+01	0956E+00	0956E+00	4000E+01
7731E+01	0325E+01	7731E+01	7398E+00	7398E+00	4050E+01
9430E+01	1108E+02	9430E+01	5729E+00	5729E+00	4100E+01
1033E+02	1108E+02	1033E+02	2306E+00	2306E+00	4150E+01
1021E+02	1126E+02	1021E+02	3591E+00	3591E+00	4200E+01
9680E+01	1060E+02	9680E+01	6184E+00	6184E+00	4250E+01
0279E+01	0279E+01	0279E+01	0233E+00	0233E+00	4300E+01
7005E+01	7595E+01	7005E+01	9543E+00	9543E+00	4350E+01
6584E+01	0499E+01	6584E+01	1000E+01	1000E+01	4400E+01
1576E+01	1074E+01	1576E+01	0564E+00	0564E+00	4450E+01
1369E+01	1619E+01	1369E+01	0277E+00	0277E+00	4500E+01
4433E+01	4024E+01	4433E+01	6244E+00	6244E+00	4550E+01
6705E+01	7123E+01	6705E+01	3657E+00	3657E+00	4600E+01
9898E+01	0602E+01	9898E+01	7427E-01	7427E-01	4650E+01
1265E+02	1160E+02	1265E+02	2230E+00	2230E+00	4700E+01
1166E+02	1196E+02	1166E+02	7350E+00	7350E+00	4750E+01
1184E+02	1153E+02	1184E+02	9026E+00	9026E+00	4800E+01
1076E+02	1095E+02	1076E+02	0895E+00	0895E+00	4850E+01
9178E+01	9269E+01	9178E+01	0803E+00	0803E+00	4900E+01
6254E+01	7249E+01	6254E+01	0949E+00	0949E+00	4950E+01
4057E+01	4416E+01	4057E+01	7244E+00	7244E+00	5000E+01
6254E+01	6523E+01	6254E+01	0949E+00	0949E+00	5050E+01
4057E+01	4416E+01	4057E+01	7244E+00	7244E+00	5100E+01
1264E+01	9641E+00	1264E+01	0933E+00	0933E+00	5150E+01
2232E+01	1912E+01	2232E+01	2143E+00	2143E+00	5200E+01
4674E+01	0916E+01	4674E+01	0397E-01	0397E-01	5250E+01
7605E+01	7956E+01	7605E+01	3747E+00	3747E+00	5300E+01
9075E+01	0963E+01	9075E+01	6320E+00	6320E+00	5350E+01
0893E+01	1083E+02	0893E+01	0328E+00	0328E+00	5400E+01
1023E+02	1137E+02	1023E+02	0992E+00	0992E+00	5450E+01
1042E+02	1138E+02	1042E+02	0990E+00	0990E+00	5500E+01
8725E+01	0967E+01	8725E+01	0513E+00	0513E+00	5550E+01
7450E+01	0049E+01	7450E+01	6112E+00	6112E+00	5600E+01
5093E+01	0557E+01	5093E+01	3500E+00	3500E+00	5650E+01
2247E+01	2546E+01	2247E+01	5749E-01	5749E-01	5700E+01
4782E+00	5055E+00	4782E+00	2401E+00	2401E+00	5750E+01
5847E+01	3720E+01	5847E+01	5163E+00	5163E+00	5800E+01
7688E+01	0849E+01	7688E+01	0697E+00	0697E+00	5850E+01
8615E+01	0632E+01	8615E+01	0913E+00	0913E+00	5900E+01
9847E+01	0935E+01	9847E+01	0945E+00	0945E+00	5950E+01
9801E+01	0935E+01	9801E+01	0945E+00	0945E+00	6000E+01
9801E+01	0935E+01	9801E+01	0945E+00	0945E+00	6050E+01
1020E+02	0635E+01	1020E+02	0935E+00	0935E+00	6100E+01

CASE 4 X₀₁=X₀₂

TABLE II

X ₁	X ₂	X ₃	X ₀	X ₀₂	TIME
-7.7975E-01	-1.715E-12	-7.7975E-01	-1.2225E-07	-1.2225E-07	1660E+02
-5.611E-01	-2.174E-12	-5.611E-01	-5.6195E+00	-5.6195E+00	1665E+02
-2.908E-01	-2.251E-12	-2.908E-01	-3.250E+00	-3.250E+00	1670E+02
-2.849E-02	-2.2225E-12	-2.849E-02	-3.096E-01	-3.096E-01	1675E+02
-2.614E-01	-1.995E-12	-2.614E-01	-2.655E+00	-2.655E+00	1680E+02
-4.065E-01	-1.591E-12	-4.065E-01	-4.165E+00	-4.165E+00	1735E+02
-6.129E-01	-1.235E-12	-6.129E-01	-6.655E+00	-6.655E+00	1740E+02
-7.890E-01	-7.154E-13	-7.890E-01	-8.560E+00	-8.560E+00	1745E+02
-8.072E-01	-2.692E-14	-8.072E-01	-8.795E+00	-8.795E+00	1750E+02
-9.205E-01	-6.629E-13	-9.205E-01	-9.994E+00	-9.994E+00	1755E+02
-9.675E-01	-1.292E-12	-9.675E-01	-9.721E+00	-9.721E+00	1760E+02
-7.764E-01	-1.815E-12	-7.764E-01	-7.920E+00	-7.920E+00	1765E+02
-5.315E-01	-2.171E-12	-5.315E-01	-5.262E+00	-5.262E+00	1770E+02
-2.551E-01	-2.336E-12	-2.551E-01	-3.090E+00	-3.090E+00	1775E+02
-1.730E-02	-2.249E-12	-1.730E-02	-1.415E-01	-1.415E-01	1780E+02
-2.597E-01	-2.037E-12	-2.597E-01	-2.823E+00	-2.823E+00	1785E+02
-5.055E-01	-1.622E-12	-5.055E-01	-5.329E+00	-5.329E+00	1790E+02
-7.139E-01	-1.021E-12	-7.139E-01	-7.745E+00	-7.745E+00	1795E+02
-9.574E-01	-3.672E-12	-9.574E-01	-9.268E+00	-9.268E+00	1800E+02
-9.196E-01	-7.629E-13	-9.196E-01	-9.964E+00	-9.964E+00	1805E+02
-9.098E-01	-1.061E-12	-9.098E-01	-9.727E+00	-9.727E+00	1810E+02
-8.025E-01	-1.5825E-12	-8.025E-01	-8.703E+00	-8.703E+00	1815E+02
-6.255E-01	-2.265E-12	-6.255E-01	-6.458E+00	-6.458E+00	1820E+02
-4.060E-01	-2.175E-12	-4.060E-01	-4.401E+00	-4.401E+00	1825E+02
-1.473E-01	-2.374E-12	-1.473E-01	-1.551E+00	-1.551E+00	1830E+02
-1.323E-01	-2.211E-12	-1.323E-01	-1.439E+00	-1.439E+00	1835E+02
-1.969E-01	-1.853E-12	-1.969E-01	-1.298E+00	-1.298E+00	1840E+02
-6.264E-01	-1.321E-12	-6.264E-01	-6.774E+00	-6.774E+00	1845E+02
-7.269E-01	-5.725E-13	-7.269E-01	-8.645E+00	-8.645E+00	1850E+02
-9.994E-01	-3.734E-14	-9.994E-01	-9.744E+00	-9.744E+00	1855E+02
-9.195E-01	-2.749E-12	-9.195E-01	-9.973E+00	-9.973E+00	1860E+02
-8.595E-01	-1.395E-12	-8.595E-01	-9.311E+00	-9.311E+00	1865E+02
-7.208E-01	-1.915E-12	-7.208E-01	-7.817E+00	-7.817E+00	1870E+02
-5.189E-01	-2.266E-12	-5.189E-01	-5.524E+00	-5.524E+00	1875E+02
-2.703E-01	-2.474E-12	-2.703E-01	-2.833E+00	-2.833E+00	1880E+02
-2.204E-02	-2.204E-03	-2.204E-02	-2.664E-02	-2.664E-02	1885E+02
-2.265E-01	-2.158E-12	-2.265E-01	-2.291E+00	-2.291E+00	1890E+02
-5.224E-01	-1.692E-12	-5.224E-01	-5.668E+00	-5.668E+00	1895E+02
-7.236E-01	-9.952E-13	-7.236E-01	-7.850E+00	-7.850E+00	1900E+02
-8.670E-01	-2.964E-13	-8.670E-01	-9.330E+00	-9.330E+00	1905E+02
-9.195E-01	-4.734E-13	-9.195E-01	-9.972E+00	-9.972E+00	1910E+02
-9.073E-01	-1.124E-12	-9.073E-01	-9.712E+00	-9.712E+00	1915E+02
-7.294E-01	-1.245E-12	-7.294E-01	-8.619E+00	-8.619E+00	1920E+02
-6.21E-01	-2.157E-12	-6.21E-01	-6.735E+00	-6.735E+00	1925E+02
-1.927E-01	-2.471E-12	-1.927E-01	-1.222E+00	-1.222E+00	1930E+02

