ELASTIC-PLASTIC RESPONSE CHARTS FOR NUCLEAR OVERPRESSURES

by

L. K. Guice, S. A. Kiger

Structures Laboratory

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Waterways Experiment Station, Corps of Engineers
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L. K. Guice and S. A. Kiger

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**ABSTRACT**
The single-degree-of-freedom equation of motion for an elastic-plastic system with forcing functions that are representative of nuclear weapon simulations is nondimensionalized and solved. Numerical solutions are calculated by the Newmark method, and response charts incorporating nondimensionalized structural and loading parameters for the Speicher-Brode nuclear pressure history description are provided. A computer code is presented for solving the elastic-plastic problem for Speicher-Brode overpressure as well as triangular-shaped overpressures.
PREFACE

The preparation of this report was sponsored by the Defense Nuclear Agency (DNA) under Subtask Y99QAXSC, Work Unit 00080, "Key Worker Shelter," and by the Office, Chief of Engineers, U. S. Army, under R&D Project 4A762719AT40, Task AO, Work Unit 008, "Target Response from Low-Yield Nuclear Surface and Subsurface Bursts." Dr. K. L. Goering, DNA, was Technical Monitor.

This report was prepared at the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. James T. Ballard, Acting Assistant Chief, SL, and under the direct supervision of Dr. Jimmy P. Balsara, Acting Chief, Structural Mechanics Division (SMD), SL. This paper was prepared by Mr. L. K. Guice, Associate Professor, Louisiana Tech University, and Dr. S. A. Kiger of the Research Group, SMD.

COL Tilford C. Creel, CE, was Commander and Director of WES during this study and the preparation and publication of this report. Mr. F. R. Brown was Technical Director.
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3
Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

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<td>centimetres</td>
</tr>
<tr>
<td>kilofeet</td>
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<td>kilometres</td>
</tr>
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<td>kilotons (nuclear equivalent of TNT)</td>
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<td>terajoules</td>
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<td>pounds (mass)</td>
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</tr>
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<td>pounds per square inch</td>
<td>6.894757</td>
<td>kilopascals</td>
</tr>
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<td>6.894757</td>
<td>kilopascals/second</td>
</tr>
<tr>
<td>tons (nuclear equivalent of TNT)</td>
<td>4.184</td>
<td>gigajoules</td>
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CHAPTER 1

INTRODUCTION

Very few structures are designed to remain elastic under highly impulsive loads. Systems that are designed to behave elastically under such loads are generally uneconomical and tend to have structural characteristics that attract greater dynamic forces. Consequently, some plastic behavior is desirable for the largest dynamic loads that are anticipated to occur.

The stress distribution in a structure that undergoes a plastic response is complex and difficult to predict. Hence, the design and failure criteria for such structures are generally governed by limitations on response, e.g., deflections and rotations, rather than by limitations on stresses.

This paper presents the mathematical model and the numerical solution for the response of structures that behave as elastic-perfectly plastic systems when subjected to monotonically decaying loads. The loading definition is intended to simulate the pressure-time history of a nuclear pulse with zero rise time and no negative phase.
CHAPTER 2

ANALYTICAL PROCEDURE

2.1 DEFINITIONS OF DUCTILITY
AND RESISTANCE

A measure of the total elastic and plastic deformation in a structure is its ductility. In this paper, ductility will be defined as the ratio of the maximum displacement under a prescribed load to peak elastic displacement, i.e., $x_m/x_y$ in Figure 2.1. The maximum ductility that a structure can sustain without collapse is controlled by its material and geometric characteristics and is an indicator of the amount of energy that can be absorbed prior to failure.

The relationship between static load and deflection, i.e., the resistance function, for many structural elements may be idealized as the elastic-perfectly plastic curve shown in Figure 2.1. For monotonic dynamic loads, it is generally assumed that the resistance function maintains the same characteristic form as for the static situation. However, the magnitudes may be increased to represent the enhanced strength of the material under the high strain rates associated with dynamic loads.

2.2 DESCRIPTION OF LOAD

In the past, nuclear pressure histories have often been represented as simple triangular functions or as superimposed combinations of simple triangles (References 1 and 2). Analyses made with such loading definitions have often proved to be reliable, particularly when the loads are most impulsive or when the duration of the load is large compared to the natural period of the structure. However, when attempting to represent some nuclear weapon loadings, the use of an "equivalent" triangular function introduces significant error. The selection of an appropriate triangle to represent a particular nuclear pulse adds one more degree of uncertainty to the already subjective dynamic analysis.

Analytic approximations to actual nuclear burst overpressures have recently been developed. The most recent expression for the overpressures can

\[ \text{For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix C).} \]
be found in Reference 3 with subsequent modifications by memoranda from the authors. The Speicher-Brode fit relates height of burst, range, time of arrival, positive phase duration, and overpressure for a 1-kiloton\(^2\) (KT) weapon. Calculation of the quantities listed above, as well as positive phase impulse, for a 1 megaton (MT) surface burst weapon are included in Table 2.1 and Figure 2.2. Cube-root scaling can be used to relate the quantities of interest for different weapon yields.

2.3 STRUCTURAL IDEALIZATION

Many structures may be idealized as single-degree-of-freedom (SDOF) spring-mass models in order to determine their fundamental response. More complex structures may be idealized as a combination of spring-mass models that are superimposed by modal superpositioning. The idealized SDOF model used in this paper, as well as the resistance and loading idealizations, are shown in Figure 2.1.

The differential equation of motion for the undamped SDOF model is given below.

\[
mx'' + kx = F(t) \tag{2.1}
\]

where

\[
x = d^2y/dt^2 = \text{acceleration}
\]

and \(kx = r_m\), if plastic response has occurred

Viscous damping is generally not included in the analysis of structures that are subjected to short-duration monotonic loads, particularly when only the peak response is of primary interest. Damping at less than 5 or 6 percent of critical will have only a minor effect on peak response for nonoscillating loads.

Equation 2.1 can be nondimensionalized by a transformation of the independent variables to yield the following equations from Reference 2.

\[
\frac{1}{4\pi^2} \ddot{\eta} + \eta = \frac{F_1}{r_m} f(\xi) , \text{ if elastic,} \tag{2.2}
\]

\(^2\)A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.
and

\[ \frac{1}{4n^2} \ddot{\eta} + 1 = \frac{F_I}{r_m} f(\xi), \]  

if plastic, \hspace{1cm} (2.3)

where

\[ \eta(\xi) = \frac{x(t)}{x_y} \]
\[ \ddot{\eta}(\xi) = \frac{T^2 \ddot{x}(t)}{x_y} \]
\[ \xi = \frac{t}{T} \]
\[ x_y = \text{displacement at first yield} \]
\[ T = 2\pi \sqrt{\frac{m}{k}} = \text{natural period} \]

It should be noted that the specified forcing function in Equations 2.2 and 2.3 implies that pressures may be normalized with respect to a single time parameter. However, the Speicher-Brode loading definition is a function of time and peak overpressure and may not be normalized by a single parameter as illustrated in Figure 2.3. Thus, a separate response chart must be developed for each value of peak overpressure, \( P_s \).

