ANALYSIS OF DYNAMIC IN SITU BACKFILL PROPERTY TESTS
REPORT 1 A METHOD FOR... (U) HEBREW UNIV JERUSALEM
(ISRAEL) L SEAMAN ET AL. JUL 86 WES/TR/SL-87-11-1/
UNCLASSIFIED DCA39-83-K-0002 F/G 8/10 NL
ANALYSIS OF DYNAMIC IN SITU BACKFILL PROPERTY TESTS

Report 1
A METHOD FOR REMOVING OSCILLATIONS AND DAMPING FROM DIAPHRAGM-TYPE STRESS GAGE RECORDS

by
Lynn Seaman

with contributions from
Bonnie Lew, Tom Cooper, and Frances Lovell

SRI International
333 Ravenswood Avenue
Menlo Park, California 94025-3493

July 1987
Report 1 of a Series

Approved For Public Release, Distribution Unlimited

Prepared for US Army Corps of Engineers
Washington, DC 20314-1000
Under Project No. 4A162719AT40, Task AO, Work Unit 024
(Contract No. DACA39-83-K-0002)
Monitored by Structures Laboratory
US Army Engineer Waterways Experiment Station
PO Box 631, Vicksburg, Mississippi 39180-0631
Destroy this report when no longer needed. Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.
### Title
Analysis of Dynamic In Situ Backfill Property Tests; A Method for Removing Oscillations and Damping from Diaphragm-Type Stress Gage Records

### Personal Authors
Seaman, Lynn; Lew, Bonnie; Cooper, Tom; and Lovell, Frances

### Type of Report
Report 1 of a series

### Time Covered
July 1987

### SOURCE OF FUNDING NUMBERS

<table>
<thead>
<tr>
<th>FIELD</th>
<th>GROUP</th>
<th>SUB-GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### ABSTRACT
A procedure for eliminating or minimizing the effects of stress gage frequency and damping has been developed. The method was applied to SE (diaphragm) stress gages used to measure soil stress during the passage of shock waves.

The purposes of this study were to understand how stress records of diaphragm gages are related to imposed stress histories and to develop a method for deriving the stress histories from the records. Two-dimensional wave propagation simulations of embedded gages were made to determine the effects of the gage frequency characteristics on the gage record; the results of these calculations showed that the gage filters the imposed stress like a single-degree-of-freedom oscillator would. Then a method was developed for deriving analytically a stress record corresponding to the response of an oscillator to an imposed stress history. This method was incorporated into an iterative procedure with which a user can construct a best estimate of a stress history acting on a diaphragm gage. This

(Continued)
18. SUBJECT TERMS (Continued).

Diaphragm-type stress gage
In situ soil properties
Oscillatory stress record

Plane shock waves
Processed stress histories
SDOF oscillator gage model

19. ABSTRACT (Continued).

...estimate is not necessarily the soil stress that would have existed in the absence of the gage.

This record-processing procedure was used to compute stress histories for gages measuring vertical and horizontal stress in the DISKO-1 event executed by the US Army Engineer Waterways Experiment Station.
PREFACE

The work described herein was performed by SRI International for the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES) under Contract No. DACA39-83-K-0002. It was sponsored by the Office, Chief of Engineers, US Army, as a part of Project No. 4A162719AT40, Task AO, Work Unit 024, "Ground Shock Prediction Techniques for Earth and Earth-Structure Systems." OCE Technical Monitor was Mr. R. L. Wight.

Dr. Lynn Seaman was the Principal Investigator for this study. Mr. Tom Cooper conducted the two-dimensional calculations that provided the basis for the approach. Ms. Bonnie Lew wrote and tested the original version of the computer program, RECFIT. Ms. Frances Lovell modified the program for ease of use interactively and augmented the plotting capability. Dr. Joseph S. Zelasko, Geomechanics Division (GD), SL, was the WES Contracting Officer's Representative. Dr. J. G. Jackson, Jr., was Chief, GD, and Mr. Bryant Mather was Chief, SL.

COL Dwayne G. Lee, CE, is Commander and Director of WES; Dr. Robert W. Whalin is Technical Director.
CONTENTS

PREFACE ................................................................. i

LIST OF FIGURES ...................................................... iv

LIST OF TABLES ........................................................ vi

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT..... vii

I INTRODUCTION .................................................................. 1

II TWO-DIMENSIONAL SIMULATIONS OF THE EMBEDDED SE STRESS GAGE ... 5

III THE RECORD PROCESSING PROCEDURE ............................. 13
   A. Feasibility of a Record Processing Procedure .................. 13
   B. Development of the Procedure ................................... 19
      1. Initial Estimate of the Stress History ..................... 19
      2. Computation of the Pseudo Record ....................... 22
      3. Variance between the Actual and Computed Record ...... 22
      4. Horizontal Stress Records .................................. 24

IV GUIDELINE FOR USING THE RECORD PROCESSING PROCEDURE AND RECFIT .............................................. 29
   A. Outline of the Procedure ....................................... 29
   B. Input and Sample Calculation .................................. 30

V SAMPLE RESULTS FROM THE RECFIT PROCEDURE .................. 45

REFERENCES ....................................................................... 51

APPENDICES

A CONSTRUCTION OF A GAGE RECORD FOR A PRESCRIBED VERTICAL STRESS HISTORY ........................................ A-1

B ACCOUNTING FOR A STRESS WAVE THAT SWEEPS OVER A DIAPHRAGM GAGE FACE ........................................ B-1

C LISTING OF RECFIT ....................................................... C-1
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plan and Cross Section of the DISKO-I Small-Scale, High-Explosive Simulation Test Conducted by WES</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Stress Records Obtained from Several SE Gages in the DISKO-1 Event</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Cross Section of an SE Stress Gage for Stress Measurements Below 2000 psi (14 MPa)</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Cell Layout Used in Simulating the Free Response of an SE Stress Gage</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>Response of the SE Diaphragm Stress Gage to a Pulse Loading</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>Response of the Embedded SE Gage to a Pulse Loading</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>Response of the Embedded SE Gage in a Large Soil Mass</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>Idealization of the Soil-Gage System to a Damped Oscillator</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>Response of a One-Degree-Of-Freedom Gage to a Single Ramp Loading Function</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>Response of a One-Degree-Of-Freedom Gage to a Double Ramp Loading: Sensitivity of the Record to the Amplitude of the First Node of the Loading Function</td>
<td>17</td>
</tr>
<tr>
<td>11</td>
<td>Response of a One-Degree-Of-Freedom Gage to a Double Ramp Loading: Sensitivity of the Record to the Time of the First Node of the Loading Function</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>Idealized Stress Record and Sample Actual Record Showing Method for Constructing Initial Trial Stress History</td>
<td>21</td>
</tr>
<tr>
<td>13</td>
<td>Horizontal Stress Record and Nomenclature for Analysis of the Sweeping Wave</td>
<td>27</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Sequence of Calculations to Construct a Pseudo Gage Record for a Horizontal Stress Gage</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Measured Stress Record from Horizontal Gage SH10 in DISKO-1 with Initial Trial Stress History</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Measured Horizontal Stress Record SH10 from DISKO-1 Plus Smeared Stress History Computed from the Trial History in Figure 15</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Sequence of Changes to the Trial Stress History to Produce a Close Match Between the Measured Record and Computed History for Horizontal Stress Record SH10 on DISKO-1</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Comparison of Measured Record, Estimated Stress History and Computed Stress Record for SH10 on DISKO-1</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Final Estimated Stress History Derived from RECFIT for Horizontal Stress Gage SH10 on DISKO-1</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Constructed Stress History and Stress Records from SE Gage SV1 in the DISKO-1 Experiment</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Constructed Stress History and Stress Records from SE Gage SV15 in the DISKO-1 Experiment</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Constructed Stress History and Stress Records from SE Gage SH8 in the DISKO-1 Experiment</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Constructed Stress History and Stress Records from SE Gage SH10 in the DISKO-1 Experiment</td>
<td></td>
</tr>
<tr>
<td>A.1</td>
<td>Description of a Prescribed Loading Composed of Linear Segments</td>
<td></td>
</tr>
<tr>
<td>B.1</td>
<td>Nomenclature for Analysis of the Response of the SE Diaphragm Gage to a Sweeping Wave</td>
<td></td>
</tr>
<tr>
<td>B.2</td>
<td>Response of a Horizontal Stress Gage to a Sweeping Step Pulse</td>
<td></td>
</tr>
<tr>
<td>B.3</td>
<td>Response of the Horizontal Stress Gage to an Increment of the Wave</td>
<td></td>
</tr>
</tbody>
</table>
TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Parameters of the Stress History, Parameter Shift, and Variances from the Actual Stress Record</td>
<td>25</td>
</tr>
</tbody>
</table>
Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>degrees (angle)</td>
<td>0.01745329</td>
<td>radians</td>
</tr>
<tr>
<td>dynes per square</td>
<td>0.1</td>
<td>pascals</td>
</tr>
<tr>
<td>centimeter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ergs</td>
<td>0.1</td>
<td>microjoules</td>
</tr>
<tr>
<td>feet</td>
<td>0.3048</td>
<td>meters</td>
</tr>
<tr>
<td>grams per cubic</td>
<td>1,000</td>
<td>kilograms per cubic</td>
</tr>
<tr>
<td>centimeter</td>
<td></td>
<td>meter</td>
</tr>
<tr>
<td>inches</td>
<td>25.4</td>
<td>millimeters</td>
</tr>
<tr>
<td>kips (force)</td>
<td>4.448222</td>
<td>kilonewtons</td>
</tr>
<tr>
<td>kips (force) per</td>
<td>6.894757</td>
<td>megapascals</td>
</tr>
<tr>
<td>square inch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pounds (force) per</td>
<td>6.894757</td>
<td>kilopascals</td>
</tr>
<tr>
<td>square inch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pounds (mass)</td>
<td>0.4535924</td>
<td>kilograms</td>
</tr>
<tr>
<td>pounds (mass) per</td>
<td>16.01846</td>
<td>kilograms per cubic</td>
</tr>
<tr>
<td>foot</td>
<td></td>
<td>meter</td>
</tr>
</tbody>
</table>
ANALYSIS OF DYNAMIC IN SITU BACKFILL PROPERTY TESTS
A METHOD FOR REMOVING OSCILLATIONS AND DAMPING
FROM DIAPHRAGM-TYPE STRESS GAGE RECORDS