CASE 4 $X_{01} = -X_{02}$

TABLE III

FIGURE 15

Case 6, shown in Figure 12f, is a three degree of freedom system with all four springs having similar non-linear characteristics. The designated clearances are all equal. Figure 16 shows the response for $B=4.0$ inphase inputs. As is indicated, X_1 and X_3 are equal in magnitude except that the ordinate is displaced differently for each. This is due to the clearance effect associated with every spring which results in a cyclic reversal of the effective spring constant acting on masses m_1 and m_3 . As is to be expected the cyclic change for m_1 and m_3 is 180 degrees out of phase.

Figure 17 shows a plot of maxima for the X_1 displacement at different frequencies, $B=4.0, 5.0$ and 6.0 . Note that the maximum response occurs at the lower frequency. The reason for this is that symmetric clearances will lower the system natural frequencies below those predicted for the linear system.

Figure 18 depicts the response of Case 6 for each mass, resulting from out of phase inputs. In this case, X_3 is a mirror image of X_1 while X_2 is essentially zero. Because of the symmetrical configuration of the system, this characteristic is to be expected. The results for this case are especially interesting since this configuration is closely related to the single plane core model.

Results from Cases 1 through 6 show that the program can predict the response behavior of non-linear, multi-degree of freedom systems. Employed with proper input data it should permit a realistic assessment of HTGR core seismic response.

FIGURE 16

FIGURE 17

FIG. 18

Parametric Study of 7-Mass System

The first detailed analysis of a complete horizontal section of the HTGR core using OSCIL was made with 7 masses. The masses M_1 and M_7 represent a pair of diametrically opposed side reflector blocks while the interior masses M_2 through M_6 represent a lumped arrangement of the associated horizontal fuel elements. The springs K_1 and K_8 represent the spring packs placed between the wall and reflector blocks. The spring constants K_3 through K_6 represent the stiffnesses between the fuel elements, while the spring constants K_2 and K_7 represent the stiffnesses between the reflector block and the adjacent fuel elements. A total operating clearance of 4.15 inches was distributed symmetrically across the entire horizontal array with a different clearance assigned for the spring pack as opposed to the fuel elements. In this model damping was accounted for by lumped equivalent viscous coefficients between the adjacent structural components of the core. Although both the material stiffness and the energy dissipation in the system are known to be nonlinear, it was decided that the two effects should be studied separately. Thus, in the initial model, viscous damping was assumed and the non-linear features were assigned only to the elastic forces.

Numerous runs were made with the 7 mass representation. (See figures 21-25). Damping was varied from zero to large amounts and clearances from 30% to 130% of normal. Figure 19 shows a typical computer generated plot. As shown in the figure, 9 variables are plotted. These include the two input displacements, the displacements of the two side reflector blocks, and the displacements of the 5 internal masses representing the fuel elements. The vertical axis represents the displacement amplitudes of each of the components is located in accordance with the initial clearances assumed for this problem with

the centermost core block taken as the zero point of the system. The plot is intended to show the displacement-time history of the elements relative to the center of the model.

Referring to Figure 19, the uppermost and lowermost curves represent the wall inputs which in this case are harmonic. The next set of inner and outer curves represent the motion of the two reflector blocks, while the 5 inner curves represent the motions of the core blocks. As can be seen collisions between internal elements, reflector block and the wall are apparent. The case illustrated is for moderate damping and normal clearance.

Cases with no damping show a greater number of collisions. These initiate sooner and involve higher velocities. With heavy damping, far fewer collisions take place. Those that occur result in substantially lower velocities. The motion for these cases appears to approach steady state behavior. However, too few cases involving variations of clearances were run, and thus conclusions can be drawn at present.

In order to assess the validity of the model, systems with a different number of masses were also investigated. A typical result for a 12 mass model is shown in Figure 26. The same total clearance and total mass were used for both the 7 and 12 mass systems. Comparable input and damping conditions were assumed for the two solutions.

DISPLACEMENT - TIME HISTORY 7 MASS MODEL

FIG. 19

SINUSOIDAL IN - PHASE FUNCTION PARAMETERS

AMPLITUDE= 1.00

C FREQ = 5.00

ALPHA= 0.00

NUMBER OF MASSES = 7

1.10.670 2.26.550 3.26.550 4.26.550 5.26.550
6.26.550 7.10.670

THERE ARE 8 SPRINGS

I	SPRING TYPE	KI1	KI2	CHANGE FOR	CI	EXP. FOR	GROUND
	NGAR(I)			DISP GT		DISP LT	C(I)
1	2 0.	.20E+05	-.140	92.390	-.140	17.735	
2	2 0.	.37E+08	-.645	5248.123-10000.000	44.129		
3	2 0.	.37E+08	-.645	5248.493-10000.000	44.129		
4	2 0.	.37E+08	-.645	5248.493-10000.000	44.129		
5	2 0.	.37E+08	-.645	5248.493-10000.000	44.129		
6	2 0.	.37E+08	-.645	5248.493-10000.000	44.129		
7	2 0.	.37E+08	-.645	5248.123-10000.000	17.735		
8	2 0.	.20E+05	-.140	92.390	-1.140	0.500