2.4 NUMERICAL SOLUTION

There are several numerical methods for solving the nondimensionalized equations of motion. A method that is frequently applied to problems in structural dynamics is the Newmark \( \beta \) method (Reference 4). This method was selected for numerical analysis because of its flexibility and established criteria for stability and convergence.

From previously defined relationships, we have

\[ x(t) = x_y \eta(\xi) \]
\[ \dot{x}(t) = x_y \ddot{\eta}(\xi)/T \]
\[ \ddot{x}(t) = x_y \dddot{\eta}(\xi)/T^2 \]
\[ \xi = \frac{t}{T} \]

For our initial conditions

\[ \eta_0 = 0 \]

8
The initial value of the acceleration term is
\[ \ddot{\eta}_0 = 0 \]

The Newmark \( \beta \) equations may be written in nondimensionalized form as indicated below:

\[ \eta_{i+1} = \eta_i + \left( \frac{\Delta t}{T} \right) \dot{\eta}_i + \left( \frac{1}{2} - \beta \right) \left( \frac{\Delta t}{T} \right)^2 \ddot{\eta}_i + \beta \left( \frac{\Delta t}{T} \right)^2 \ddot{\eta}_{i+1} \quad (2.5) \]

\[ \ddot{\eta}_{i+1} = \ddot{\eta}_i = 1/2 \left( \frac{\Delta t}{T} \right)(\ddot{\eta}_i + \ddot{\eta}_{i+1}) \quad (2.6) \]

By making an assumption for the acceleration at the \((i+1)\) time step, approximations of the corresponding displacement and velocity terms can be made with the equations above. The resulting displacement can then be inserted into the original differential equation and tested for convergence. The process may be repeated iteratively until convergence is met within a prescribed tolerance.

Criteria for selecting an appropriate normalized time increment \((\Delta t/T)\) should not be based solely upon the value of \( \beta \), i.e., the implied assumption of acceleration between time steps, but should also depend upon the duration of the load. Sufficiently small time steps must be used to provide an appropriate description of the loading function.

As an example of the numerical parameters which might be used: for linear acceleration, \( \beta = 1/6 \); the normalized time increment limit for convergence = 0.389; and the normalized time increment limit for stability = 0.551 (Reference 4). Also, the time increment typically should not exceed about 1/10 of the duration of the load.
Table 2.1. Speicher-Brode relationships for a 1-MT surface burst weapon.

<table>
<thead>
<tr>
<th>PSO - Surface overpressure (psi)</th>
<th>R - Range (kft)</th>
<th>$t_a$ - Time of arrival (ms)</th>
<th>$t_d$ - Positive phase duration (ms)</th>
<th>$I_p$ - Positive phase impulse (psi-ms)</th>
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Figure 2.1. SDOF analytical model.
Figure 2.2. Speicher-Brode relationships for a 1-MT surface burst weapon.
a. Nuclear overpressure decay curve.

b. Normalized pressure history.

Figure 2.3. Typical overpressure decay curves for a specific nuclear weapon at various overpressures.
CHAPTER 3
SOLUTIONS

3.1 RESPONSE CHARTS

Once the differential equations have been nondimensionalized, the solutions can be plotted over specific ranges of the nondimensionalized parameters to produce a practical design tool. Normalized response charts for triangular loads (Reference 2) and bilinear loads (Reference 5) are available in the open literature.

Charted solutions for the Speicher-Brode overpressure description are provided in Figures 3.1-3.9. It should be repeated that because the normalized pressure history definition is a function of two independent variables, i.e., time and peak overpressure, a unique solution to the differential equation cannot be obtained. However, uniqueness was obtained in this case by holding the peak overpressure constant, thereby creating an equation with a single independent variable. As a result, separate charts were plotted for each peak overpressure.

3.2 SOLUTION ACCURACY

Response charts are provided for peak overpressures ranging from 10 psi to 50,000 psi. For design purposes, reasonable accuracy may be obtained at intermediate overpressures by interpolating between the given charts. If more accurate solutions are desired, a computer code is provided in Appendix A that will give numerically accurate solutions for any desired overpressure.

A comparison of solutions obtained from the response charts with solutions obtained from the computer code has indicated that logarithmic interpolation formulas will in general provide more accurate solutions between respective charts. Although linear interpolation between any of the charts will provide reasonable answers, more accurate solutions can sometimes be obtained with logarithmic interpolation formulas. Appropriate interpolation formulas are presented in Table 3.1.

3.3 EXAMPLE PROBLEMS

The number of ways that the response charts may be used are too numerous to sufficiently describe here. In addition to the fact that the user may
enter the charts with several different combinations of input parameters, there are many different ways to arrive at those parameters themselves, e.g., natural period, yield deflection, and maximum resistance. Hence, the following examples are only provided to illustrate the actual mechanics of using the charts. It is assumed that the user will know how to compute the basic properties of the physical model.

In this example, the maximum response is determined for a system with a natural period of 0.300 seconds, a maximum resistance of 10 psi, and a peak elastic deflection of 0.5 inch. The structure is subjected to a 20-KT surface burst weapon at 25 psi.

In the response curves, the natural period of the structure has been normalized with respect to the positive phase duration of the load. To find the positive phase duration for the prescribed loading, see Figure 2.2 ($t_d = 1.6$ seconds).

By cube-root scaling, the duration of a 20-KT weapon is computed as

\[ \frac{t_d}{1.6 \text{ s}} = \left( \frac{20 \text{ KT}}{1,000 \text{ KT}} \right)^{1/3} \]

\[ t_d = 0.434 \text{ s} \]

Computing the response chart input parameters

\[ \frac{t_d}{T} = \frac{0.434}{0.300} = 1.45 \]

\[ \frac{p_s}{r_m} = \frac{25}{10} = 2.50 \]

Now, entering the 10-psi response chart (Figure 3.1)

\[ \mu_{10} = \frac{x_m}{x_y} = 16 \]

and, entering the 50-psi response chart (Figure 3.2)

\[ \mu_{50} = 6.5 \]
Interpolating (Table 3.1)

\[ \mu_{25} = \exp \left[ \frac{\ln \left( \frac{25}{50} \right)}{\ln \left( \frac{10}{50} \right)} \cdot \ln \left( \frac{16}{6.5} \right) + \ln(6.5) \right] = 9.58 \]

The predicted maximum response is

\[ x_m = \mu_{25} x_y = 9.58 \text{ (0.5 inch)} = 4.79 \text{ inches} \]

Similarly, the estimated time to maximum response is

\[ t_m = 0.38 \text{ second} \]

The maximum response as determined directly by computer analysis is indicated in Appendix B. In this case, there is an interpolation error of approximately 2 percent. Using a linear interpolation, the maximum response would be predicted as \( \mu = 12.4 \), which is an error of approximately 32 percent.

In a second example, consider a system with a natural period of 0.50 second and a maximum resistance of 50 psi. Using a 75-KT weapon, the peak overpressure for which the structure can maintain a ductility of 15 may be obtained by the following procedure.