I INTRODUCTION

The U. S. Army Engineer Waterways Experiment Station (WES) has conducted a series of small-scale, high explosive simulation tests on prepared soil beds to determine their dynamic uniaxial strain constitutive relations and the ratio \( K_o \) of horizontal to vertical stress. In these tests, a series of SE diaphragm stress gages were placed at a range of depths in the soil. A diagram of the experimental layout for the first of these tests \(^1\), \(^2\) is shown in Figure 1. Many of the records showed severe oscillations near the wave front, causing uncertainties in the record interpretation. The sample records in Figure 2 illustrate these problems. In this study we wanted to eliminate these oscillations because they are mainly associated with the natural frequency of the gage and are not part of the actual soil stress history. Also we wanted to determine the actual arrival time and rise time of the wave front.

This effort was part of a larger study by SRI for WES to determine

The stress-strain relations for the soil in one-dimensional compression.

The stress path, or relation, between the axial and transverse stress.

The study had three major parts:

(1) Remove oscillations and other irregularities from the stress records and obtain the best estimate of the actual stress history experienced by the gage (the effort described in this report).

(2) Perform a Lagrangian analysis of the stress histories to obtain the stress-strain paths taken by the gages. \(^3\)

(3) Modify the ONED one-dimensional wave propagation program \(^4\) for simulating the stress-wave experiments, including the detonation.
FIGURE 1 PLAN AND CROSS SECTION OF THE DISKO-1 SMALL-SCALE HIGH-EXPLOSIVE SIMULATION TEST CONDUCTED BY WES.

Source: Reference 1.
FIGURE 2  STRESS RECORDS OBTAINED FROM SEVERAL LRSE GAGES IN THE DISKO-1 EVENT
Because these three parts are quite distinct, a separate report was prepared for each part. However, all three parts constitute essential steps in the determination of soil properties from the gaged experiments.

First, it was necessary to determine the cause of the oscillations to develop a valid procedure for eliminating the oscillations. The cause was studied through two-dimensional simulations of the gage embedded in soil; these results are presented in Section II. Next, we devised a method for deriving a pseudo record based on an actual stress history plus the gage frequency and damping. This study, described in Section III, guided us in developing a procedure for determining the stress history acting on a gage from the stress record. Section IV provides a guideline for using the procedure and the computer program RECFIT. Results of sample calculations performed using the procedure are described in Section V.

It should be noted that the record processing described in this report does not necessarily provide histories of the true free-field stress. This procedure removes most of the effects of the gage frequency and damping and of the time for the wave to sweep across the gage. But the effects on the stress wave of the gage itself, packing materials around the gage, and the soil disturbance that occurred during placement of the gage are not accounted for. We hope to address these latter topics in further studies.
II TWO-DIMENSIONAL SIMULATIONS OF THE EMBEDDED SE STRESS GAGE

Two-dimensional finite-element simulations of the SE stress gages embedded in soil were conducted primarily to determine what caused the oscillations and other features of the stress records. We suspected that the record appearances were caused mainly by the frequency and damping characteristics of the gage and (for horizontal stress gages) the time for the stress wave to sweep over the gage.

In this study calculations were made for a free gage, for a gage in soil receiving the vertical stress, and for an embedded gage receiving the horizontal stress (from a wave sweeping over the gage).

The free gage calculations were made to compare with the manufacturer's rated frequency (51 kHz) to verify that our representation was sufficiently accurate. The gage considered has the form shown in Figure 3. Because of the thinness and unknown boundary conditions of the sensing element, this verification of the accuracy was important. The cell layout used for the calculation is shown in Figure 4. This coarse layout was necessary to allow for a reasonable calculation time for the later simulations of an embedded gage. The free gage shown in Figure 4 was loaded by a flat-topped stress pulse with an instantaneous rise. The response of the plate in the vicinity of the sensing elements (strain gages) is shown in Figure 5. The apparent frequency is about 37 kHz. This computed frequency should be compared with the manufacturer's listed frequency of 51 kHz and WES observations of frequencies around 40 kHz. This match of the computational frequency to the actual frequency was considered adequate for our purpose with these computations. The damping shown in Figure 5 is about 4% of critical. This damping is caused by the artificial viscosity in the calculation.

The first embedded gage simulations were made for the situation in which the wave strikes the entire gage face simultaneously (vertical
FIGURE 3  CROSS SECTION OF AN SE STRESS GAGE FOR STRESS MEASUREMENTS BELOW 2000 psi (14 MPa)
FIGURE 4  CELL LAYOUT USED IN SIMULATING THE FREE RESPONSE OF AN SE STRESS GAGE
FIGURE 5 RESPONSE OF THE SE DIAPHRAGM STRESS GAGE TO A PULSE LOADING
stress case). Two configurations were used here: one with a small amount of surrounding soil and the second with a large amount. The first of these configurations is shown in Figure 6. The loading pulse with an amplitude of 20 MPa was applied to the top of the soil in the figure. The computed radial strain on the inner surface of this diaphragm is also shown in the figure. The frequency is approximately 29 kHz and the damping is 7 to 11% of critical damping.

The second embedded gage calculation, in which a large volume of soil was used, is illustrated in Figure 7. As before, a step loading pulse with an amplitude of 20 MPa was applied to the top of the soil. In this case the apparent gage frequency is about 25 kHz and the damping varies from 14% near the wave front to nearly zero after several cycles. This computed record looks remarkably similar to field stress gage records. Comparison of the records in Figures 6 and 7 indicates that the computed behavior depends on the amount of soil included in the calculation. The result in Figure 7 is the more reliable result because the side and base boundary conditions (not present in the field) have less influence on the gage response. These results also indicate that embedment in soil reduces the gage frequency considerably (from 37 to 25 kHz) and increases the damping.

A similar series of simulations was performed for the wave sweeping over the gage face (horizontal stress configuration). In this case the simulations were performed under plane strain conditions. Here the gage is infinitely long in one plan dimension. Again, free vibration calculations verified that the simulated gage had approximately the correct natural frequency. The embedded gage calculations were performed only with the large mass of soil, as in Figure 7. The results showed a gradual rise of strain over 90 µs and almost no oscillations. We had expected a longer rise time corresponding to the time for the wave to sweep across the gage face.

The results of these two-dimensional simulations indicate that the SE stress gages can be simply treated as damped oscillators of finite size responding to stress waves with steep fronts. The rise time of the
Figure 6: Response of the Embedded SE Gage to a Pulse Load

(a) Configuration for the Embedded Gage Simulation

(b) Radial Strain at Point A on the Gage Sensing Element
(a) Configuration for the Embedded Gage Computation after 500 μs

(b) Radial Stress in the Center of the Diaphragm

FIGURE 7 RESPONSE OF THE EMBEDDED SE GAGE IN A LARGE SOIL MASS
wave is less than the period of the gage, but we cannot yet estimate the rise time (estimates are made in Section V). From the simulations we can also expect that embedment of the gages will reduce the natural frequency and increase the damping. Because of the variability of the soil, we assume that the gages will each show somewhat different frequencies and damping characteristics in each experiment.
III THE RECORD PROCESSING PROCEDURE

The development of the record processing procedure began with the examination of the feasibility of such a procedure. The feasibility study led us to define a method and also to determine the conditions under which such a method is possible. Following this study, the basic analytical steps for this procedure were developed, as outlined in this section. A guideline for using the computer program embodying this procedure is presented in the next section.

A. Feasibility of a Record Processing Procedure

A feasibility study was undertaken to explore methods for removing the effects of the gage characteristics from the stress records. The following questions were considered:

(1) How can the oscillations be removed without also eroding the wave front? Standard smoothing techniques (e.g., a low-pass filter) would eliminate the oscillations, but they would also erode the wave front. Procedures for operating on the wave to remove specific frequencies are basically unstable because they are attempting to recover information that has been lost by the recording system.