FIGURE 20

PARAMETRIC EVALUATION

I. DETERMINE MINIMUM NUMBER OF
MASSES FOR REALISTIC DYNAMIC
MODEL

II. DETERMINE SENSITIVITY TO:

A. DAMPING { INTER-ELEMENTAL
 TO GROUND
B. CLEARANCE

III. INPUT CONDITIONS:

A. SINUSOIDAL { FREQUENCY
 AMPLITUDE
B. EARTHQUAKE TIME HISTORY

PARAMETRIC STUDY FOR HORIZONTAL MODEL

	PARAMETER	M	C (% CRITICAL)	CL (% NOMINAL)	$W \left(\frac{\text{RAD}}{\text{SEC}} \right)$	Xo (INCHES)
I	NUMBER OF MASSES	5,7,9,30	30%	N	11.4	1
II	INTERELEMENTAL DAMPING	7	1%,10%, .30%,50%	N	11.4	1
III	TOTAL CLEARANCE	7	30%	0,30%N, N,130%N	11.4	1
IV	INPUT FREQUENCY	7	30%	N	2.5,2.525 5,11.4	1
V	INPUT AMPLITUDE	7	30%	N	11.4	.5,1,2

EVALUATION OF COEFFICIENT OF RESTITUTION
FROM VISCOUSLY DAMPED MODEL

(M=7, NORMAL CLEARANCE, W=11.4, $X_0=1$)

INTERELEMENTAL DAMPING (% CRITICAL)	DAMPING COEFFICIENT ($\frac{\text{LB-SEC.}}{\text{INCH}}$)	COEFFICIENT OF- RESTITUTION (EVALUATED FROM OUTPUT)
1%	626	0.96
10%	6,260	0.64
30%	18,800	0.23
50%	31,300	0.044
100%	62,600	<.001

RUN 1 - NUMBER OF MASSES

FIG. 21

RUN II - DAMPING

FIG. 22

RUN III - CLEARANCE

FIG. 23

RUN IV - FREQUENCY (ω)

FIG. 24

RUN V - INPUT AMPLITUDE

FIG. 25

DISPLACEMENT - TIME HISTORY 12 MASS MODEL

FIG. 26

Non-linearity Effects

The collision process involves contact times that are extremely short, with large variations in force and rapid motion changes. A detailed knowledge of these effects is essential for the stress and failure calculations. The computer program must be capable of accurately revealing the details of the collision process. In order to ascertain this, it is necessary to check the validity of the program in predicting accurate results for these circumstances when non-linear conditions predominate.

The literature dealing with forced vibrations of systems with non-linear restoring elements is almost entirely devoted to periodic solutions. For periodic, or even harmonic forcing functions, transient effects are generally not considered. This is the case even for the forced response of the one degree of freedom problem. However, the computer program solution includes both the transient as well as the steady state response.

In order to assess how well these solutions are handled in the program, two non-linear one degree of freedom problems for which some characteristics are known were investigated.

One system for which checks were carried out was a single mass supported by springs with clearance gaps. For this case the periodic oscillations are readily predicted. This is true even where steep changes in elastic characteristics are encountered. The importance of this procedure is that it permits the development of more efficient solution methods.

A second test problem intended to show how the computer solution reveals the jump phenomena associated with non-linear vibrations was also investigated. For this case a one degree of freedom system having a cubic type of restoring force was investigated. The governing equation for this type of problem can

be written as

$$\ddot{y} + 2\xi \omega_n^2 \dot{y} + \omega_n^2 (y + \varepsilon^2 y^3) = F \cos(\omega t + \phi) \quad [1]$$

where $\dot{y} = \frac{dy}{dt}$, $\omega_n^2 = \frac{K}{m}$, $\xi = \frac{C}{C_c}$, $\varepsilon^2 =$ the non-linearity (in^{-2}). An exact solution for Equation [1] is not known, only approximate solutions are available. Following the standard procedure given in reference (8) a solution is assumed in the form $y = A \cos \omega t$, which after integrating twice yields:

$$y = \left(\frac{\omega_n A}{\omega^2} + \frac{3}{4} \frac{\omega_n^2 \varepsilon^2 A^3}{\omega^2} - \frac{B_1}{\omega^2} \right) \cos \omega t + \left(\frac{B_2}{\omega^2} - \frac{2\xi \omega_n A}{\omega^2} \right) \sin \omega t + \frac{\omega_n^2 \varepsilon^2 A^3}{36 \omega^2} \cos 3 \omega t \quad [2]$$

where $F^2 = B_1^2 + B_2^2$ and $\frac{B_2}{B_1} = \tan \phi$, $A =$ the amplitude of the non-linear response. After equating coefficients of appropriate terms it can be shown that the relationship between the excitation and the response is

$$\left(\frac{\omega_n^2}{\omega^2} \right)^2 + \left(\frac{\omega_n^2}{\omega^2} \right) \left[-2 + 4\xi^2 - \frac{3}{2} \varepsilon^2 A^2 \right] + \left[1 + \frac{3}{2} \varepsilon^2 A^2 + \frac{9}{16} \varepsilon^4 A^4 \right] = \left(\frac{F}{K} \right)^2 \frac{1}{A^2} \quad [3]$$

Figure 27 shows a plot of the computer generated solution for amplitude vs. frequency. Typical computer outputs are shown in Figures 28 and 29 in which the jump phenomena is seen. The results were obtained by programming the computer code to sweep-up in frequency and then to sweep-down in frequency. The circles indicate the sweep-up solutions while the crosses indicate the maximum response for the sweep-down case. No solutions were obtained for the branch of the system that is mathematically unstable. Except for the points which involve rapid jumps or transients, all points fall as predicted by Equation [3] since this equation is only for steady state conditions and for a single term approximation. To the results of Equation [3] the sweep rate was reduced to

FIG. 27

ω RAD/SEC
CUBIC RESPONSE SWEEP UP

FIG. 28

CUBIC RESPONSE SWEEP DOWN

FIG. 29

NONLINEAR RESPONSE
DIFFERENT INPUT AMPLITUDES
SUBHARMONIC RESPONSE AT 5 rad/sec

FIG 30

the point where the steady state phenomena was revealed. Changing the sweep rate affects the sensitivity of the jump phenomena to the presence of third and higher harmonic components of the motion. Too rapid a sweep rate masks the severity of the jump phenomena.

Since the actual problem involves collisions, the effects of initial conditions were also looked into. In particular, the effect of initial arbitrary displacement conditions on the steady state response was investigated at one frequency in the frequency band where there are two stable roots. The specific purpose here was to determine which of the two stable roots would ultimately be obtained for various values of damping as well as for different conditions of initial displacement. Table IV summarizes the results of this investigation. For each of the initial displacements shown in column 1 the initial velocity was assumed to be zero.

The table shows that for a fixed amount of damping either the upper or the lower root is established as the initial displacement condition is increased, the particular root obtained being a discontinuous function of the initial displacement. For instance, for 2% of critical damping, the upper root is established for an initial displacement (X_0) of -0.16 through -0.20, -0.22 and -0.23. However, the lower root is established for (X_0) values of -0.21 and -0.24.