Assume a peak overpressure of 100 psi. From Table 2.1, the positive phase duration for a 1-MT weapon is 1.198 seconds. For a 75-KT weapon, the duration is scaled as follows:

\[ \frac{t_d}{1.198 \text{ s}} = \left( \frac{75 \text{ KT}}{1,000 \text{ KT}} \right)^{1/3} \]

\[ t_d = 0.505 \text{ s} \]

Now, computing the nondimensionalized parameters based on the assumed overpressure

\[ \frac{t_d}{T} = \frac{0.505}{0.050} = 10.1 \]

\[ \frac{P_s}{r_m} = \frac{100}{50} = 2.0 \]

16
Using the 100-psi response chart, a ductility of 28 is read. That is higher than our limiting ductility. Therefore, try a lower peak overpressure of 50 psi (Figure 3.2). The positive phase duration of 1.297 seconds for a 1-MT weapon at 50 psi scales to 0.547 second for a 75-KT weapon.

The new input parameters are

\[ \frac{t_d}{T} = \frac{0.547}{0.050} = 10.9 \]

\[ \frac{P_s}{r_m} = \frac{50}{50} = 1.0 \]

From the 50-psi response chart (Figure 3.2), a much lower ductility of 3.2 is read. Finally, interpolating between the 50- and 100-psi values (Table 3.1)

\[ P_s = \frac{(15 - 3.2)}{(28 - 3.2)} \times (100 - 50) + 50 \]

\[ P_s = 74 \text{ psi} \]

The correct solution was determined by computer analysis to be approximately 77 psi. The interpolation error is approximately 4 percent.

3.4 COMPUTER CODE

The code provided in Appendix A was written in Fortran for the Tektronix 4081. It is an interactive code that has been modularized to minimize memory requirements. The code should be easily adaptable to other machines with modification or elimination of the plot routines and overlay structure. The user should also find it quite simple to add alternate loading definitions to the code, if so desired.

Upon initialization of the program, a list of the available user options is displayed to the screen. These options and a brief description of each follow. A sample session is included in Appendix B.

X - EXIT PROGRAM - The user may exit the program any time there is a request to SELECT OPTION.
A - ANALYZE - The Newmark $\beta$ analysis is performed and results are displayed. A complete response history including normalized displacements, velocities, and accelerations may be optionally displayed.

D - DISPLAY DATA - All numerical parameters, the current loading description, and structural parameters are displayed to the screen.

H - HELP - A list of the available options is provided upon request.

I - INITIAL PASS - This option assists the new user in making a first run through the program. The experienced user may find it to be a beneficial option when no modifications in the numerical parameters are required prior to analysis.

L -LOADING FUNCTION - The user may select a Speicher-Brode or triangular loading description. The weapon, peak overpressure, and height of burst are requested if the Speicher-Brode description is selected. Peak overpressure and duration are requested for the triangular function.

N - NUMERICAL PARAMETERS - Certain numerical parameters may be changed by the user. The values of Beta, the integration increment, the convergence tolerance, and the number of pressure stations to be computed may be changed by selecting this option. Default values are displayed.

O - OUTPUT DEVICE - When large quantities of data are to be output, the user may select for that data to be routed to the printer.

P - PLOT - Normalized displacements, velocities, accelerations, and a description of the loading function may be displayed in graphical form upon request.

S - SET VALUES FOR ANALYSIS - The natural period of the structure and its peak resistance are requested by this option.

T - TITLE - Output data and plots display a title that may be changed by selecting this option.
### Table 3.1. Interpolation formulas.

<table>
<thead>
<tr>
<th>Type of Interpolation</th>
<th>To Find</th>
<th>Formula</th>
<th>Suggested Ranges (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>μ</td>
<td>$\mu_p = \frac{(P_s - P_{s1})}{(P_{s2} - P_{s1})} \cdot (\mu_2 - \mu_1) + \mu_1$</td>
<td>50-100</td>
</tr>
<tr>
<td></td>
<td>$P_s$</td>
<td>$P_s = \frac{(\mu_{ps} - \mu_1)}{(\mu_2 - \mu_1)} \cdot (P_{s2} - P_{s1}) + P_{s1}$</td>
<td></td>
</tr>
</tbody>
</table>

**Natural logarithmic**

| μ | $\mu_p = \exp \left\{ \frac{\ln \left( \frac{P_s}{P_{s2}} \right)}{\ln \left( \frac{P_{s1}}{P_{s2}} \right)} \cdot \ln \left( \frac{\mu_1}{\mu_2} \right) + \ln(\mu_2) \right\}$ | 10-50 |
|   | $P_s = \exp \left\{ \frac{\ln \left( \frac{\mu_{ps}}{\mu_2} \right)}{\ln \left( \frac{\mu_1}{\mu_2} \right)} \cdot \ln \left( \frac{P_{s1}}{P_{s2}} \right) + \ln(P_{s2}) \right\}$ | 100-200 |

**Natural logarithmic**

Notation:  
- $P_s$ - overpressure for which solution is desired  
- $P_{s1}$ - overpressure of response chart before $P_s$  
- $P_{s2}$ - overpressure of response chart after $P_s$  
- $\mu_{ps}$ - ductility at desired overpressure  
- $\mu_1$ - ductility from response chart before $P_s$  
- $\mu_2$ - ductility from response chart after $P_s$
Figure 3.1. Maximum response of an elastic-plastic system subjected to a 10-psi Speicher-Brode pulse.
Figure 3.2. Maximum response of an elastic-plastic system subjected to a 50-psi Speicher-Brode pulse.
Figure 3.3. Maximum response of an elastic-plastic system subjected to a 100-psi Speicher-Brode pulse.
Figure 3.4. Maximum response of an elastic-plastic system subjected to a 200-psi Speicher-Brode pulse.
Figure 3.5. Maximum response of an elastic-plastic system subjected to a 500-psi Speicher-Brode pulse.
Figure 3.6. Maximum response of an elastic-plastic system subjected to a 1,000-psi Speicher-Brode pulse.
Figure 3.7. Maximum response of an elastic-plastic system subjected to a 10,000-psi Speicher-Brode pulse.
Figure 3.8. Maximum response of an elastic-plastic system subjected to a 20,000-psi Speicher-Brode pulse.
Figure 3.9. Maximum response of an elastic-plastic system subjected to a 50,000-psi Speicher-Brode pulse.
The analysis and design of structures to resist loadings from nuclear weapons involve many parameters that are difficult to define. However, if those unknowns can be determined or at least approximated, then a straightforward solution can be readily obtained.

Two different ways for arriving at that solution for elastic-plastic systems with simulated nuclear loading definitions have been provided in this paper. The computer solution offers a quick and accurate way to investigate the effects of different parameters on the response. However, if a computer is not readily available or if a rough approximation to the numerically accurate solution is adequate, then the response charts are most beneficial. The response charts provide an efficient method for preliminary design calculations and for parametric investigations into such things as the effect of peak overpressure, weapon yield, structural resistance, and structural stiffness on the maximum response of a structure.

The charts do provide numerically accurate solutions for the specified overpressures, but interpolation to those overpressures not included on a chart does introduce some error into the analysis.
REFERENCES


3. S. J. Speicher and H. L. Brode; "Airblast Overpressure Analytical Expression for Burst Heights, Range and Time--Over an Ideal Surface"; PSR Note 385, November 1981; Pacific Sierra Research, Santa Monica, California.