(2) Can we detect the actual arrival time and rise time of the wave front?

(3) How can we develop a procedure for constructing the actual stress histories from the stress records?

To answer these questions, we began by representing the stress gage as a one-degree-of-freedom, damped oscillator, as indicated by the simulations in the preceding section. This idealization is shown in Figure 8. In Figure 8(a), the diaphragm of the gage moves in response to the applied stress; the diaphragm motion is measured by strain gages producing the "stress" record. The vertical stress history applied to the gage is the information of interest. Given the stress record, we are attempting to determine the applied stress history. In Figure 8(b), the
Explosive Loading to Soil

Vertical Stress History

Motion of Gage Diaphragm
Gives Record

(a) Soil and Gage System that Provides Stress Record

Mass

\[ \text{\( y \), Motion of Oscillator Mass} \]

\[ \text{\( y_{ST} \), Applied Motion} \]

(b) Damped Oscillator Representing Response of Soil Stress Gage

FIGURE 8  IDEALIZATION OF THE SOIL-GAGE SYSTEM TO A DAMPED OSCILLATOR
foundation of the oscillator is moved in accordance with the applied
motion \( y_{ST} \). The motion \( y \) of the mass constitutes the record. Thus, we
obtain \( y \) and attempt to reconstitute \( y_{ST} \). The oscillator is a good
representative of the soil-gage system to the extent that higher
frequencies in the soil-gage system can be ignored and that the damping
can be approximated by a linear viscous model.

Using the oscillator model, we began the study by analyzing simple
wave forms, treating them as the true (free-field) stress histories,
\( y_{ST} \). Then we computed the response \( y \) of the damped oscillator to these
stress histories and obtained pseudo stress records. By studying the
relationships between the stress histories and pseudo records, we were
able to answer the questions above.

Sample wave forms for stress histories are shown in Figures 9
through 11. These histories were applied as forcing functions to the
oscillator representing the stress gage. For each wave form a pseudo
record (motion of the oscillator) was computed by the analytical method
of Appendix A. These stress histories have a bilinearly rising front to
facilitate studying the sensitivity of the computed record to the wave
front shape. Comparing these records in Figures 9 through 11 shows that
the first stress peak is very sensitive to the rise time of the wave and
to the stress amplitude at the break in the bilinear rise (the first node
of the history). Thus, it appears that a record does contain enough
information to determine both the rise time and the arrival time of the
wave. These results are pertinent to the case where the stress history
has the simple form of a series of linear segments with no more than two
segments in the rise. We also made calculations with three segments in
the rise, but these records did not give such a clear dependence of the
points in the record to the wave form. (Our later experience in proces-
sing the DISKO-1 records suggested that two segments in the wave front
are probably the maximum that should be considered.)

Later nodes in the sample stress histories were also altered system-
atically. Of course, shifts of a node in the history only alter points
in the record at later times. We found that with about two nodes per
FIGURE 9 RESPONSE OF A ONE-DEGREE-OF-FREEDOM GAGE TO A SINGLE RAMP LOADING FUNCTION
Period = 25 μs
Damping = 10%

(a) Loading Functions

(b) Computed Records

FIGURE 10 RESPONSE OF A ONE-DEGREE-OF-FREEDOM GAGE TO A DOUBLE RAMP LOADING: SENSITIVITY OF THE RECORD TO THE AMPLITUDE OF THE FIRST NODE OF THE LOADING FUNCTION
Period = 25 µs
Damping = 10%

(a) Loading Functions

(b) Computed Records

FIGURE 11 RESPONSE OF A ONE-DEGREE-OF-FREEDOM GAGE TO A DOUBLE RAMP LOADING: SENSITIVITY OF THE RECORD TO THE TIME OF THE FIRST NODE OF THE LOADING FUNCTION
period of the gage, there was a distinct effect in the record for each nodal shift.

Now we were able to answer the questions posed at the beginning of the section. The oscillations can be removed from the record if we restrict the shape of the generated stress history to linear segments with about two nodes per period. With this constraint we can determine the arrival time and rise time of the wave front.

The shape of the history can be found by starting with a history composed of linear segments with about two nodes per period. Beginning with the first nodes, the nodes can be shifted one at a time, and records constructed for each shift. The shifts should be made in a manner to cause the amplitude and time of the extrema of the computed record to match the extrema of the actual record. When the records match, the wave front of the constructed history will provide the arrival time and rise time of the wave. The remainder of the stress history can be constructed in the same fashion.

Thus, it appeared that an iterative procedure could be developed for processing the stress records and obtaining stress histories.

B. Development of the Procedure

The procedure outlined above contains the following steps: estimation of a trial stress history based on the stress record, computation of a pseudo record that would be obtained if the history were applied to the gage, revision of the trial history, and repetition of the computation and revision steps until the computed record matches the actual record satisfactorily. The analytical studies required to develop this procedure are outlined here. The following subsections include the derivation of the initial trial history, computation of the record, comparison of the pseudo record and actual record, and treatment of the horizontal gage effects.

1. Initial Estimate of the Stress History. Before a stress history can be constructed, some means must be developed to produce an
initial estimate. If the initial estimate is a good one, the further work required to modify the history is minimized. The method we used acts like a low-pass filter in eliminating oscillations or noise, and also eroding the shock fronts. Therefore, this initial estimate is accurate except at shock fronts.

The method of constructing an initial estimate was undertaken by examining the response of a damped oscillator to a step loading. The loading and response (record) are shown in Figure 12(a). The response $Y$ was computed by integrating equation (A.2) in Appendix A.

$$Y = Y_0 \left[ 1 - e^{-\beta t} \left( \frac{\beta}{\omega_d} \sin \omega_d t + \cos \omega_d t \right) \right]$$

where $Y_0$ is the amplitude of the step loading, $\beta$ is the damping factor, $t$ is time, and $\omega_d$ is the damped circular frequency. As shown in Figure 12(a), the peaks and valleys of this function are above and below the $Y = Y_0$ line. In fact, an average of the peaks and valleys would approximate the $Y = Y_0$ line. Hence, one could find the midpoint positions between successive peaks and valleys and connect these points to construct the estimated history. Such a construction is shown in Figure 12(b). Here the averaging factor $f$ is not necessarily equal to 0.5. From equation (1) we can determine the correct averaging factor to provide a horizontal line at $Y = Y_0$ in Figure 12(a). The factor is

$$f = \frac{Y_0 - Y_{i+1}}{Y_i - Y_i} = \frac{1}{1 + e^{-\pi \beta/\omega_d}}$$

where $Y_i$ and $Y_{i+1}$ are successive extrema of the function. With this procedure for constructing an estimated history, we obtained the dashed line in Figure 12(a). This constructed history has an eroded wave front, but the correct amplitude past the wave front.

The procedure for constructing an initial trial history in RECFIT follows closely the foregoing development. The user is asked to supply
Figure 12: Idealized Stress Record and Sample Actual Record Showing Method for Constructing Initial Trial Stress History.
the factor \( f (f = 0.58 \text{ for } 10\% \text{ damping}) \). The midheight points (nodes) are chosen by RECFIT in a manner like that used in Figure 12(b). RECFIT does not maintain a constant \( f \) value, but allows \( f \) to gradually reduce toward 0.5.

For choosing the peaks and valleys of the record, RECFIT must be supplied with a time window size. An approximate window size is about one-half the period of the gage. RECFIT moves the window through the record, choosing successive extrema of the record and the appropriate midpoints.

If the record is monotonic within a window, the midpoint of the window is used. This procedure gives smoothed histories and is a good starting point for constructing an accurate wave front.

2. Computation of the Pseudo Record. For each trial stress history a pseudo stress record is computed numerically. The additional information required is the frequency and damping of the gage. The derivation of the numerical procedure is given in Appendix A.

3. Variance Between the Actual and Computed Record. For this report, the variance between the two records is computed from

\[
V = \sum_{i=1}^{N} (Y_{pi} - Y_{ai})^2
\]

where the sum is taken over the \( N \) time increments in the digitized (actual) record. \( Y_{pi} \) and \( Y_{ai} \) are the amplitudes at the same time \( t_i \) in the pseudo and actual records.

This variance is used in two parts of the calculation. First, this variance is used to compare the pseudo and actual records to aid in judging whether the trial stress history is sufficiently accurate. Second, this variance is used to determine the appropriate directions and amounts to shift the parameters of the trial stress history to bring the pseudo record into correspondence with the actual record. The first use is evident, so the rest of this subsection is devoted to the second use.

The parameters of the trial history that can be shifted to improve the match between the pseudo and actual records are the coordinates of
the first 3 or 4 points at the wave front [nodes in Figure 12(b)], plus the frequency and the damping of the gage. A variance calculation is used to aid the user in determining the best parameter to change, and the amount and sign of the change. The calculation has three steps:

- Shift each of the wave front and gage characteristic parameters by about 10% (one at a time), and construct the revised trial stress history:

\[ P_i = P_{io} + \Delta_i \]  

where \( P_i \) and \( P_{io} \) are the revised and original values of one of the parameters, and \( \Delta_i \) represents the 10% shift. For pressure or time values, \( \Delta_i = 0.1 \max (|P_i - P_{io} - 1|, |P_i + 1 - P_{io}|) \). With frequency and damping values, \( \Delta_i \) is simply 10% of the current value of the parameter. Note that the complete calculation is performed for \( + \Delta_i \) for each parameter, and then for \( -\Delta_i \).