A similar characteristic is also revealed for changes in the damping constant. For example, at (X_0) = -0.21, the lower root occurs for 4% and 2% of critical damping while the upper root occurs for 1%. At (X_0) = -0.23, however, the lower root occurs at 4%, the upper at 2% and the lower again at 1% of critical damping.

It is seen that the response for even this simple non-linear system in which the determination of whether the upper or lower stable root is established is strongly dependent on initial conditions and damping. For a multi-component system the response may be even more sensitive to these parameters. A thorough evaluation of the collision process is therefore important. In any case, these studies show that the computer program works and that care must be taken taken in selecting parameters.

Presently, the horizontal mass model is being used to conduct parametric studies. The effects of input level and type, clearance, damping and mass subdivisions are being evaluated. Simple model tests are planned to study the correlation between the computer and experimental results. In addition, an investigation has been initiated to predict the response characteristics of two-dimensional vertical block arrays.

Table IV

Stable Roots of One-Mass Cubic System at Frequency 7 cps

x_o	$\frac{C}{C_c} = 4\%$	$\frac{C}{C_c} = 2\%$	$\frac{C}{C_c} = 1\%$
-0.16	upper	upper	upper
-0.20	upper	upper	upper
-0.21	lower	lower	upper
-0.22	lower	upper	upper
-0.23	lower	upper	lower
-0.24	lower	lower	upper

References

1. Non linear Dynamic Analysis of a stacked Fuel Column Subjected to Boundary Motion. T.H. Lee, General Atomic Project 912, GA-A12933, Aug. 29, 1974.
2. Analytical Model Development for Core Seismic Response, J.G. Bennett et. al., in HTGR Safety Research Program Quarterly Report, compiled by W.L. Kirk, Los Alamos Progress Report LA-5870-PR, Feb. 1975.
3. Proposal for Analysis of HTGR Core Response to Seismic Input, J.G. Bennett and R.C. Dove, Los Alamos Informal Report, LA-5821-MS, Jan. 1975.
4. The Automatic Integration of Ordinary Differential Equations, C.W. Gear, Comm. of ACM, VI4, No. 3, March 1971.
5. GEAR: Ordinary Differential Equation System Solver, A.C. Hindmarsh, Lawrence Livermore Laboratory, UCID-30001, Rev. 3, Dec. 1974.
6. Linear Multistep Methods for Ordinary Differential Equations, A.C. Hindmarsh, Lawrence Livermore Laboratory UCRL-51126, Rev. 1, March 1972.
7. GEARB: Solution of Ordinary Differential Equations Having Banded Jacobian, A.C. Hindmarsh Lawrence Livermore Laboratory, UCID-30059, Rev. 1, July 1975.

APPENDIX

Listing of Program and Subroutines.

OSCIL

STORE

RDIN

COEF

FESTART

SHOK

PROUT

FORCE

DIFFUN

PLOTV

CLEAN

PRNTE

PROGRAM OSCIL(INPUT,OUTPUT,REST,TAPE 5=INPUT,TAPE 3=OUTPUT,TAPE 4=
1REST)

C
G PROGRAM OSCIL WRITTEN FOR SEISMIC RESPONSE OF BREEDER REACTOR CORE
G RESEARCH GROUP AT BROOKHAVEN NATIONAL LAB.
C AUTHOR... LESLIE LASKER JULY 1975
C

COMMON/GEAR9/HUSED,NQUSED,NSTEP,NFE,NJE
COMMON/CINT/T,DT,JS,JN,DXA(250),XA(250),IO,JS4
COMMON/CPF/NPR,NGPR,L(10,14),STP(10,24),STR(5,250),NS,TPRNT,KOUT
COMMON/ORD/XX1(32,1000)
COMMON/PLT/POUT
COMMON/CASE/TITLE(8)
COMMON/TIME/PFI,FINTIM,NTIME,TINT,METH,ERP,CPT
COMMON/PRT/A,BINT,B,FRQ,ALPHA1,NSTEP,NFUN
COMMON/CONST/TWOPI,TAU,IWAVE
COMMON/CMAIN/NOR,NGOF,NSTART
COMMON/M/NM,SCAL, PM(70),NGAP(71),PK(71),C(71),K(71,2),XINT(70)
COMMON/M/ D1XIN(70),D2XINT(70),A1(71),A2(71),DIF(71),DIF1(71)
COMMON/M/ D1X(70),D2X(70),F(71),XOL,XOR,X(70)
COMMON/CCOEF/UMU,CH(70)

LEVEL 2,XX1
DIMENSION Y(70),YDOT(70)

LOGICAL KOUT,JS
LOGICAL DONE,CHECK

LOGICAL POUT

REAL K

DATA EMAX/.0001/

GUSED=0.0

30 CALL RDIN

NDIF=2*NH

TWOPI=4.0*ASIN(1.0)

NSPF=NM+1

VT=1

3 IF(NGOF.EQ.2) CALL COEF

CALL CLEAN

IF(NSTART.GT.0) CALL RESTART

DO 24 I=1,NM

X(I)=XINT(I) \$ D1X(I)=D1XINT(I) \$ D2X(I)=D2XINT(I)

Y(2*I-1)=X(I) \$ Y(2*I)=D1X(I)

24 CONTINUE

INDEX=1

KX=0

DELT=0.0

DONE=.TRUE.

KOUT=.FALSE.

TAU=0.0

IF(IWAVE.EQ.1) BINT=BINT*TWOPI

PRINT 5

PRINT 29,TITLE

29 FORMAT(8A10,/,/)

CALL POUT

12 CONTINUE

1 CALL SHOK(T,XOL,D1XL,XOR,D1XF)

IF(DONE) PRINT 5

5 FORMAT(1H1)

IF(DONE) PRINT 4

```

4  FORMAT(1X,5X,3HXOL,11X,          2HX1,12X,2HX2,11X,2HX3,9X,
1  4HD1X1,9X,4HD1X2,9X,4HD1X3,11X,4HTIME,9X,5HOMEGA,11X,1HH)
   DT=.CCC1
   CALL PPNTF(PRI,FINTIM,DONE,XOL,    X(1),X(2),X(3),D1X(1),D1X(2),
1D1X(3),T,NQUSED,HUSED)
   IF(POUT) CALL STOF(KX)
   IF(DONE) GO TO 2
   TOLD=TPRNT
45  CONTINUE
   CALL DRIVE(NDIF,T,TINT ,Y,TPRNT,ERR,METH,INDEX)
   T=TPRNT
   CPTIM=SECOND(CP)
   IF((CPTIM-CUSED).LT.CPT) GO TO 50
   FINTIM=T
50  CONTINUE
   IF(INDEX.EQ.0) GO TO 40
   PRINT 41,INDEX,T
41  FORMAT(* INDEX= *,I5,* AT T= *,F10.3)
   IF(INDEX.LT.-5.OR.INDEX.GT.-4) GO TO 43
   CALL REMARK(27HRUN HALTED-CHECK PARAMETEPS)
43  ERR=ERF*10.0
   PPINT 44,ERR
44  FORMAT(* NEW ERR= *,E10.4)
   INDEX=-1
   TPRNT=TOLD
   IF(ERR=EMAX) 45,46,46
46  CALL REMARK(45HRUN HALTED-LOWER ERROR LIMIT HAS BEEN REACHED)
   FINTIM=T
45  INDEX=2
   DO 42 I=1,NM
   X(I)=Y(2*I-1)  S  D1X(I)=Y(2*I)
42  CONTINUE
   GO TO 1
2  CONTINUE
   IF(MOD(NOP,10).NE.2) GO TO 7
   CALL PLOTV(PRI,KX,1,2)
   DO 8 I=1,KX
   XX1(2,I)=100.
3  XX1(1,I)=100.
   CALL PLOTV(PRI,KX,3,8)
   GO TO 6
7  CALL PLOTV(PRI,KX,1,NM)
6  CONTINUE
   BINT=BINT+FRQ
   NT=NT+1
   IF(NT.LE.NTIME) GO TO 3
   CUSED=CUSED+CPT
   GO TO 30
100 CONTINUE
   END