APPENDIX A

COMPUTER CODE LISTING
C PROGRAM FOR DETERMINING THE NORMALIZED RESPONSE OF AN SDOF ELASTIC-PLASTIC MODEL SUBJECTED TO A SPEICHER-BRODE OR A TRIANGULAR PULSE. RESPONSES ARE NORMALIZED BY THE ELASTIC DEFLECTION. LES GUICE AUGUST 1983

C************************************************************************************************************
C IMPLICIT INTEGER*2(I-, INTEGER*1 TITLE(72)
C DIMENSION P(250),RNU(501),RNUD1(501),RNUDD(501)
C DATA
C C
C INITIALIZE ALL VALUES
C
C CALL GRSTRT(9) CALL BFACT(0,'USR:ANLQLY.LIB')
1 LUO=6 JOP=4 IPASS=0 NSTP=501 NST=500 NT=250 NP=250 W=1000.0 PTK=100.0 HOBK=0.0 BT=0.16667 TOL=1.0E-3 T11=0.01 T12=0.01 TN=1.0 RMX=1.0
10 CALL OVRLNK('HELPOP ',LUO)
C
98 CALL OVRLNK('GETOPT ',NOPT,JOP)
GO TO(99999,1000,2000,10,3000,3000,4000,5000,6000,17000,8000),JOP
C
C ANALYZE BY NEWMARK BETA METHOD
C
1000 CALL OVRLNK('NEWMRK ',LUO,P,NP,RNU,RNUU,RNUDD,NSTP,NST, 1 TD,TN,T11,T12,PTK,SRM,BT,TOL,NNU,TINC)
IPASS=2 GO TO 98
C
C DISPLAY DATA
C
2000 CALL OVRLNK('DISPOP ',LUO,JOP,LFUNC,W,PTK,TD,TA,R,HOBK,TN,SRM, 1
1 DPT,P,NT,LPK,TITLE,BT,TI1,TI2,TOL,NP)
   IF(JOP.EQ.5)GO TO 7000
   GO TO 98
C
C  LOADING FUNCTION
C
3000 CALL OVLINK('LOADOP ',LUO,JOP,LFUNC,W,PKT,TD,TAT,VAR,HOBK,DPT,
   1   P,NT,NP)
   IPASS=1
   IF(JOP.EQ.5)GO TO 2000
   GO TO 98
C
C  NUMERICAL PARAMETERS
C
4000 CALL OVLINK('NUMOP ',LUO,BT,TI1,TI2,TOL,NP)
   GO TO 98
C
C  OUTPUT DEVICE
C
5000 CALL OVLINK('OUTOP ',LUO)
   GO TO 98
C
C  PLOT RESULTS
C
6000 CALL OVLINK('PLOTOP ',LUO,TITLE,NU,NUD,NUDD,NSTF,
   1   F,FNTPNP,FNP,TINC,IPASS)
   GO TO 98
C
C  SET VALUES FOR ANALYSIS
C
7000 CALL OVLINK('SEIOF ',LUO,TPN,XTM)
   IF(JOP.EQ.5)GO TO 1000
   GO TO 98
C
C  TITLE
C
8000 CALL OVLINK('TITLE ',TITLE)
   GO TO 98
C
C  EXIT PROGRAM
C
99999 STOP
END
SUBROUTINE HELPOP(LUO)
IMPLICIT INTEGER*2(I-N+0)
CALL VTSCA(3)
CALL HIBRN8(1)
WRITE(LUO,*) ' NORMALIZED RESPONSE OF AN SDOF ELASTIC-
PLASTIC MODEL'
WRITE(LUO,*) ' NOTE: DEFAULT UNITS ARE INCHES, POUNDS, AND SEC'
WRITE(LUO,*) ' UNLESS OTHERWISE SPECIFIED.'
WRITE(LUO,*) ' AVAILABLE OPTIONS:'
WRITE(LUO,*) ' X - EXIT PROGRAM'
WRITE(LUO,*) ' A - ANALYZE'
WRITE(LUO,*) ' D - DISPLAY DATA'
WRITE(LUO,*) ' H - HELP'
WRITE(LUO,*) ' I - INITIAL PASS'
WRITE(LUO,*) ' L - LOADING FUNCTION'
WRITE(LUO,*) ' N - NUMERICAL PARAMETERS'
WRITE(LUO,*) ' O - OUTPUT DEVICE'
WRITE(LUO,*) ' P - PLOT'
WRITE(LUO,*) ' S - SET VALUES FOR ANALYSIS'
WRITE(LUO,*) ' T - TITLE'
RETURN
END

SUBROUTINE GETOPT(NOPT,JOP)
IMPLICIT INTEGER*2(I-N+0)
INTEGER*2 JOPT(N)
DATA JOPT/"X","A","D","H","I","L","N","O","P","S","T"
WRITE(6,*) ' SELECT OPTION: (X,A,D,H,I,L,N,O,P,S,T)'
CALL READC(IOPT,0,0)
WRITE(6,*) ' I=1,NOPT
IF(IOPT.EQ.JOPT(I))JOP=I
RETURN
END
SUBROUTINE NEWMRK(LUOPPNTNPRNUpRNUDDNSTPNST,
1      TD,TN,TI1,TI2,PKT,RMX,BT,TOL,RNU,TINC)

C THIS SUBROUTINE IS USED TO INTEGRATE THE SDOF EQUATIONS
C OF MOTION BY THE NEWMARK-BETA METHOD

IMPLICIT INTEGER*2(I-N)
DIMENSION P(NT),RNU(NSTP),RNUD(NSTP),RNUDD(NSTP)
DATA INO/'N' /
PI=3.1415927
ANUM=4.0*PI**2.0

C COMPUTE MAXIMUM RESPONSE FOR THE RATIO OF TD/TN AND PKT/RMX
POR=PKT/RMX

C DETERMINE TIME INCREMENT TO SATISFY CONVERGENCE AND
C PROPER DESCRIPTION OF LOADING FUNCTION

TI=TI1
TINC=TI*TN
IF(TD.GT.TN)GO TO 1000
TI=TI2
TINC=TI*TD

C SET INITIAL VALUES OF NORMALIZED DISPLACEMENT(RNU),
C VELOCITY(RNUD), AND COMPUTE INITIAL ACCELERATION(RNUDD)