- Compute the pseudo record for each trial history and the variance \( V_i \) from the actual record.

- Compute the derivative \( D_i \) of the parameter with respect to the variance. A useful numerical approximation for this derivative is

\[ D_i = \frac{V_o \Delta_i}{V_o - V_i} \]  

With the derivative in equation (5), we can compute the amplitude of the parameter required to produce zero variance, assuming that the variance is a linear function of the parameter. This amplitude is

\[ P_{id} = P_{io} + D_i \]  

This series of calculations is performed each time the user is provided with a pseudo record and a variance. Thus, he is guided toward the selection of the next trial history.

Table 1 shows the results of such a variance calculation. Here the
variances $V_1$ can be compared with $V_0 = 3.101 \times 10^5$, listed below the Table. In improving our trial histories, we noticed which parameter changes led to significant variance changes. In the Table, the change in $T_1$ has the most important effect on the variance, so we chose it for changing. Then we looked to the derivatives to find how much to change the parameter we had identified. We could use the 10% change indicated in the Table, or possibly a 50% change, but for large changes we run the risk of jumping over the best solution. In all cases we changed only one parameter at a time and used judgment in deciding how much change to make.

4. **Horizontal Stress Records.** Some of the SE stress gages used in DISKO-1 were oriented to be sensitive to the horizontal stress during the event. The experiment was designed to be essentially a uniaxial strain experiment; hence, the ratio of horizontal stress $S_H$ to vertical stress $S_V$ was expected to provide a dynamic value of $K_o$:

$$K_o = \frac{S_H}{S_V} \quad (7)$$

The factor $K_o$ and both stresses can vary through the loading time. Therefore, it is important to obtain histories of $S_H$ and $S_V$ at the same location, with similar rise times, and with gage and recording characteristics removed from the records. The horizontal stress gage records contain two effects that must be accounted for: the gage frequency characteristics and the gradual sweeping of the stress wave over the gage face. The gage frequency effects are like those for the vertical stress gages, and the method for treating these effects was outlined above. Here a method is developed for handling the sweeping wave effect. With a computational procedure to treat both these effects, we anticipated obtaining reasonable estimates of the actual horizontal stress histories.

When a wave sweeps across the face of a horizontal SE stress gage, the record shows a gradual rise of about 40 μs. Samples of such records
Table I

PARAMETERS OF THE STRESS HISTORY, PARAMETER SHIFT, AND VARIANCES FROM THE ACTUAL STRESS RECORD

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal Value</th>
<th>Shift of the Parameter</th>
<th>Variance of History</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_0$</td>
<td>$3.787 \times 10^{-3}$</td>
<td>$1.700 \times 10^{-6}$</td>
<td>$3.098 \times 10^5$</td>
</tr>
<tr>
<td>$T_1$</td>
<td>$3.804 \times 10^{-3}$</td>
<td>$2.700 \times 10^{-6}$</td>
<td>$2.779 \times 10^5$</td>
</tr>
<tr>
<td>$T_2$</td>
<td>$3.831 \times 10^{-3}$</td>
<td>$2.700 \times 10^{-6}$</td>
<td>$3.283 \times 10^5$</td>
</tr>
<tr>
<td>$T_3$</td>
<td>$3.858 \times 10^{-3}$</td>
<td>$2.700 \times 10^{-6}$</td>
<td>$3.336 \times 10^5$</td>
</tr>
<tr>
<td>$Y_1$</td>
<td>$3.759 \times 10^1$</td>
<td>$2.211 \times 10^1$</td>
<td>$3.296 \times 10^5$</td>
</tr>
<tr>
<td>$Y_2$</td>
<td>$1.835 \times 10^2$</td>
<td>$2.211 \times 10^1$</td>
<td>$3.060 \times 10^5$</td>
</tr>
<tr>
<td>$Y_3$</td>
<td>$3.925 \times 10^2$</td>
<td>$2.090 \times 10^1$</td>
<td>$2.956 \times 10^5$</td>
</tr>
<tr>
<td>$\beta/\omega$</td>
<td>$0.1$</td>
<td>$0.01$</td>
<td>$3.079 \times 10^5$</td>
</tr>
<tr>
<td>$2\pi/\omega$</td>
<td>$3.000 \times 10^{-5}$</td>
<td>$3.000 \times 10^{-6}$</td>
<td>$3.090 \times 10^5$</td>
</tr>
</tbody>
</table>

Notes: $Y_i$, $T_i$ are coordinates of the $i^{th}$ point of the trial stress history. $\beta/\omega$ is the fraction of critical damping. $2\pi/\omega$ is the period of the gage. Initial variance $V_o$ is $3.101 \times 10^5$. 

25
are shown in Figures 2(c) and 2(d). This gradualness reflects the fact that the record is related to the central deflection of the gage plate and thus to some average of the stress applied to the gage face (see Figure 13). To analyze this gradual loading, we considered the response of a clamped circular elastic plate to a step wave that sweeps over the plate. Timoshenko has given an expression for the central plate deflection for a load at any point on the plate. The differential deflection for a stress \( p \) applied on a differential area \( dA \) is

\[
\frac{dW}{\pi D} = \frac{p}{8\pi D} \left( b^2 \ln \frac{b}{a} + \frac{a^2 - b^2}{2} \right) dA
\]

where \( b \) is the radius to the loaded area as shown in Figure 13(c), \( a \) is the radius of the plate, and \( D \) is the bending stiffness of the plate. As shown in Appendix B, equation (8) can be integrated to obtain the plate deflection under a sweeping stress wave. Thus, for a known stress history, a stress record that accounts for the sweeping effect can be constructed. This sweeping effect was incorporated into RECFIT for processing the horizontal stress records.

Some of the steps in the horizontal stress gage calculation are illustrated schematically in Figure 14. Figure 14(a) is the trial history with the nodes that can be moved to improve the match of the records in Figure 14(c). Figure 14(b) contains the record produced by passing the trial history through the smearing process just described above. This smearing associated with the sweeping wave is handled in a subroutine called HORGAGE. Next the smeared record is applied to the damped oscillator, and the pseudo stress record is computed. This second computation occurs in the RUNG subroutine and is described in Appendix A.
(a) Stress History from Horizontal Stress Gage SH8

(b) Wave Sweeping over a Horizontal Stress Gage (Gage Element is Vertical)

(c) Nomenclature for Analysis of the Response of the SE Diaphragm Gage to a Sweeping Wave

FIGURE 13 HORIZONTAL STRESS RECORD AND NOMENCLATURE FOR ANALYSIS OF THE SWEEPING WAVE
FIGURE 14 SEQUENCE OF CALCULATIONS TO CONSTRUCT A PSEUDO GAGE RECORD FOR A HORIZONTAL STRESS GAGE
IV GUIDELINE FOR USING THE RECORD PROCESSING PROCEDURE AND RECFIT

A procedure was constructed for deriving a stress history from
vertical and horizontal stress records. (Vertical stress here means the
stress in the direction of wave propagation and horizontal means trans-
verse to this direction.) These records are presumed to be obtained from
gages whose frequency and damping characteristics have modified the
applied stress in forming the records. The stress history is taken here
as the actual stress occurring on the gage face. The procedure consists
of a computer program, RECFIT, and a method for using it. The result is
a stress history that, when imposed on the gage (or on a damped oscil-
lator with the gage characteristics), will provide a record that matches
the actual record.

A. Outline of the Procedure

In using the RECFIT program the user must provide a digitized gage
record. Then through a series of trials, the user constructs a stress
history that will produce the matching stress record. RECFIT computes a
stress record for each trial history and also guides the user in the
choice of alterations to make at each step.

For undertaking the record construction RECFIT has these elements:

(1) An initial smoothing process which automatically selects
a starting estimate of the stress history imposed on the
gage.

(2) A method of computing the gage record in response to any
imposed stress history. The computed record is compared
with the actual record and the statistical variance is
obtained.

(3) Provision for incrementally changing one at a time each
coordinate of the trial history, plus the period and
damping; constructing a gage record for each altered
trial history; and computing the variance from the
actual record. These variances can guide the user to
choose subsequent improvements in the trial stress history.

(4) Means for plotting the histories and records and for storing the final stress history.

These elements of the program are explained below using a sample calculation.

B. Input and Sample Calculation

In the following example, the record from a horizontal stress gage from DISKO-1 is processed. The RECFIT program is interactive, so a fixed appearance cannot be prescribed for the input file. During the calculation the user is asked for data or decisions at several steps. As a guide to the user, a listing is given below of a possible sequence of questions and responses.

The following sample calculation contains the questions and data provided by the computer, the user's responses, a prepared data file, plus notes on the computational process. These four types of information can be distinguished by the indicators at the left of each line:

Blank, written by the program,
- to be written by the user, and
1 for input from file 1, the stress gage data.