```

SUBROUTINE STORE(KX)

```

C
C THIS ROUTINE STORES DISPLACEMENTS
C
COMMON/CINT/T,DT,JS,JN,DXA(250),XA(250),IO,JS4
COMMON/CPR/NPR,NCPR,L(10,14),STP(10,24),STR(5,250),NS,TPRNT,KOUT
COMMON/ORD/XX1(32,1000)
COMMON/PLT/POUT
COMMON/CASE/TITLE(8)
COMMON/TIME/PRI,FINTIM,NTIME,TINT,METH,ERR,CPT
COMMON/PRT/A,9INT,8,FRQ,ALPHA1,NSTEP,NFUN
COMMON/CONST/TWOPI,TAU,IWAVE
COMMON/CHAIN/NOR,NCOF,NSTART
COMMON/M/NM,SCAL, PH(70),NGAP(71),PK(71),C(71),K(71,2),XINT(70)
COMMON/M/ D1XINT(70),D2XINT(70),A1(71),A2(71),DIF(71),DIF1(71)
COMMON/M/ D1X(70),D2X(70),F(71),XOL,XOR,X(70)
COMMON/CCOEFF/UMU,CW(70)
LEVEL 2,XX1
LOGICAL POUT
KX=KX+1
XX1(1,KX)=XOL
XX1(2,KX)=XOR
NC=(NM+1)/2
NP=MOD(NOR,10)
NCC=NC
IF(NP.EQ.2) NC=4
DO 1 I=1,NM
XX1(I+2,KX)=X(I)
IF(NSTEP.EQ.2) XX1(I+2,KX)=X(I)+(NC-I)*A1(NC)
1 CONTINUE
IF(NSTEP.NE.2) GO TO 2
XX1(1,KX)=XOL+(NC-1)*A1(NC)+A2(1)
XX1(2,KX)=XOR+(NC-NM)*A1(NC)-A2(NM+1)
2 CONTINUE
IF(NP.NE.2) GO TO 4
NC=6
DO 3 I=3,8
XX1(I+2,KX)=X(NCC-6+I)
IF(NSTEP.EQ.2) XX1(I+2,KX)=X(NCC-6+I)+(NC-I)*A1(NCC)
3 CONTINUE
4 CONTINUE
WRITE(4) T,X,D1X,D2X,F
C IF(MOD(KX-1,10).EQ.0) WRITE(4) T,X,D1X,D2X,F
POUT=.FALSE.
RETURN
END

```

SUBROUTINE RDIN

C

C THIS ROUTINE READS IN ALL PERTINENT DATA.

C

```
COMMON/CINT/T,DT,JS,JN,DXA(250),XA(250),IO,JS4
COMMON/CPR/NPR,NCPR,L(10,14),STP(10,24),STR(5,250),NS,TPRNT,KOUT
COMMON/ORD/XX1(32,1000)
COMMON/PLT/POUT
COMMON/CASE/TITLE(8)
COMMON/TIME/PRI,FINTIM,NTIME,TINT,METH,ERR,CPT
COMMON/PRT/A,BINT,9,FRQ,ALPHA1,NSTEP,NFUN
COMMON/CONST/TWOPI,TAU,IWAVE
COMMON/CHAIN/NOR,NCOF,NSTART
COMMON/H/NM,SCAL,PH(70),NGAP(71),PK(71),C(71),K(71,2),XINT(70)
COMMON/H/D1XINT(70),D2XINT(70),A1(71),A2(71),DIF(71),DIF1(71)
COMMON/H/D1X(70),D2X(70),F(71),XOL,XOR,X(70)
COMMON/CCOEF/UMU,CW(70)
```

LEVEL 2,XX1

30 READ 28,TITLE

29 FORMAT(8A10)

IF(EOF(5)) 100,40

40 READ 15,NFUN,NM,NTIME

15 FORMAT(3I10)

IF(NFUN.NE.1) GO TO 2

READ 17,A

B=BINT=ALPHA1=FRQ=D.C

GO TO 4

2 READ 17,A,BINT,FRQ,ALPHA1,NSTEP,IWAVE

17 FORMAT(4F10.2,2I10)

4 NSPR=NM+1

READ 25,NSTART,NIN,NCOF,NOR,UMU

25 FORMAT(I7,3I1,E10.2)

C

C IF NIN=1 READ IN EACH MASS INDIVIDUALLY, TOGETHER WITH THEIR INITIAL
C DISPLACEMENTS, VELOCITIES AND ACCELERATIONS.

C

IF(NIN.EQ.2) GO TO 21

READ 16,(PH(I),I=1,NM)

READ 16,(XINT(I),I=1,NM)

READ 16,(D1XINT(I),I=1,NM)

READ 16,(D2XINT(I),I=1,NM)

16 FORMAT(12F6.2)

C

C IF NIN=1 READ IN DATA FOR EACH INDIVIDUAL SPRING

C

DO 19 I=1,NSPR

19 READ 20,NGAP(I),K(I,1),K(I,2),A1(I),C(I),A2(I)

20 FORMAT(I10,5E10.2)

C

C IF NIN=2 HAVE SYMMETRIC PROBLEM. READ IN OUTER MASSES AND INNER MASSES

C

GO TO 22

C

C OUTER SPRINGS FOR NIN=2

C

21 READ 16,PH(1),PH(2)

C

C SECOND AND NEXT-TO-LAST SPRINGS FOR NIN=2

C

READ 20,NGAP(1),K(1,1),K(1,2),A1(1),C(1),A2(1)

READ 20,NGAP(2),K(2,1),K(2,2),A1(2),C(2),A2(2)

C

C INNER SPRINGS FOR NIN=2

C

READ 20,NGAP(3),K(3,1),K(3,2),A1(3),C(3),A2(3)

NINN=NM-1

DO 23 I=3,NINN

PM(I)=PM(2) \$ NGAP(I)=NGAP(3) \$ K(I,1)=K(3,1) \$ K(I,2)=K(3,2)

A1(I)=A1(3) \$ A2(I)=A2(3) \$ C(I)=C(3)