RNU(1)=0.0
RNUMX=RNU(1)
TMXT=0.0
RNUD(1)=0.0
RNUDD(1)=ANUM*POR
TIDTN=TINC/TN

C PERFORM THE INTEGRATION ITERATIVELY
C BY ASSUMING AN ACCELERATION AND CHECKING CONVERGENCE

DO 1500 J=IPNST
   RNUDD(JJ)=RNUDD(J)
C DETERMINE THE NORMALIZED PRESSURE THIS TIME STEP
CALL PRESS(P,NSTP,TD,JJ,TINC,SI,FT)
C COMPUTE NORMALIZED DISPLACEMENT AND VELOCITY
1100 RNU(JJ)=RNU(J)+TIDTN*RNUD(J)+TIDTN*TIDTN*(0.5-BT)*RNUDD(J)+
      1      TIDTN*TIDTN*BT*RNUDD(JJ)
RNUD(JJ)=RNUD(J)+0.5*TIDTN*(RNUDD(JJ)+RNUDD(JJ))
TMU=RNU(JJ)
C DETERMINE IF RESPONSE IS IN PLASTIC RANGE
IF(RNU(JJ).GT.1.0)TNLJ=1.0
C CHECK CONVERGENCE
RNUCK=ANUM*(FT*POR-TNU)
IF(ABS(RNUCK-RNUDD(JJ)).LE.TOL)GO TO 1200
IF(RNUCK,EQ,RNUDD(JJ))GO TO 1200
C NOT CONVERGED, ASSUME NEW ACCELERATION
RNUDD(JJ)=RNUCK
GO TO 1100
C CONVERGED, DETERMINE IF A MAXIMUM
1200 IF(RNU(JJ).LE.RNU(J))GO TO 2000
RNUMX=RNU(JJ)
TM=SI
FM=FT
NNU=JJ
1500 CONTINUE
WRITE(LU0,*)' CAUTION: SOLUTION NOT CONVERGED!
C
C DISPLACEMENT IS DECREASING, MAX. AT PREVIOUS STEP
C WRITE OUT RESULTS OF ANALYSIS
2000 WRITE(LU0,*)'
WRITE(LU0,*)' MAXIMUM DUCTILITY =',RNUMX
WRITE(LU0,*)' OCCURS AT TIME =',TM
WRITE(LU0,*)' NORMALIZED PRESSURE AT THIS TIME =',FM
WRITE(LU0,*)'
WRITE(LU0,*)' NATURAL PERIOD =',TN
WRITE(LU0,*)' LOAD DURATION =',TD
WRITE(LU0,*)' TIME INCREMENT =',TINC
WRITE(LU0,*)'
WRITE(6,*)' COMPLETE HISTORY? (Y/N):'
CALL READC(IANS,0,0)
WRITE(6,*)'
IF(IANS.EQ.0)RETURN
WRITE(LU0,*)'
WRITE(LU0,*)' NOTE: RESPONSES ARE NORMALIZED:
WRITE(LU0,*)'
WRITE(LU0,*)' TIME DISP VEL ACC
T=0.0-TINC
DO 2500 I=1,JJ
T=T+TINC
2500 WRITE(LU0,2510)T,RNU(I),RNU(I),RNU(I)
2510 FORMAT(2(2X,F10.5),2(2X,F10.5))
WRITE(LU0,*)'
RETURN
END
SUBROUTINE PRESS(P, NT, NP, TD, JJ, TINC, SI, FT)

SUB FOR COMPUTING NORMALIZED PRESSURE AT A GIVEN TIME STEP

IMPLICIT INTEGER*2(I-N,*)
DIMENSION P(NT)

SI = REAL TIME FOR THIS STEP
SID = NORMALIZED TIME AT END OF DURATION
FT = NORMALIZED PRESSURE AT GIVEN TIME
TINC = TIME INCREMENT
DELT = TIME INCREMENT BASED ON NUMBER OF PRESSURE STATIONS

SI = TINC*FLOAT(JJ - 1)
IF TIME IS BEYOND POSITIVE DURATION, SET PRESSURE = 0
IF(SI.LT.TD)GO TO 500
FT=0.0
RETURN

FIND PRESSURE STATION ON EITHER SIDE OF GIVEN TIME
DELT = TD/FLOAT(NP-1)
IST1=INT2(SI/DELTT)+1
ST1=FLOAT(IST1)
ST2=ST1+1.0
IST2=IST1+1
P11=P(IST1)
P12=P(IST2)
TST1=(ST1-1.0)*DELT
TST2=TST1+DELT

INTERPOLATE TO FIND PRESSURE THIS TIME STEP
FT=(P11-P12)*(SI-IST2)/(TST1-TST2)+P12
RETURN

END
SUBROUTINE DISPOP(LUO,JOP,LFUNC,W,PKT,T,A,R,HOBK,TN,RMX,  
  DPT,P,NT,P,PKT,TITLE,BT,TI1,TI2,TOL,TP)
IMPLICIT INTEGER*2(I-N,*
INTEGER*2 IFU(3)
INTEGER TITLE(72)
DIMENSION P(NT)
DATA INO/'N '/,IFU/'S '?,'T '?,'X '/
C DISPLAY DATA
C WRITE(LUO,**)
WRITE(LUO,2010)(TITLE(I),I=1,72)
2010 FORMAT(1X,72A1)
WRITE(LUO,**)
WRITE(LUO,**)  NUMERICAL PARAMETERS:
WRITE(LUO,**)  BETA = ',BT
WRITE(LUO,**)  INTEGRATION INTERVAL =',TI,' OF PERIOD'
WRITE(LUO,**)  INTEGRATION INTERVAL =',TI2,' OF DURATION'
WRITE(LUO,**)  TOLERANCE =',TOL
WRITE(LUO,**)  NUMBER OF PRESSURE STATIONS =',NP
WRITE(LUO,**)
WRITE(LUO,**)  LOAD DESCRIPTION:
IF(LFUNC.EQ.IFU(1))GO TO 2050
IF(LFUNC.EQ.IFU(2))GO TO 2100
GO TO 2200
2050 WRITE(LUO,**)  WEAPON (KT)='W
2100 WRITE(LUO,**)  PEAK OVERPRESSURE =',PKT
WRITE(LUO,**)  POSITIVE PHASE DURATION =',TD
IF(LFUNC.EQ.IFU(2))GO TO 2200
WRITE(LUO,**)  TIME OF ARRIVAL =',TA
WRITE(LUO,**)  RANGE (KFEET) =',R
WRITE(LUO,**)  HEIGHT OF BURST (KFEET) =',HOBK
IF(JOP.EQ.5)GO TO 2250
2200 WRITE(LUO,**)
WRITE(LUO,**)  STRUCTURE DESCRIPTION:
WRITE(LUO,**)  NATURAL PERIOD =',TN
FREQ=1.0/TN
WRITE(LUO,**)  FREQUENCY =',FREQ
WRITE(LUO,**)  PEAK RESISTANCE =',RMX
2250 WRITE(LUO,**)
WRITE(6,**)  PRESSURE-TIME HISTORY? (Y/N)'
CALL READC(IANS,0,0)
WRITE(6,**)
IF(IANS.EQ.INO)RETURN
T=0.0-DPT
WRITE(LUO,**)
WRITE(LUO,**)  TIME PRESSURE NORMALIZED'
WRITE(LUO,**)
DO 2300 I=1,NT
PTPKT=P(I)*PKT
T=T+DPT
2300 WRITE(LUO,2310)T,PTPKT,P(I)
2310 FORMAT(3(2X,F10.4))
RETURN
END
SUBROUTINE LOADOP(LUOPJOP,LFUNC,WP,PKT,TD,TA,HOBK,DPT,P,NT,NP)
IMPLICIT INTEGER*2(I-N,N)
INTEGER*2 IFU(3)
DIMENSION P(NT)
DATA IFU//"S"/"T"/"X"