Note: Notes on the process are written in lower case, and are filled to the left of the line.

The interactive session begins with the message:

***** RECFIT, AN INTERACTIVE RECORD FITTING PROGRAM

ENTER FILE NAME CONTAINING ORIGINAL DATA

- SH10.DAT

Note: In addition to the foregoing two lines read from file 1, labelled SH10.DAT, are the following lines:

1 5000 2.00000000E-06
1 9.16333570E+00 2.29083390E+00 4.58166780E+00 6.87250180E+00 1.37450040E+01
1 1.37450040E+01 1.14541700E+01 6.87250180E+00 0.00000000E+00 -2.29083390E+00
1 -4.58166780E+00 -2.29083390E+00 -2.29083390E+00 0.00000000E+00 0.00000000E+00
1 etc.
Notes: The input from file 1 has the following form:
First line: 60 alphanumeric characters.
2nd line: 15 for NPT the number of points, and E16.8 for the
time step DT.
3rd and subsequent lines are in the format 5E16.8.

IS THIS A RESTART RUN?
-> N

Notes: For a restart run, enter Y. The restart data are on file 3.
These restart data are the trial stress history parameters obtained
during a previous series of calculations.

FILE CONTAINING DATA IS IN FOLLOWING FORM:

TITLE (A60)
NO. OF POINTS (15), TIME INCREMENT (E16.8) INITIAL TIME (E16.8)
AMPLITUDE (5E16.8)

IS THAT CORRECT?
-> Y

27-JUN-86 -1-SAND 1-3-7 STRESS - PSI SH 10
NPT = 5000 DT = 2.00000E-06 T(I) = 0.00000E+00

ENTER PERIOD OF THE GAGE (SEC) AND FRACTION OF DAMPING
EXAMPLE: 2.5E-5, 0.05
-> 4.0E-05, 0.2

ARE THE DATA FROM A HORIZONTAL GAGE?
-> Y

DO YOU WANT A PLOT OF ACTUAL RECORD AND TRIAL RECORD?
-> Y

XMIN, XMAX = 0.000E+00 0.000E+00 WANT TO CHANGE THEM?
-> Y

ENTER XMIN, XMAX
-> 3.500E-03 5.500E-03

Notes: At this point a figure, such as Figure 15, is plotted. In this
figure the oscillatory history is the original record, and the smoothed
one is the initial trial history obtained in the program by taking the
mid-points of the oscillations.

WANT TO MODIFY RECORD?
FIGURE 15  MEASURED STRESS RECORD FROM HORIZONTAL GAGE SH10 IN DISKO-1 WITH INITIAL TRIAL STRESS HISTORY
FIGURE 15  MEASURED STRESS RECORD FROM HORIZONTAL GAGE SH10 IN DISKO-1 WITH INITIAL TRIAL STRESS HISTORY
-N- EXITS WITHOUT WRITING ANY OUTPUT FILES

Y

ENTER GAGE RADIUS (CM)
-> 0.95

ENTER SOUND SPEED (CM/SEC)
-> 5.6E+04

Notes: The sound speed of the soil is used to compute the crossing time of the gage face.

WANT TO PLOT ACTUAL RECORD AND STRESS HISTORY OBTAINED FROM HORIZONTAL GAGE DATA?

Y

XMIN, XMAX = 3.500E-03 5.500E-03 WANT TO CHANGE THEM?

Y

ENTER XMIN,XMAX

-> 3.800E-03 5.000E-03

Notes: Now a plot like Figure 16 is generated. Here the original record is the oscillatory solid curve and the dashed line is the response obtained by passing the trial history (from Figure 15) through the smearing process.

WANT TO PLOT STRESS RECORD, ESTIMATED HISTORY, AND COMPUTED?

Y

Notes: Here the stress history obtained by computing the response of the gage (or an equivalent one-degree-of-freedom system) to the smeared history is plotted. Not shown.

XMIN, XMAX = 3.800E-03 5.000E-03 WANT TO CHANGE THEM?

N

WANT TO EXAMINE AND MODIFY RECORD IN DETAIL?

-N- WRITES OUTPUT FILE AND PREPARES TO EXIT

Y

WANT TO PLOT STRESS RECORD, ESTIMATED HISTORY, AND COMPUTED?

Y

XMIN, XMAX = 3.800E-03 5.000E-03 WANT TO CHANGE THEM?

Y

ENTER XMIN,XMAX

-> 3.800E-03 3.900E-03

Notes: Here a plot like that in Figure 17a is generated showing a small portion of the records, the shock front in the present case. The solid line is the original record, the points are the trial history, and the dashed line is the computed response of the gage to this trial.

WANT TO REПLOT WITH DIFFERENT SCALES TO EXAMINE A SMALL REGION?
FIGURE 16 MEASURED HORIZONTAL STRESS RECORD SH10 FROM DISKO-1 PLUS SMEARED STRESS HISTORY COMPUTED FROM THE TRIAL HISTORY IN FIGURE 15
FIGURE 17  SEQUENCE OF CHANGES TO THE TRIAL STRESS HISTORY TO PRODUCE A CLOSE MATCH BETWEEN THE MEASURED RECORD AND COMPUTED HISTORY FOR HORIZONTAL STRESS RECORD SH10 ON DISKO-1
IS RECORD FINISHED? WANT TO EXIT?

1st SHOCK AT T = 3.8240E-03 STRESS JUMP = 3.2065E+02
2nd SHOCK AT T = 3.5360E-03 STRESS JUMP = 4.8650E+01

Notes: The shocks are selected by the program to guide the user in finding the areas of interest for his work of modifying the history. In the present case, the shock to examine is the first shock, at 3.824 ms. The shocks are selected for the steepness of their rise in time and are listed in order of amplitude, not time. The amplitudes in this example are given in psi and the times are in seconds. The times are at the beginning of the shock front, the location for the user to begin his modifications of the record.

ENTER TIME INTERVAL FOR CHANGING RECORD - TBEG, TEND (SEC)
THREE POINTS ARE USED, BEGINNING WITH TBEG

-> 3.8E-03, 3.9E-03

Notes: The program uses TBEG and selects three (time, amplitude) points in the history to begin the modifications. At this point in the operation we begin the manual modification of the estimated stress history.

WANT TO PLOT STRESS RECORD, ESTIMATED HISTORY, AND COMPUTED?

-> N

XMIN, XMAX = 3.800E-03 3.900E-03 WANT TO CHANGE THEM?

-> N
VARIANCE V0 = 2.865E+05

Notes: The variance is computed from the difference between the original record and the computed history.

FR. DAMP = 1.500E-01 PERIOD = 4.000E-05

FOR TIME INTERVAL( 3.800E-03, 3.920E-03)

Notes: We note here that the program has chosen a slightly different window (ending at 3.92 ms. instead of 3.9 ms.) from the one we specified earlier.

<table>
<thead>
<tr>
<th>I</th>
<th>LABEL(I)</th>
<th>VALUE(I)</th>
<th>DEL(1)</th>
<th>DEL(2)</th>
<th>VARIANCE(I)</th>
<th>VARIANCE(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>THIST(0)</td>
<td>3.787E-03</td>
<td>1.000E-06</td>
<td>-1.000E-06</td>
<td>2.889E+05</td>
<td>2.991E+05</td>
</tr>
<tr>
<td>2</td>
<td>THIST(1)</td>
<td>3.804E-03</td>
<td>1.700E-06</td>
<td>-1.700E-06</td>
<td>2.636E+05</td>
<td>3.291E+05</td>
</tr>
<tr>
<td>3</td>
<td>THIST(2)</td>
<td>3.831E-03</td>
<td>2.700E-06</td>
<td>-2.700E-06</td>
<td>3.296E+05</td>
<td>2.871E+05</td>
</tr>
<tr>
<td>4</td>
<td>THIST(3)</td>
<td>3.860E-03</td>
<td>2.000E-06</td>
<td>-2.000E-06</td>
<td>3.098E+05</td>
<td>2.839E+05</td>
</tr>
<tr>
<td>5</td>
<td>YHIST(1)</td>
<td>-3.759E+01</td>
<td>1.000E+01</td>
<td>-1.000E+01</td>
<td>3.198E+05</td>
<td>2.783E+05</td>
</tr>
<tr>
<td>6</td>
<td>YHIST(2)</td>
<td>1.835E+02</td>
<td>2.068E+01</td>
<td>-2.068E+01</td>
<td>2.712E+05</td>
<td>3.368E+05</td>
</tr>
<tr>
<td>7</td>
<td>YHIST(3)</td>
<td>3.903E+02</td>
<td>1.000E+01</td>
<td>-1.000E+01</td>
<td>2.954E+05</td>
<td>3.056E+05</td>
</tr>
<tr>
<td>8</td>
<td>DAMP</td>
<td>1.500E-01</td>
<td>1.500E-02</td>
<td>-1.500E-02</td>
<td>2.956E+05</td>
<td>3.058E+05</td>
</tr>
<tr>
<td>9</td>
<td>TAU</td>
<td>4.000E-05</td>
<td>4.000E-06</td>
<td>-4.000E-06</td>
<td>2.624E+05</td>
<td>3.230E+05</td>
</tr>
</tbody>
</table>
Notes: THIST(i) and YHIST(i) in the preceding list are the abscissae and ordinates of the successive points defining the trial history (as in Fig. 17a). Consequently, this list shows the VALUES of the variables that can now be changed in the trial history, the incremental changes (DEL) that have been tested, and the effects that these changes have on the VARIANCEs. We can see that an increase in THIST(1), YHIST(2), and TAU, and a decrease in YHIST(1) would offer improvements (decreases in the variance).