23 CONTINUE

PM(NM)=PM(1) \$ NGAP(NSPR)=NGAP(1) \$ K(NSPR,1)=K(1,1)

K(NSPR,2)=K(1,2) \$ A1(NSPR)=A1(1) \$ A2(NSPR)=A2(1) \$ C(NSPR)=C(1)

NGAP(NM)=NGAP(2) \$ K(NM,1)=K(2,1)

K(NM,2)=K(2,2) \$ A1(NM)=A1(2) \$ A2(NM)=A2(2) \$ C(NM)=C(2)

22 CONTINUE

READ 41,PRI,FINTIM,TINT,METH,ERR

READ 41,SCAL,CPT

41 FORMAT(3E10.2,I10,E10.2)

RETURN

101 STOP

END

SUBROUTINE COEF

C THIS ROUTINE COMPUTES DAMPING COEFFTS. BETWEEN SPRINGS AND GROUND
C DAMPERS. COEF ONLY CALLED IF NCDF=2.

```

COMMON/CINT/I,DT,JS,JN,DXA(250),XA(250),IO,JS4
COMMON/CPR/NPR,NCPR,L(10,14),STP(10,24),STR(5,250),NS,TPRNT,KOUT
COMMON/ORD/XX1(32,1000)
COMMON/PLT/POUT
COMMON/CASE/TITLE(8)
COMMON/TIME/PR1,FINTIN,NTIME,TINT,METH,ERR,CPT
COMMON/PRT/A,BINT,B,FPQ,ALPHA1,NSTEP,NFUN
COMMON/CONST/THOPI,TAU,IWAVE
COMMON/CMAIN/NOR,NCDF,NSTART
COMMON/H/NM,SCAL, PH(70),NGAP(71),PK(71),C(71),K(71,2),XINT(70)
COMMON/H/ D1XINT(70),D2XINT(70),A1(71),A2(71),DIF(71),DIF1(71)
COMMON/H/ D1X(70),D2X(70),F(71),XOL,XOR,X(70)
COMMON/CCOEF/UMU,CH(70)
LEVEL 2,XX1
REAL K
NSPP=NM+1
PI=2.0*ASIN(1.0)
CLEAR=C.0
B=BINT
DO 1 I=1,NSPP
1 CLEAR=CLEAR-A1(I)
IF(CLEAR.NE.0.0.AND.B.NE.C.0) CTH=(1544*UMU)/(PI*CLEAR*B)
IF(NGAP(1).EQ.2) C(1)=.02*SQRT(PH(1)*K(1,2))
IF(NGAP(NSPP).EQ.2) C(NSPP)=.02*SQRT(PH(NM)*K(NSPP,2))
DO 2 N=2,NM
IF(NGAP(N).EQ.2) C(N)=.02*SQRT(K(N,2)*(PH(N-1)+PH(N))/2.0)
2 CH(N)=CTH*PH(N)
CH(1)=CTH*PH(1)
DO 4 N=1,NSPP
4 C(N)=C(N)*30.
TEM=B/11.4
DO 5 I=1,NM
5 CH(I)=TEM*CH(I)
RETURN
END

```

SUBROUTINE RESTART

C

C THIS ROUTINE IS USED TO RESTART A FUN FROM T=1C*PRI*NSTART

C

COMMON/CINT/T,DT,JS,JN,DXA(25C),XA(25C),IO,JS4

COMMON/CPR/NPR,NCPR,L(1C,14),STP(16,24),STR(5,25C),NS,TPRNT,KOUT

COMMON/ORD/XX1(32,10J0)

COMMON/PLT/POUT

COMMON/CASE/TITLE(8)

COMMON/TIME/PRI,FINTIM,NTIME,TINT,METH,ERR,CPT

COMMON/PRT/A,BINT,B,FRQ,ALPHA1,NSTEP,NFUN

COMMON/CONST/TWOPI,TAU,IWAVE

COMMON/CHAIN/NOF,NOF,NSTART

COMMON/M/NM,SCAL, PH1(7C),NGAP(71),PK(71),C(71),K(71,2),XINT(7C)

COMMON/M/ D1XINT(7C),D2XINT(7C),A1(71),A2(71),DIF(71),DIF1(71)

COMMON/M/ D1X(7C),D2X(7C),F(71),XOL,XOR,X(7C)

COMMON/CCOEF/UMU,CW(7C)

LEVEL 2,XX1

TSTART=NSTART*1C*PRI

MSTART=NSTART*1C

DO 1 I=1,MSTAPT

1 READ(4)

READ(4) T,XINT,D1XINT,D2XINT,F

BACKSPACE 4

IF(ABS(T-TSTART).LE..01) RETURN

WRITE 3,T,TSTART

3 FORMAT(* CHECK RESTART TIME T=*,F5.2,* TSTART= *,F5.2)

STOP

END

SUBROUTINE SHOK(DELTA,XOL,D1XL,XOR,D1XR)

C

C

C THIS ROUTINE DETERMINES MOTION OF WALLS DUE TO SEISMIC FORCING FUNCTION
C DIFFERENT FUNCTIONS ARE DETERMINED BY NFUN. NEW NFUN OPTIONS CAN BE

C ADDED

C

C

COMMON/PRT/A,BINT,B,FRQ,ALPHA1,NSTEP,NFUN

COMMON/CONST/THOPI,TAU,IWAVE

IF(NFUN.NE.1) GO TO 2

XOL=L.C \$ D1XL=C.C

XOL=A

XOR=XOL \$ D1XR=D1XL

RETURN

2

B=BINT+ALPHA1*DELTA

TAU=BINT*DELTA+ALPHA1*(DELTA**2)/2.C

IF(NFUN.EQ.4) GO TO 4

XOL=A*SIN(TAU) \$ D1XL=A*B*COS(TAU)

IF(NFUN.NE.2) GO TO 3

XOR=XOL \$ D1XR=D1XL

RETURN

3

XOR=-XOL \$ D1XR=-D1XL

RETURN

4

XOL=XOR=C.C \$ D1XL=D1XR=C.C

RETURN

END

SUBROUTINE PROUT

C

C THIS ROUTINE OUTPUTS MASS AND SPRING DATA.