LOADING FUNCTION

WRITE(6,*)' SELECT SPEICHER-BRODE, TRIANGULAR, OR EXIT: (S,T,X)'
CALL READC(LFUNC,0,0)
WRITE(6,*)' OR EXIT: (S,T,X)'
DO 3100 I=1,3
IF(LFUNC.EQ.IFU(I))IFUOP=I
CONTINUE
GO TO(3200,3300,3500),IFUOP
3200 WRITE(6,*)' ENTER WEAPON(KT):'
READ(5,*) W
WRITE(6,*)' ENTER PEAK OVERPRESSURE:'
READ(5,*) PKT
WRITE(6,*)' ENTER HEIGHT OF BURST(KFEET):'
READ(5,*) HOBK
CALL BRODEPF,P,TD,DPT,W,PKT,NT,NP,HOBK,TA)
TD=TD/1000.0
TA=TA/1600.0
DPT=DPT/1000.0
GO TO 3400
3300 WRITE(6,*)' ENTER PEAK OVERPRESSURE:'
READ(5,*) PKT
WRITE(6,*)' ENTER DURATION:'
READ(5,*) TD
CALL BIGGS(P,NT,NP,TD,DPT,PKT)
3400 READ(5,3410) IDUMMY
3410 FORMAT(A2)
3500 RETURN
END
C*TITLE FILED IN BRODEP
SUBROUTINE BRODEP(PEST, DP, DT, W, P, NPTS, NP, HOBK, R, TA)
IMPLICIT INTEGER *2(I-N)
DOUBLE PRECISION XP, YP, DPP

C C
C DIMENSION PEST(NPTS)
C C TA ARRIVAL TIME (MSEC)
C RANGE IN KFEET
C DP POSITIVE PHASE DUR. (MSEC)
C DT INCREMENT BETWEEN PRESSURE STATIONS
IONE = 0
W13 = W**(1./3.)
YP = HOBK/W13
DTT = DT/W13

XP = ((1.58 * 2. * W / P) ** (1. / 3.))/W13
10 CALL PT(XP, YP, DTT, PEST(1), DPP, IONE, NPTS, NP, TA)
   IF (ABS(PEST(1)/P - 1.) .LE. 5.E-5) GO TO 20
   CALL PT(XP*1.00001, YP, DTT, EST, DPP, IONE, NPTS, NP, TA)
   XP = XP + (PEST(1) - P) * 0.00001 * XP / (PEST(1) - EST)
   GO TO 10
20 R = XP*W13
IONE=1
CALL PT(XP, YP, DTT, PEST, DPP, IONE, NPTS, NP, TA)
DP = DPP*W13
TA = TA*W13
C NOTE - REDEFINATION OF DT BELOW - LKG 7/83
DT=DTT*W13
C C
RETURN
END
C$TITLE FILED IN PT
SUBROUTINE PT(XPYPDTTPDP, IPPNPTPNPPTAS)
C
C THIS IS AN IMPLEMENTATION OF THE SPEICHER AND BRODE
C OCT 1981 P(TvXvY) NUC, HISTORY
C REF. PSR NOTE 385 WITH MOD FOR P ABOVE 10000 PSI
C WALKER NOV.17-1982
C
C INPUT PARAMETERS
C X = RANGE (KFT/W**1/3)
C Y = Hob (KRT/W**1/3)
C T = TIME AFTER TIME OF ARRIVAL (MSEC)
C IP = 0 FOR PEAK PRESSURE ONLY
C DTT = TIME STEP SCALED (MSEC/W**1/3)
C
C OUTPUT PARAMETERS
C
C P = PRESSURE*TT(PSI)
C DP = POSITIVE PHASE DURATION (MSEC)
C ***NOTE T IS CHANGE IN THIS ROUTINE.

IMPLICIT INTEGER*2 (I-N*)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)

REAL Py
DIMENSION P(NPT)

C XLEAST=1 .E-4-
YLEAST=1 .E-4
ZLEAST=1 .E-4
ZMOST= 100.
IF(X.LT.XLEAST) X=XLEAST
IF(YLT..YLEAST) Y=YLEAST
R=DSQRT(X*X+Y*Y)
Z=Y/X
IF(Z.LT.ZLEAST) Z=ZLEAST
IF(Z.GT.ZMOST) Z=ZMOST
CALL PPEAK(XvYvRvZ,'EL.TAP)
P(1)=DELTAP
IF(IP.EQ.0) RETURN
XM=170.*Y/(1+.337.*Y**.25)+.914*Y**.5
U=(.543-21.8*R+386.*R*R+2383.*R**R)*R**R
UD=2.99E-14-(1.91E-10*R*R)+(1 .032E-6*R**4)-(4.43E-6*R**6)+
& (1.028+(2.087*R)+(2.69*R*R])*R**R
U=U/UD
TA=U
IF(X.LT.XM)GO TO 200
W=(1.086-34.605*R+486.3*R*R+2383.*R**R)*R**R
& (1.632+2.629*R+2.69*R*R)*R**R
W=W/WD
TA=(U*XM/X)+(W*(1.-XM/X))

200 CONTINUE
S = 1.-1.1E10*(Y**7)/(1.+1.1E10*Y**7)-(2.441E-8*Y**Y/
& (1.+9.11E10*Y**7))*(1./4.41E-11+X**10))
F = (.01495*(TA**.75)/(1.+.005836*TA)+7.402E-5*(TA**2.5)/
& (1.+1.429E-5*TA**4.75)-.216)*S +.7076-3.077E-5*TA*TA*TA/
& (1.+4.36E-5*TA**2.5)
G = 10.+(77.8-64.99*(TA**.125)/(1.+.04348*DSQRT(TA)))**S
\[ H = 2.753 + 0.05601 \frac{TA}{(1 + 1.473E-9 \times TA^{2})} + (1.13207E-10 \times TA^{2.25}) - 0.03292 \frac{(TA^{0.25})}{(1 + 1.914E-8 \times TA^{4})} \]
\[ DP = \left( \frac{1640700 + 24629 \times TA + 416.15 \times TA \times TA}{(10880 + 619.76 \times TA + TA \times TA)} \right) \]
\[ H = 2.753 + 0.05601 \frac{TA}{(1 + 1.473E-9 \times TA^{5})} + (1.13207E-10 \times TA^{2.25}) \]
\[ DP = \left( \frac{1640700 + 24629 \times TA + 416.15 \times TA \times TA}{(10880 + 619.76 \times TA + TA \times TA)} \right) \]

**C**

**NOTE MODIFICATION BELOW**

**C**

**COMPUTE TIME STEP BY DIVIDING THE POSITIVE PHASE DURATION**

**C**

**BY THE NUMBER OF DESIRED TIME STEPS**

**C**

\[ DTT = DP / \text{FLOAT(NP-1)} \]
\[ DO 500 I = 1, NP \]
\[ T = TA + (DTT *(I-1)) \]
\[ B = (F \times (TA/T))^{G} + (1 - F) \times (TA/T)^{H} \times (1 - (T-TA)/DP) \]
\[ IF (X \lt X_{M} \text{ OR } Y' \gt 0.35) \text{ GO TO 1000} \]
\[ XE = 3.039 \times Y/(1 + 6.7 \times Y) \]
\[ E = \text{DABS}((X-XM)/(XE-XM)) \]
\[ IF (E \gt 50.) \text{ E=50.} \]
\[ D = 0.23 \times 5830000 \times (26667 + 1000000 \times Y \times Y) + 0.27 \times E^{2} \times (5 - 5830000 \times Y \times Y) / (26667 + 1000000 \times Y \times Y)^{5} \]

**C**

**NOTE MODIFICATION BELOW**

**C**

**NORMALIZE ALL PRESSURES BY DIVIDING BY PEAK PRESSURE**

**C**

\[ P(I) = \text{DELTAP} \times (1 + A) \times (B \times V + C) \]