WANT TO CHANGE THE WINDOW?
-> N
WANT TO CHANGE ANY VALUE OF TRIAL RECORD?
-> Y
  TO CHANGE ANY VALUE ENTER THE "I" VALUE FOR THE VARIABLE
  0 - TO EXIT CHANGE LOOP

Notes: At this point we decide to change the time and amplitude of the first point (I values 2 and 5).

-> 2
ENTER NEW VALUE OF VARIABLE BEING CHANGED
-> 3.817E-03
I= 1 THIST(ORIGINAL)= 3.787E-03 (NEW)= 0.000E+00
I= 2 THIST(ORIGINAL)= 3.804E-03 (NEW)= 3.817E-03
I= 3 THIST(ORIGINAL)= 3.831E-03 (NEW)= 0.000E+00
I= 4 THIST(ORIGINAL)= 3.860E-03 (NEW)= 0.000E+00
I= 5 YHIST(ORIGINAL)= -3.759E+01 (NEW)= 0.000E+00
I= 6 YHIST(ORIGINAL)= 1.835E+02 (NEW)= 0.000E+00
I= 7 YHIST(ORIGINAL)= 3.903E+02 (NEW)= 0.000E+00
I= 8 DAMP(ORIGINAL)= 1.500E-01 (NEW)= 0.000E+00
I= 9 TAU(ORIGINAL)= 4.000E-05 (NEW)= 0.000E+00
  TO CHANGE ANY VALUE ENTER THE "I" VALUE FOR THE VARIABLE
  0 - TO EXIT CHANGE LOOP

-> 5
ENTER NEW VALUE OF VARIABLE BEING CHANGED
-> -9.000E+01
I= 1 THIST(ORIGINAL)= 3.787E-03 (NEW)= 0.000E+00
I= 2 THIST(ORIGINAL)= 3.804E-03 (NEW)= 3.817E-03
I= 3 THIST(ORIGINAL)= 3.831E-03 (NEW)= 0.000E+00
I= 4 THIST(ORIGINAL)= 3.860E-03 (NEW)= 0.000E+00
I= 5 YHIST(ORIGINAL)= -3.759E+01 (NEW)= -9.000E+01
I= 6 YHIST(ORIGINAL)= 1.835E+02 (NEW)= 0.000E+00
I= 7 YHIST(ORIGINAL)= 3.903E+02 (NEW)= 0.000E+00
I= 8 DAMP(ORIGINAL)= 1.500E-01 (NEW)= 0.000E+00
I= 9 TAU(ORIGINAL)= 4.000E-05 (NEW)= 0.000E+00
  TO CHANGE ANY VALUE ENTER THE "I" VALUE FOR THE VARIABLE
  0 - TO EXIT CHANGE LOOP

-> 0

WANT TO PLOT STRESS RECORD, ESTIMATED HISTORY, AND COMPUTED?
Notes: The resulting change in the match between the original record and the computed history is evident in Figure 17b. The variance (which follows) has been significantly reduced.

\[
\text{VARIANCE } V_0 = 1.574E+05
\]

\[
\text{FR. DAMP } = 1.500E-01 \quad \text{PERIOD } = 4.000E-05
\]

FOR TIME INTERVAL( 3.800E-03, 3.920E-03)

<table>
<thead>
<tr>
<th>I</th>
<th>LABEL(I)</th>
<th>VALUE(I)</th>
<th>DEL(1)</th>
<th>DEL(2)</th>
<th>VARIANCE(I)</th>
<th>VARIANCE(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>THIST(0)</td>
<td>3.787E-03</td>
<td>1.000E-06</td>
<td>-1.000E-06</td>
<td>1.579E+05</td>
<td>1.570E+05</td>
</tr>
<tr>
<td>2</td>
<td>THIST(1)</td>
<td>3.817E-03</td>
<td>1.400E-06</td>
<td>-1.400E-06</td>
<td>1.743E+05</td>
<td>1.462E+05</td>
</tr>
<tr>
<td>3</td>
<td>THIST(2)</td>
<td>3.831E-03</td>
<td>1.400E-06</td>
<td>-1.400E-06</td>
<td>1.950E+05</td>
<td>1.261E+05</td>
</tr>
<tr>
<td>4</td>
<td>THIST(3)</td>
<td>3.860E-03</td>
<td>2.000E-06</td>
<td>-2.000E-06</td>
<td>1.720E+05</td>
<td>1.441E+05</td>
</tr>
<tr>
<td>5</td>
<td>YHIST(1)</td>
<td>-9.000E+01</td>
<td>1.000E+01</td>
<td>-1.000E+01</td>
<td>1.559E+05</td>
<td>1.616E+05</td>
</tr>
<tr>
<td>6</td>
<td>YHIST(2)</td>
<td>1.835E+02</td>
<td>2.068E+01</td>
<td>-2.068E+01</td>
<td>1.157E+05</td>
<td>2.085E+05</td>
</tr>
<tr>
<td>7</td>
<td>YHIST(3)</td>
<td>3.903E+02</td>
<td>1.000E+01</td>
<td>-1.000E+01</td>
<td>1.532E+05</td>
<td>1.641E+05</td>
</tr>
<tr>
<td>8</td>
<td>DAMP</td>
<td>1.500E-01</td>
<td>1.500E-02</td>
<td>-1.500E-02</td>
<td>1.677E+05</td>
<td>1.483E+05</td>
</tr>
<tr>
<td>9</td>
<td>TAU</td>
<td>4.000E-05</td>
<td>4.000E-06</td>
<td>-4.000E-06</td>
<td>1.814E+05</td>
<td>1.657E+05</td>
</tr>
</tbody>
</table>

WANT TO CHANGE THE WINDOW?

\[\rightarrow \text{N}\]

WANT TO CHANGE ANY VALUE OF TRIAL RECORD?

\[\rightarrow \text{Y}\]

TO CHANGE ANY VALUE ENTER THE "I" VALUE FOR THE VARIABLE

0 - TO EXIT CHANGE LOOP

Notes: Here we move the 2nd point in time and amplitude (I values of 3 and 6).

\[\rightarrow 3\]

ENTER NEW VALUE OF VARIABLE BEING CHANGED

\[\rightarrow 3.829E-03\]

<table>
<thead>
<tr>
<th>I</th>
<th>THIST(ORIGINAL)</th>
<th>VALUE</th>
<th>NEW</th>
<th>DEL(1)</th>
<th>DEL(2)</th>
<th>VARIANCE</th>
<th>VARIANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>THIST(ORIGINAL)</td>
<td>3.787E-03</td>
<td>(NEW)</td>
<td>0.000E+00</td>
<td>0.000E+00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>THIST(ORIGINAL)</td>
<td>3.804E-03</td>
<td>(NEW)</td>
<td>3.817E-03</td>
<td>3.829E-03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>THIST(ORIGINAL)</td>
<td>3.831E-03</td>
<td>(NEW)</td>
<td>3.829E-03</td>
<td>0.000E+00</td>
<td>-3.759E+01</td>
<td>-9.000E+01</td>
</tr>
<tr>
<td>4</td>
<td>THIST(ORIGINAL)</td>
<td>3.860E-03</td>
<td>(NEW)</td>
<td>0.000E+00</td>
<td>0.000E+00</td>
<td>1.835E+02</td>
<td>0.000E+00</td>
</tr>
<tr>
<td>5</td>
<td>YHIST(ORIGINAL)</td>
<td>-3.759E+01</td>
<td>(NEW)</td>
<td>0.000E+00</td>
<td>0.000E+00</td>
<td>3.903E+02</td>
<td>0.000E+00</td>
</tr>
<tr>
<td>6</td>
<td>YHIST(ORIGINAL)</td>
<td>1.835E+02</td>
<td>(NEW)</td>
<td>0.000E+00</td>
<td>0.000E+00</td>
<td>1.500E-01</td>
<td>0.000E+00</td>
</tr>
<tr>
<td>7</td>
<td>YHIST(ORIGINAL)</td>
<td>3.903E+02</td>
<td>(NEW)</td>
<td>0.000E+00</td>
<td>0.000E+00</td>
<td>4.000E-05</td>
<td>0.000E+00</td>
</tr>
</tbody>
</table>

TO CHANGE ANY VALUE ENTER THE "I" VALUE FOR THE VARIABLE

0 - TO EXIT CHANGE LOOP
-> 6
ENTER NEW VALUE OF VARIABLE BEING CHANGED
-> 2.400E+02
I= 1 THIST(ORIGINAL)= 3.787E-03 (NEW)= 0.000E+00
I= 2 THIST(ORIGINAL)= 3.804E-03 (NEW)= 3.817E-03
I= 3 THIST(ORIGINAL)= 3.831E-03 (NEW)= 3.829E-03
I= 4 THIST(ORIGINAL)= 3.860E-03 (NEW)= 0.000E+00
I= 5 YHIST(ORIGINAL)= -3.759E+01 (NEW)= -9.000E+01
I= 6 YHIST(ORIGINAL)= 1.835E+02 (NEW)= 2.400E+02
I= 7 YHIST(ORIGINAL)= 3.903E+02 (NEW)= 0.000E+00
I= 8 DAMP(ORIGINAL)= 1.500E-01 (NEW)= 0.000E+00
I= 9 TAU(ORIGINAL)= 4.000E-05 (NEW)= 0.000E+00
TO CHANGE ANY VALUE ENTER THE "I" VALUE FOR THE VARIABLE
0 - TO EXIT CHANGE LOOP

WANT TO PLOT STRESS RECORD, ESTIMATED HISTORY, AND COMPUTED?
-> Y

Notes: The resulting plot is in Figure 17c. Again the match has been improved considerably.