C

```

COMMON/CINT/I,DT,JS,JN,DXA(250),XA(250),IO,JS4
COMMON/CPR/NPR,NCPF,L(10,14),STP(10,24),STR(5,250),NS,TPRNT,KOUT
COMMON/ORD/XX1(32,1000)
COMMON/PLT/POUT
COMMON/CASE/TITLE(8)
COMMON/TIME/PRI,FINTIM,NTIME,TINT,METH,ERR,CPT
COMMON/PRT/A,BINT,B,FRQ,ALPHA1,NSTEP,NFUN
COMMON/CONST/TWOPI,TAU,IHAVE
COMMON/CMAIN/NOR,NCOF,NSTART
COMMON/M/NM,SCAL, PM(70),NGAP(71),PK(71),C(71),K(71,2),XINT(70)
COMMON/M/ D1XINT(70),D2XINT(70),A1(71),A2(71),OIF(71),OIF1(71)
COMMON/M/ D1X(70),D2X(70),F(71),XOL,XOR,X(70)
COMMON/CCOEF/UMU,CW(70)
LEVEL 2,XX1
REAL K
NSPR=NM+1
IF(NFUN.NE.1) GO TO 2
PRINT 10
10 FORMAT(* STEP FUNCTION PAFAMETERS *,/)
PRINT 11,A,NM,UMU
11 FORMAT(* AMPLITUDE= *,F10.2,/,
3 * COEF OF FRIC *,F5.2,/)
GO TO 12
2 IF(NFUN.NE.2) GO TO 3
PRINT 20
20 FORMAT(* SINUISOIDAL IN-PHASE FUNCTION PARAMETERS *,/)
GO TO 24
3 IF(NFUN.NE.3) GO TO 4
PRINT 30 $ GO TO 24
30 FORMAT(* SINUISOIDAL OUT-OF-PHASE FUNCTION PARAMETERS *,/)
4 PRINT 40
40 FORMAT(* FIXED WALL, SINUISOIDAL FORCE PARAMETERS *,/)
24 PRINT 17,A,BINT,ALPHA1,NM
17 FORMAT(* AMPLITUDE= *,F10.2,/,
1* OMEGAC =*,F10.2,1CX,* ALPHA= *,F10.2,/,
2 * NUMBEF OF MASSES = *,I3,/)
12 PRINT 18,(I,PM(I),I=1,NM)
18 FORMAT(/,5(I5,14,,F8.3))
PRINT 21,NSPR
21 FORMAT(/,* THERE ARE *,I5,* SPRINGS *,/,/,
1* I SPRING TYPE KI1 KI2 CHANGE FOR CI EXP. FO
2R GROUND *,/
3* NGAP(I) OISP GT DISP LT
4 C(I) *,/)
DO 22 I=1,NSPR
22 PRINT 23,I,NGAP(I),K(I,1),K(I,2),A1(I),C(I),A2(I),CW(I)
23 FORMAT(I5,I11,2E10.2,4F10.3)
RETURN
END

```

SUBROUTINE FORCE(NSPR)

C
C THIS ROUTINE, CALLED BY DIFFUN, DETERMINES THE FORCES IN THE SPRINGS
C AS A FUNCTION OF DISPLACEMENTS. THE NATURE OF THE FORCE IS DETERMINED
C BY THE SPRING TYPE=NGAP(LL). DIFFERENT SPRING RESPONSES CAN BE ADDED
C TO THIS ROUTINE.

C
COMMON/CINT/T,DT,JS,JN,DXA(250),XA(250),IO,JS4
COMMON/CPR/NPR,NCPR,L(10,14),STP(10,24),STR(5,250),NS,TPRNT,KOUT
COMMON/ORD/XX1(32,1000)
COMMON/PLT/POUT
COMMON/CASE/TITLE(8)
COMMON/TINE/PRI,FINTIM,NTIME,TINT,METH,ERR,CPT
COMMON/PRT/A,BINT,B,FPO,ALPHA1,NSTEP,NFUN
COMMON/CONST/TWOPI,TAU,IWAVE
COMMON/CMAIN/NOF,NCOF,NSTART
COMMON/M/NM,SCAL, PM(70),NGAP(71),PK(71),C(71),K(71,2),XINT(70)
COMMON/M/ D1XINT(70),D2XINT(70),A1(71),A2(71),DIF(71),DIF1(71)
COMMON/M/ D1X(70),D2X(70),F(71),XOL,XOR,X(70)
COMMON/CCOEF/UMU,CW(70)
LEVEL 2,XX1
REAL K
DO 11 LL=1,NSPF
NTYP=NGAP(LL)
GO TO(10,20,30),NTYP
11 IF(DIF(LL).LT.A1(LL)) 15,13
23 IF(DIF(LL).GT.A1(LL)) 12,25
15 IF(DIF(LL).GT.A2(LL)) 12,14
25 IF(DIF(LL).GT.A2(LL)) 13,14
12 F(LL)=DIF(LL)*K(LL,1)
GO TO 11
13 F(LL)=K(LL,2)*(DIF(LL)-A1(LL))+K(LL,1)*A1(LL)
GO TO 11
14 F(LL)=30000000.0*(DIF(LL)-A2(LL))+
1K(LL,NTYP)*(A2(LL)-(NTYP-1)*A1(LL))+(NTYP-1)*K(LL,1)*A1(LL)
IF(K(LL,2).EQ.0.0) F(LL)= 1.0-EXP(A2(LL)-DIF(LL))
GO TO 11
30 F(LL)=K(LL,1)*(DIF(LL)**3)
11 CONTINUE
RETURN
END

SUBROUTINE DIFFUN(NN,TT,Y,YDOT)

```

C
C THIS ROUTINE DETERMINES VECTOR YDOT AT TIME TT, GIVEN THE VALUE OF Y.
C YDOT=(D1X,D2X) I.E. THE VELOCITIES AND ACCELERATIONS OF THE MASSES.
C Y=(X,D1X) I.E. THE DISPLACEMENTS AND VELOCITIES.
C
COMMON/CINT/T,DT,JS,JN,DXA(250),XA(250),IO,JS4
COMMON/CPR/NPR,NCPR,L(10,14),STP(10,24),STR(5,250),NS,TPRNT,KOUT
COMMON/ORD/XX1(32,1000)
COMMON/PLT/POUT
COMMON/CASE/TITLE(8)
COMMON/TIME/PRI,FINTIM,NTIME,TINT,ME(H,ERR,CPT
COMMON/PRT/A,BINT,B,FRQ,ALPHA1,NSTEP,NFUN
COMMON/CONST/TWOPI,TAU,IWAVE
COMMON/CMAIN/NOR,NCOF,NSTART
COMMON/M/NM,SCAL, PH(70),NGAP(71),PK(71),C(71),K(71,2),XINT(70)
COMMON/M/ D1XINT(70),D2XINT(70),A1(71),A2(71),DIF(71),DIF1(71)
COMMON/M/ D1X(70),D2X(70),F(71),XOL,XOR,X(70)
COMMON/CCOEF/UMU,CW(70)
LEVEL 2,XX1
DIMENSION Y(NN),YDOT(NN)
TWOPI=4.*ASIN(1.)
NSPR=NM+1
CALL SHOK(TT,XOL,D1XL,XOR,D1XR)
DO 14 I=1,NM
X(I)=Y(2*I-1) $ D1X(I)=Y(2*I)
14 CONTINUE
3 DIF(1)=X(1)-XOL $ DIF(NM+1)=XOR-X(NM)
DIF1(1)=D1X(1)-D1XL $ DIF1(NM+1)=D1XR-D1X(NM)
DO 10 I=2,NM
DIF1(I)=D1X(I)-D1X(I-1)
10 DIF(I)=X(I)-X(I-1)
CALL FORCE(NSPR)
IF(NFUN.EQ.4) F(2)=A*COS(TAU)-10*G.0*DIF(1)
DO 13 N=1,NM
CL=C(N) $ CR=C(N+1)
IF(NGAP(N).EQ.2.AND.DIF(N).GT.A1(N)) CL=C.1
IF(NGAP(N+1).EQ.2.AND.DIF(N+1).GT.A1(N+1)) CR=D.0
D2X(N)=(F(N+1)-F(N)-DIF1(N)*CL+DIF1(N+1)*CR+(XOL-X(N))*CW(N))/PM(N)
1)
13 CONTINUE
DO 15 I=1,NM
YDOT(2*I-1)=D1X(I) $ YDOT(2*I)=D2X(I)
15 CONTINUE
RETURN
END