**GO TO 495**

**1000 CONTINUE**

**P(I) = \text{DELTAP} \times B**

**C**

**NOTE MODIFICATION BELOW**

**C**

**CONTINUE**

**495 CONTINUE**

**P(I) = P(I) / \text{DELTAP}**

**500 CONTINUE**

**TAS = TA**

**RETURN**

**END**
SUBROUTINE PPEAK(X, Y, R, Z, DELTAP)

C SUB FOR PEAK OVERPRESSURE BY SPEICHER AND BRODE, SEPT. 1980
C MOD BY WALKER FROM MOD BY SPEICHER AND BRODE MARCH 1991
C RANGE TO 0.1 PSI

INPUT PARAMETERS
C X = RANGE (KFT/KT**1/3)
C Y = H (KFT/KT**1/3)
C R = SQRT(X**2 + Y**2) (KFT/KT**1/3)
C Z = Y/X

OUTPUT
C DELTAP = PEAK PRESSURE (PSI)

IMPLICIT INTEGER*2 (I-N)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)

A = 1.22 - (3.908*Z*Z)/(1 + 810.2*Z**5)
B = 2.321 + (Z**18)/(1 + 1.113*Z**18)**6.195 - (0.03831*Z**17)/
(1 + 0.02415*Z**17) + 6692/(1 + 4164*Z**8)
C = 4.153 - (1.149*Z**18)/(1 + 1.641*Z**18) - 1.1/(1 + 2.771*Z**2.5)
D = -4.166 + (25.76*Z**11.75)/(1 + 1.382*Z**18) + 8.257*Z/(1 + 3.219*Z)
E = 1.1 - (0.04642*Z**18)/(1 + 0.03886*Z**18)
F = 0.6096 + (2.879*Z**9.25)/(1 + 2.359*Z**14.5) - 17.15*Z/Z/
(1 + 71.66*Z**Z)
G = 1.83 + 5.361*Z/Z/(1 + 3139*Z**6)
H = - (64.67*Z**5 + 2905)/(1 + 441.5*Z**5) - 1.389*Z/(1 + 49.03*Z**5) +
(8.808*Z**11.5)/(1 + 154.5*Z**3.5) + (0.0144*R*R/(1 + 158*R + 0.486*+
R**1.5 + 0.0128*R*R))**(1/(1 + 2*Y))

DELTA P = 10.47/(R**A) + B/(R**C) + D/E/(1 + F*R**G) + H
RETURN
END
SUBROUTINE BIGGS(P, NT, NP, TD, DTT, PKT)

C
C GENERATE NONDIMENSIONALIZED PRESSURES FOR TRIANGULAR PULSE
IMPLICIT INTEGER*2(I-N+1)
DIMENSION P(NT)

DTT = TD / FLOAT(NP-1)
P(1) = PKT / PKT

DO 500 I = 1, NT

500 P(I) = P(1) - (I-1) * DTT / TD

RETURN
END
SUBROUTINE NUMOP(LUOP,BT,TI1,TI2,TOL,NP)

C NUMERICAL PARAMETERS

IMPLICIT INTEGER*2(I-NP)
INTEGER*2 NUOP(5)
DATA NUOP/'B ', 'I ', 'T ', 'N ', 'X '/
NOP=5
NUMOPT=5

WRITE(6,**)' SELECT NUMERICAL PARAMETER: (B, I, T, N, X)
WRITE(6,**)' B - BETA'
WRITE(6,**)' I - INTEGRATION INCREMENT'
WRITE(6,**)' T - TOLERANCE'
WRITE(6,**)' N - NUMBER OF PRESSURE STATIONS'
WRITE(6,**)' X - EXIT'

CALL READC(IOPT=0,0)
WRITE(6,**)' NUMOPT=5
DO 10 I=1,NOP
10 IF(IOPT.EQ.NUOP(I)) NUMOPT=I
GO TO(100,200,300,400,500), NUMOPT

WRITE(6,**)' ENTER BETA: (LINEAR ACCELERATION = 0.16667)
READ(5,**)BT
GO TO 498

WRITE(6,**)' ENTER TIME INCREMENT/PERIOD: (TI/TN = 0.01)
READ(5,**)TI1
WRITE(6,**)' ENTER TIME INCREMENT/LOAD DURATION: (TI/TD = 0.01)
READ(5,**)TI2
GO TO 498

WRITE(6,**)' ENTER CONVERGENCE TOLERANCE: (TOL. = 1E-3)
READ(5,**)TOL
GO TO 498

WRITE(6,**)' ENTER NUMBER OF PRESSURE STATIONS: (MAX. = 250)
READ(5,**)NP

498 READ(5,499)IDUMMY
499 FORMAT(A2)
500 RETURN
END

45
SUBROUTINE OUTOP(LUO)
IMPLICIT INTEGER*2(I-N,*)
INTEGER*2 JDEV(2)
DIMENSION P(250),RNU(1001),RNUD(1001),RNUDD(1001)
DATA JDEV/'T ', 'P '/

C OUTPUT DEVICE

C 5000 WRITE(6,*)' SELECT TERMINAL OR PRINTER: (T,P)'
    CALL READC(IDEV,0,0)
    WRITE(6,*)'
    IF(IDEV.EQ.JDEV(1))LUO=6
    IF(IDEV.EQ.JDEV(2))GO TO 5100
    RETURN

5100 LUO=8
    CALL ASSIGN('LP: ',LUO,ISTAT)
    RETURN
END
SUBROUTINE PLOTOP(LUO,TITLE,RNU,RNUD,RNUDD,NSTP,
  I P,NT,NP,TD,NNU,TINC,IPASS)
IMPLICIT INTEGER*2(I-N)
INTEGER*1 TITLE(72)
INTEGER*2 JPLT(5)
DIMENSION P(NT),RNU(NSTP),RNUD(NSTP),RNUDD(NSTP)
DATA JPLT/'D', 'V', 'A', 'L', 'X'/