VARIANCE VO = 4.889E+04
FR. DAMP = 1.500E-01 PERIOD = 4.000E-05
FOR TIME INTERVAL( 3.800E-03, 3.920E-03)

<table>
<thead>
<tr>
<th>LABEL(I)</th>
<th>VALUE(1)</th>
<th>DEL(1)</th>
<th>DEL(2)</th>
<th>VARIANCE(1)</th>
<th>VARIANCE(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>THIST(0)</td>
<td>3.787E-03</td>
<td>1.000E-06</td>
<td>-1.000E-06</td>
<td>4.867E+04</td>
</tr>
<tr>
<td>2</td>
<td>THIST(1)</td>
<td>3.817E-03</td>
<td>1.200E-06</td>
<td>-1.200E-06</td>
<td>5.517E+04</td>
</tr>
<tr>
<td>3</td>
<td>THIST(2)</td>
<td>3.829E-03</td>
<td>1.200E-06</td>
<td>-1.200E-06</td>
<td>5.661E+04</td>
</tr>
<tr>
<td>4</td>
<td>THIST(3)</td>
<td>3.860E-03</td>
<td>2.000E-06</td>
<td>-2.000E-06</td>
<td>5.908E+04</td>
</tr>
<tr>
<td>5</td>
<td>YHIST(1)</td>
<td>-9.000E+01</td>
<td>1.000E+01</td>
<td>-1.000E+01</td>
<td>4.597E+04</td>
</tr>
<tr>
<td>6</td>
<td>YHIST(2)</td>
<td>2.400E+02</td>
<td>1.503E+01</td>
<td>-1.503E+01</td>
<td>4.260E+04</td>
</tr>
<tr>
<td>7</td>
<td>YHIST(3)</td>
<td>3.903E+02</td>
<td>1.000E+01</td>
<td>-1.000E+01</td>
<td>4.425E+04</td>
</tr>
<tr>
<td>8</td>
<td>DAMP</td>
<td>1.500E-01</td>
<td>1.500E-02</td>
<td>-1.500E-02</td>
<td>4.758E+04</td>
</tr>
<tr>
<td>9</td>
<td>TAU</td>
<td>4.000E-05</td>
<td>4.000E-06</td>
<td>-4.000E-06</td>
<td>4.915E+04</td>
</tr>
</tbody>
</table>

WANT TO CHANGE THE WINDOW?
-> N
WANT TO CHANGE ANY VALUE OF TRIAL RECORD?
-> Y
TO CHANGE ANY VALUE ENTER THE "I" VALUE FOR THE VARIABLE
0 - TO EXIT CHANGE LOOP

Notes: At this time we moved the third point in time and amplitude (I values of 4 and 7).

-> 4
ENTER NEW VALUE OF VARIABLE BEING CHANGED

39
Notes: We are now happy with the correspondence between the original record and the computed history, so we end the session.

WANT TO PLOT STRESS RECORD, ESTIMATED HISTORY, AND COMPUTED?  
-> Y

Notes: The figure plotted at this time is shown in Figure 17d.

VARIANCE VO =  2.768E+04
FR. DAMP = 1.500E-01  PERIOD = 4.000E-05

FOR TIME INTERVAL( 3.800E-03, 3.920E-03)
7 YHIST(3)  3.950E+02  1.000E+01  -1.000E+01  2.515E+04  3.250E+04
8 DAMP  1.500E-01  1.500E-02  -1.500E-02  2.822E+04  2.932E+04
9 TAU  4.000E-05  4.000E-06  -4.000E-06  4.858E+04  4.414E+04

WANT TO CHANGE THE WINDOW?
→ N

WANT TO CHANGE ANY VALUE OF TRIAL RECORD?
→ N

WANT TO PLOT STRESS RECORD, ESTIMATED HISTORY, AND COMPUTED?
→ N— SENDS TO END

→ Y

XMIN, XMAX = 3.800E-03 3.900E-03 WANT TO CHANGE THEM?
→ Y

ENTER XMIN,XMAX
→ 3.800E-03 5.000E-03

Notes: Here a plot like that in Figure 18 is generated. The solid line is the original record, the symbols are the trial stress history, and the dashed line is the computed stress history.

WANT TO GO BACK TO MODIFY RECORD FURTHER?
→ N— SEND TO END

→ N

WANT HARD COPIES OF RESULTS?
→ Y

*** PLOTTING ACTUAL, EST., COMPUTED RECORDS

XMIN, XMAX = 3.800E-03 5.000E-03 WANT TO CHANGE THEM?
→ N

Notes: This figure is not shown.

*** PLOTTING ACTUAL, SMEARED, AND COMPUTED RECORDS

XMIN, XMAX = 3.800E-03 5.000E-03 WANT TO CHANGE THEM?
→ N

Notes: This figure is not shown.

*** PLOTTING FINAL RECORD

XMIN, XMAX = 3.800E-03 5.000E-03 WANT TO CHANGE THEM?
→ N

Notes: The result is Figure 19.

DO YOU WANT TO CALCULATE VELOCITY?
→ N

41
FIGURE 18  COMPARISON OF MEASURED RECORD, ESTIMATED STRESS HISTORY AND COMPUTED STRESS RECORD FOR SH10 ON DISKO-1
FIGURE 19  FINAL ESTIMATED STRESS HISTORY DERIVED FROM RECIPIT FOR HORIZONTAL STRESS RECORD SH10 ON DISKO-1
V SAMPLE RESULTS FROM THE RECFIT PROCEDURE

All the vertical and horizontal SE stress gage records from DISKO-1 were processed with RECFIT. Samples of these results are presented here.

Figures 20 and 21 show the records and stress histories for vertical stress gages SV1 and SV15. The constructed histories [20(a) and 21(a)] show a rapid rise to midheight of the first shock front and a more gradual rise thereafter. This is the kind of shock front detail we had hoped to obtain with the procedure. (For this study the shock front is considered to be a portion of the record in which there is a large increase in stress in 20 to 50 μs.) Figures 20(b) and 21(b) compare the actual record and the pseudo record computed from the stress history in part (a) of each figure. The correspondence is very close in the area of the two shock fronts, the regions of particular importance for determining material properties.

The vertical stress records show a two-part rise in their wave fronts. For example, gage SV1 shows a steep rise to about 700 psi within 3 to 10 microseconds. The second step up to the first peak occurs more gradually over 40 to 100 microseconds.

Results for two horizontal stress gages are shown in Figures 22 and 23. The constructed histories have a similar appearance to those of the vertical gages, as they should. Because of the additional erosion of the sweeping wave effect, these wave fronts are not so clearly defined as those for the vertical stress gages. In Figures 22(b) and 23(b) the computed and actual records nearly coincide during the first few major oscillations; thereafter the actual record continues to oscillate, but the computed record is smooth. We did not continue the RECFIT process past 100 μs after the wave front to obtain a more precise match because the subsequent oscillations do not affect the stress-strain or $K_0$ relations that can be deduced from these records.
FIGURE 20  CONSTRUCTED STRESS HISTORY AND STRESS RECORDS FROM SE GAGE SV1 IN THE DISKO-1 EXPERIMENT

(a) Constructed Stress History

(b) Actual and Computed Stress Records
FIGURE 21  CONSTRUCTED STRESS HISTORY AND STRESS RECORDS FROM SE GAGE SV15 IN THE DISKO-1 EXPERIMENT
CONSTRUCTED STRESS HISTORY AND STRESS RECORDS FROM SE GAGE SH8 IN THE DISKO-1 EXPERIMENT
(a) Constructed Stress History

(b) Comparison of Computed and Actual Records

FIGURE 23 CONSTRUCTED STRESS HISTORY AND STRESS RECORDS FROM SE GAGE SH10 IN THE DISKO-1 EXPERIMENT
Figures 20 through 23 indicate that the RECFIT procedure produces satisfactory results for both horizontal and vertical stress gage records from the DISKO-1 event.
REFERENCES

1. Windham, J. E. January 1982. "Test Plan for Dynamic In Situ $K_0$ Tests (DISKO-1)," US Army Engineer Waterways Experiment Station, Vicksburg, MS.