```

SUBROUTINE PLOTV(TINT,IFINTIM,MFIRST,MLAST)

C
C THIS ROUTINE PLOTS THE QUANTITIES STORED IN XX1. THE VARIABLES STORED
C IN XX1 ARE DETERMINED IN SUBROUTINE #STOPE#.
C

```

COMMON/ORD/XX1(32,1000)
COMMON/CASE/TITLE(8)
COMMON/PRT/A,BINT,B,FRO,ALPHA1,NSTEP,NFUN
COMMON/M/NM,SCAL
COMMON/CMAIN/NOP,NCOF,NSTART
DIMENSION HX1(121),SYMBOL(32)
LEVEL 2,XX1
LOGICAL ED
DATA SYMBOL/1H-,1H.,1H.,1H*,1H+,1HD,1HE,1HF,1HG,1HH,1HJ,1HK,1HL,
1HM,1HN,1HO,1HP,1HQ,1HR,1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HZ,1HA,1HB,1H
2C,1H/,1H(/
ED=.FALSE.
PRINT 5
5 FORMAT(1H1)
PRINT 18,TITLE
18 FORMAT(8A10)
PRINT 29
29 FORMAT(/,/)/
CALL PROUT
PRINT 29
PRINT 11
11 FORMAT(/,4X,6HXOL= -,5X,6HXOP= ,,5X,5HX1= .,5X,5HX2= *,5X,5HX3= +
1,/,14X,* FOR K GT 3 XK= K TH. LETTER IN ALPHABET(I EXCLUDED) *,/,
2,/)
28 DO 13 L=1,121
13 HX1(L)=1H
DO 23 L=1,7
23 HX1(L)=(L-4)*SCAL*2
PRINT 24,(HX1(L),L=1,7)
24 FOPMAT(4X,F10.1,6F20.1)
IF(ED) GO TO 14
DO 1 K=1,IFINTIM
3 DO 2 L=1,120
HX1(L)=1H
2 IF(K.EQ.1.OR.K.EQ.IFINTIM) HX1(L)=1H-
HX1(61)=1HI $ HX1(1)=1HI $ HX1(121)=1HI
TIM=(K-1)*TINT+NSTART*10*TINT
IF(K.EQ.IFINTIM) GO TO 51
LL=MOD(K-1,43)
IF(LL.GT.0) GO TO 22
51 DO 21 L=11,111,10
21 HX1(L)=1HI
22 CONTINUE
DO 31 I=1,2
COORD=XX1(I,K)*10./SCAL+SIGN(0.5,XX1(I,K))
J=INT(COORD)
IF(IABS(J).GE.60) GO TO 31
J=J+61
HX1(J)=SYMBOL(I)
31 CONTINUE
DO 9 I=MFIRST,MLAST
COORD=XX1(I+2,K)*10./SCAL+SIGN(0.5,XX1(I+2,K))

```



```

J=INT(COORD)
IF(ABS(J).GE.60) GO TO 9
J=J+61
HX1(J)=SYMBOL(I+2)
9 CONTINUE
L=MOD(K-1,10)
IF(L.GT.0) GO TO 8
PRINT 4,TIM,HX1
4 FORMAT(1X,F10.2,2X,121A1)
GO TO 1
8 PRINT 6,HX1
6 FORMAT(13X,121A1)
1 CONTINUE
ED=.TRUE.
GO TO 28
14 RETURN
END

```

SUBROUTINE CLEAN

```

C
C- THIS SUBROUTINE ZEROS OUT ALL PERTINANT MEMORY LOCATIONS AT START OF
C EACH RUN.
    DIMENSION IWORDS(21)
    COMMON/CD/STRM(24,300),DATA(10,20),RCT(22),NCF,NCL,LSTR,KNAME(2,20
    )
    COMMON/CINT/T,DT,JS,JN,DXA(250),XA(250),IO,JS4
    COMMON/CPR/N2(1633),TPRNT
    DIMENSION X(7422),X1(506)
    EQUIVALENCE(X(1),STRM(1,1))
    LOGICAL LSTR,JS
    DATA IWORDS/ 2H 1,2H 2,2H 3,2H 4,2H 5,2H 6,2H 7,2H 8,2H 9,2H10,
    12H11,2H12,2H13,2H14,2H15,2H16,2H17,2H18,2H19,2H20,4HCOMP/
C
C- START OF SUBROUTINE
C
    T=0.0
    DO 1 I=1,7422
1      X(I)=0.0
      LSTR=.TRUE.
      JS=.TRUE.
      DO 5 I=1,300
5        STRM(24,I)=1.0E-20
      DO 4 I=1,20
4        KNAME(1,I)=IWORDS(21)
        KNAME(2,I)=IWORDS(I)
C
      DO 2 I=1,506
2        X1(I)=0.0
C
      DO 3 I=1,1633
3        N2(I)=0
      TPRNT=0.0
      RETURN
    END

```

```

SUBROUTINE PRNTF(PRI,FINTIM,DONE,A,B,C,D,E,F,G,O,P,Q)
C
COMMON/CINT/T,DT,JS,JN,DXA(250),XA(250),IO,JS4
C
COMMON/CPR/NPR,NCPR,L(10,14),STP(10,24),STR(5,250),NS,TPRNT,KOUT
C
COMMON/PLT/POUT
COMMON/CHAIN/NOR,NCOF,NSTART
C
INTEGER P
LOGICAL POUT
C
LOGICAL JS,LSTF,DONE,KOUT,NPF
IF(KOUT) GO TO 8
C
C- START OF SUBROUTINE
C
NPR=.FALSE.
IF(TPRNT.EQ.0.0) GO TO 4
IF(T.GE.FINTIM-(0.5*DT)) GO TO 1
2 IF(ABS(T-TPRNT).GT.DT) GO TO 9
3 IF(JS) GO TO 5
IF(JS4.EQ.4) GO TO 5
GO TO 9
4 DONE=.FALSE.
IF(TPRNT.EQ.C.C) TPRNT=TPRNT+NSTART*10*PRI
TPRNT=TPRNT+PRI
5 WRITE(3,10)A,B,C,D,E,F,G,O,P,Q
POUT=.TRUE.
1) FORMAT(1X,8E13.4,I13,E13.4)
NPR=.TRUE.
GO TO 9
1 IF(JS) GO TO 6
IF(JS4.NE.4) GO TO 2
C- THIS SECTION CLEARS THE SYSTEM AT THE END OF THE RUN
6 CONTINUE
TPRNT=C.0
DONE=.TRUE.
DO 7 J=1,250
7 XA(J)=C.0
GO TO 8
C
9 RETURN
END

```