C   PLOT RESULTS
C
WRITE(6,*) 'SELECT PLOT: (D,V,A,L,X)'
CALL READC(IPLT,0,0)
WRITE(6,*)
JPL=5
DO 6100 I=1,4
6100 IF(IPLT.EQ.JPLT(I))JPL=I
IF(JPL.EQ.5)RETURN
IF(IPASS.LT.1)GO TO 6200
IF(IPASS.LT.2.AND.JPL.LE.3)GO TO 6200
DT=TD/(FLOAT(NP-1))*1000.0
TINCP=TINC*1000.0
CALL PLOT(JPL,NSTP,NT,NP,RNU,RNUD,RNUDD,P,TITLE,
  1 NNU,TINC,DT).
RETURN
6200 WRITE(6,*) 'ERROR: DATA FOR PLOT NOT AVAILABLE!'
RETURN
END
SUBROUTINE PLOT(JPL,NSTP,NT,NP,NU,NUD,NUDD,P,TITLE,
  NNU,TINC,DELT)
C SUBROUTINE FOR PLOTTING RESPONSES
IMPLICIT INTEGER*2(I-NVT)
INTEGER*1 TITLE(72)
DIMENSION PCNT)PRNU(NSTP),RNUD(NSTP),RNUPDD(NSTP)
DATA K11/11/, K22/22/., K30/30/, K36/36/, T20/0./
C IF(JPL.LT.4)CALL TITLX('TIME (MSEC)’,K11)
CALL NEXTPG
C WRITE TITLE TO PLOT
CALL VTSCA(5)
CALL HIBRN8(1)
WRITE(6,90)TITLE
90 FORMAT(10X,72A1)
CALL VTSCA(3)
CALL OIBRN8(1)
C GO TO (100,20),300,400),JPL
100 CALL TITLY1('NORMALIZED DISPLACEMENT (D/XY)',K30)
CALL QPLOTD(TZ,TINC,NU,NNU)
CALL NEXTPG
RETURN
200 CALL TITLY1('NORMALIZED VELOCITY (V*T/XY) ’,K30)
CALL QPLOTD(TZ,TINC,NU,NU)
CALL NEXTPG
RETURN
300 CALL TITLY1('NORMALIZED ACCELERATION (A*T*T/XY) ’,K36)
CALL QPLOTD(TZ,TINC,NUDD,NU)
CALL NEXTPG
RETURN
400 CALL TITLX('TIME (MSEC)’,K11)
CALL TITLY1('NORMALIZED PRESSURE ’,K22)
CALL QPLOTD(TZ,DELT,P,NP)
CALL NEXTPG
RETURN
END
SUBROUTINE SETOP(LUO, TN, RMX)
IMPLICIT INTEGER*2(I-N*,*)
C
C SET VALUES FOR ANALYSIS
C
WRITE(6,*) 'ENTER NATURAL PERIOD: '
READ(5,*) TN
WRITE(6,*) 'ENTER PEAK RESISTANCE: '
READ(5,*) RMX
READ(5,10) IDUMMY
10 FORMAT(A2)
RETURN
END

SUBROUTINE TITLOP(TITLE)
IMPLICIT INTEGER*2(I-N*,*)
INTEGER*1 TITLE(72)
WRITE(6,*) 'ENTER NEW TITLE: (72 CHAR. MAX.)'
READ(5,10)(TITLE(I), I=1,72)
10 FORMAT(72A1)
RETURN
END
THIS PAGE IS INTENTIONALLY LEFT BLANK.
APPENDIX B

EXAMPLE COMPUTER SOLUTIONS
NORMALIZED RESPONSE OF AN SDOF ELASTIC-PLASTIC MODEL

NOTES: DEFAULT UNITS ARE INCHES, POUNDS, AND SEC
UNLESS OTHERWISE SPECIFIED

AVAILABLE OPTIONS
X = EXIT PROGRAM
A = ANALYZE
D = DISPLAY DATA
H = HELP
I = INITIAL PASS
L = LOADING FUNCTION
N = NUMERICAL PARAMETERS
O = OUTPUT DEVICE
P = PLOT
S = SET VALUES FOR ANALYSIS
T = TITLE

SELECT OPTION: (X,A,D,H,I,L,N,O,P,S,T)

SELECT OPTION: (X,A,D,H,I,L,N,O,P,S,T)

ENTER NEW TITLE: 172KAR.

ENTER WEAPON (KT): 26

ENTER PEAK OVERPRESSURE: 29

ENTER HEIGHT OF BURST (FEET): 6

SOLUTION FOR 0.3 SEC STRUCTURE AT 20 KT, 25 PSI

NUMERICAL PARAMETERS:
BETA = 0.10007
INTEGRATION INTERVAL = 0.100000E-01 OF PERIOD
INTEGRATION INTERVAL = 0.100000E-01 OF DURATION
TOLERANCE = 0.100000E-02
NUMBER OF PRESSURE STATIONS = 250

LOAD DESCRIPTION:
WEAPON (KT) = 26.000
PEAK OVERPRESSURE = 25.000
POSITIVE PHASE DURATION = 0.44229
TIME OF ARRIVAL = 0.50000
RANGE (FEET) = 1.7741
HEIGHT OF BURST (FEET) = 0.80000

PRESSURE-TIME HISTORY? (Y/N) N
ENTER NATURAL PERIOD:
V 3.00
ENTER PEAK RESISTANCE:
18 0

MAXIMUM DUCTILITY = 0.3813
OCCURS AT TIME = 0.31888
NORMALIZED PRESSURE AT THIS TIME = 0.74042E-01

NATURAL PERIOD = 0.38000
LOAD DURATION = 0.44220
TIME INCREMENT = 0.3066E-02

COMPLETE HISTORY? Y/N: N

NOTE: RESPONSES ARE NORMALIZED:

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**NUMERICAL PARAMETERS:**
- **Beta:** 6.6687
- **Integration Interval:** 9.1000E-01 of Period
- **Integration Interval:** 9.1000E-01 of Duration
- **Tolerance:** 9.1000E-02
- **Number of Pressure Stations:** 250

**LOAD DESCRIPTION:**
- **Weapon (kt):** 20.000
- **Peak Overpressure:** 25.000
- **Positive Phase Duration:** 0.44229
- **Time of Arrival:** 0.51300
- **Range (KFeet):** 1.7741
- **Height of Burst (KFeet):** 0.00000

**STRUCTURE DESCRIPTION:**
- **Natural Period:** 9.30000
- **Frequency:** 3.3333
- **Peak Resistance:** 10.000

**PRESSURE-TIME HISTORY?** (Y/N)
- **N**

**SELECT OPTION:** (X,A,D,H,I,L,N,O,P,S,T)
SOLUTION FOR 0.3 SEC STRUCTURE AT 20 KT, 25 PSI
SOLUTION FOR 0.3 SEC STRUCTURE AT 20 KT, 25 PSI
SOLUTION FOR 0.3 SEC STRUCTURE AT 20 FT, 25 PSI
APPENDIX C

NOTATION
NOTATION

\( f \) Forcing function/maximum force
\( F \) Forcing function
\( F_\text{m} \) Maximum force
\( k \) Elastic function
\( m \) Structural mass
\( P \) Peak overpressure
\( r \) Structural resistance
\( r_\text{m} \) Maximum resistance
\( t \) Time
\( t_\text{d} \) Positive phase duration of load
\( t_\text{m} \) Time to maximum response
\( T \) Natural period
\( x \) Displacement
\( \dot{x} \) Velocity
\( \ddot{x} \) Acceleration
\( x_\text{m} \) Maximum displacement
\( x_\text{y} \) Yield or peak elastic displacement
\( \beta \) Newmark \( \beta \) numerical parameter
\( \Delta t \) Time increment
\( \eta \) Normalized displacement
\( \dot{\eta} \) Normalized velocity
\( \ddot{\eta} \) Normalized acceleration
\( \mu \) Ductility
\( \xi \) Normalized time parameter
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<td>Commanding Officer, Picatinny Arsenal</td>
<td>P. Angellotti</td>
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<td>VLD/Steve Zudas J. H. Keffer DRAR-BLT/Mr. C. W. Kitchens ANXR-X/Mr. J. J. Messaros</td>
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<td>MAJ G. Focsaneanu</td>
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<td>NNED-DS/Michael M. Dembo Mr. Robert H. Wamsley NNED-DS/Mr. Paul LaHoud NNED-DS/Mr. Ron Lein</td>
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<td>Commander, U. S. Army Engineer District, Omaha</td>
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