Appendix A

CONSTRUCTION OF A GAGE RECORD
FOR A PRESCRIBED VERTICAL STRESS HISTORY

At several points in the study, it was necessary to construct a gage record for a prescribed stress history, while accounting for the gage frequency and damping. Both an analytical and a numerical procedure were developed for the record construction. For the exploratory studies, the analytical approach was used in a small program called MAKREC. For the main program RECFIT, the numerical method was used. Both procedures are outlined here.

The basic equation governing the gage response describes the displacement $y$ of a damped, one-degree-of-freedom oscillator:

$$\ddot{y} + 2\beta \dot{y} + \omega^2 y = \omega^2 y_{ST} f(t)$$  \hspace{1cm} (A.1)

where $y_{ST}$ is the peak static response that would occur under the prescribed loading and $f(t)$ is the loading history. The circular frequency of the oscillator and gage is $\omega$, and $\beta$ is the damping factor defined such that $\beta/\omega$ is the fraction of critical damping.

We consider only displacements $y$ and $y_{ST}$ and no stresses because of the nature of the SE stress gage. The gage is calibrated so that its strain (or equivalently deflection) is related to a surface stress. Thus, through the calibration factor we can relate $y_{ST}$ to the prescribed loading and $y$ to the apparent stress recorded by the gage.

For the analytical solution, we start with the integral form of equation (A.1), as given by Biggs:

$$y = y_{ST} \frac{\omega^2}{\omega^2} \int_{t_1}^{t} f(\tau) e^{-\beta(t-\tau)} \sin \omega_d(t - \tau) \, d\tau$$  \hspace{1cm} (A.2)
\[ y = e^{-\beta t} \frac{\dot{y}_0 + \beta y_0}{\omega_d} \sin \omega_d t + y_0 \cos \omega_d t + e^{-\beta t} \frac{\dot{y}_0 + \beta y_0}{\omega_d} \sin \omega_d (t - t_1) + y_0 \cos \omega_d (t - t_1) \]

Here \( \omega_d \) is the damped circular frequency:

\[ \omega_d^2 = \omega^2 - \beta^2 \]  
(A.3)

and \( y_0 \) and \( \dot{y}_0 \) are the position and velocity at \( t = t_1 \). The loading consists of a series of linear segments starting at the origin, as shown in Figure A.1. The analysis is then derived for the response of the oscillator to a single ramp loading given by

\[ y_{stf}(t) = \frac{\Delta y}{\Delta t} (t - t_1) \]  
(A.4)

where \( t_1 \) is the starting time for the ramp. The response to the series of linear segments is then obtained by superposition. The angles for the successive ramps are shown in Figure A.1. For a ramp loading extending from \( t_1 \) to some time \( t \), equation (A.2) can be integrated to give:

\[ y = \frac{\Delta y}{\Delta t} \left\{ t - t_1 - \frac{2\beta}{\omega} - \frac{e^{-\beta(t - t_1)}}{\omega_d} \left[ \left( 1 - \frac{2\beta^2}{\omega^2} \right) \sin \omega_d(t - t_1) \right] \right\} \]

where \( \Delta y/\Delta t \) is the rate of rise of the ramp loading.

When we designate the contribution of the \( i \)th ramp loading as \( y_i \), then the displacement (or apparent stress on the gage) is

\[ y = \sum_{i=1}^{I} y_i \]  
(A.6)
where \( I \) is the number of linear segments used to construct the loading at the current time \( t \).

The foregoing analysis was used in the MAKREC program. This analysis would be time-consuming and inconvenient for a calculation with many prescribed loading points, so a numerical method was used for the RECFIT program.

A numerical integration of the equation of motion was constructed for RECFIT in the subroutine RUNG. RUNG uses a fourth-order Runge-Kutta technique for each time interval of the digitized stress records. The basic equation of the damped oscillator, equation (A.1), is rewritten as two first degree equations in velocity \( u \) and position \( y \):

\[
\begin{align*}
\ddot{u} + 2\beta u + \omega^2 y &= \omega y_{ST}f(t) \\
\dot{y} &= u
\end{align*}
\]

(A.7a) \hspace{1cm} (A.7b)

This pair of equations is then integrated by the Runge-Kutta procedure to determine values of \( y \) at each time step.
FIGURE A.1 DESCRIPTION OF A PRESCRIBED LOADING COMPOSED OF LINEAR SEGMENTS
Appendix B

ACCOUNTING FOR A STRESS WAVE
THAT SWEEPS OVER A DIAPHRAGM GAGE FACE

A stress wave that gradually sweeps over a diaphragm stress gage produces a stress record with a gradual rise to it. The shape of this gradually rising record is derived here. Then a method is developed for accounting for this sweeping effect for waves of arbitrary history.

To analyze this gradual loading, we considered first the response of a clamped circular elastic plate to a step wave that sweeps over the plate. The expression for the central deflection \( dw \) for a stress \( \bar{p} \) acting on an area \( dA \) at a radius \( b \) is (from Timoshenko\(^6\))

\[
dw = \frac{\bar{p}}{8aD} \left( b^2 \ln \frac{b}{a} + \frac{a^2 - b^2}{2} \right) dA
\]  

(B.1)

where \( a \) and \( D \) are the radius and the bending stiffness of the plate, respectively. The geometry of the wave and plate dimensions are shown in Figure B.1.

The central deflection under a step wave sweeping across the gage from \(-a\) to \(b\) is obtained by integrating equation (B.1).

\[
\frac{\bar{w}}{w_m} = \frac{8}{\pi} \int_{-a}^{b} \int_{-H}^{H} \left[ \frac{b^2}{a} \ln \frac{b}{a} + \frac{1}{2} \left( 1 - \frac{b^2}{a^2} \right) \right] \frac{dh \, dx}{a^2}
\]

(B.2)

where \( H \) and \(-H\) are the limits on the vertical strip of load shown in Figure B.1 and \( w_m \) is the central deflection under a uniform load \( q \) applied to the entire plate:

\[
w_m = \frac{qa}{64D}
\]

(B.3)

For evaluating equation (B.2), \( b \) is written as

B-1
FIGURE B.1 NOMENCLATURE FOR ANALYSIS OF THE RESPONSE OF THE SE DIAPHRAGM GAGE TO A SWEEPING WAVE
\[ b^2 = h^2 + x^2 \]  \hspace{1cm} (B.4)

where \( h \) is the vertical distance to the loaded point as shown in Figure B.1.

Equation (B.2) was integrated numerically to study the response to the sweeping wave. The central deflection for the step pulse is shown in Figure B.2. Evidently, the gage responds very little when the wave first reaches the gage, so the response is not proportional to the crossing time (nor to the gage area covered). To further aid in understanding the response, the analysis was repeated for a loading only along a vertical strip, as shown in Figure B.3. Here the differential quantity \( (\Delta \omega / \Delta x) \omega_m \) is plotted. This differential quantity is the one to be used later for computing records for stress histories of arbitrary shape.

For routine use of the response function in Figure B.3, it was expedient to find a simple analytical approximation. We chose

\[ y = Y \sin \frac{2\pi}{2\pi} \left( c \frac{t - \bar{t}}{2\pi Y} + \frac{1}{2} \right) \]  \hspace{1cm} (B.5)

for \( \bar{t} = \tilde{t} - \frac{a}{Yc} \) to \( \bar{t} + \frac{a}{Yc} \)

where \( \bar{t} \) is the time at the center of the gage, \( Y = 1.13 \) is the amplitude at the center, and \( c \) is the sound speed. In this approximation, the gage response begins at the starred point at the left in Figure B.3, rises to the correct peak, and returns to zero at the starred point on the right. The coefficients in equation (B.5) were selected so that the integral over the approximate response function agrees with the exact result.

For a time increment from \( t_{i-1} \) to \( t_i \), equation (B.5) can be integrated to obtain the appropriate response function:

\[
\Delta F_i = \frac{1}{\Delta t} \int_{t_{i-1}}^{t_i} P(t) dt = \left[ \frac{c(t - \bar{t})}{2\pi Y} - \frac{1}{2\pi} \sin \frac{2\pi}{2\pi} \left( c \frac{t - \bar{t}}{2\pi Y} + \frac{1}{2} \right) \right]_{t_{i-1}}^{t_i} \]  \hspace{1cm} (B.6)

B-3
FIGURE B.2 RESPONSE OF A HORIZONTAL STRESS GAGE TO A SWEEPING STEP PULSE
FIGURE B.3 RESPONSE OF THE HORIZONTAL STRESS GAGE TO AN INCREMENT OF THE WAVE
This expression for the response function is used in RECFIT for processing horizontal stress gage records.
Appendix C

LISTING OF RECFIT

The following listing contains all the subroutines used with RECFIT, listed in alphabetical order after the main program. Included are FINDSHK, HORGAGE, MINMAX, RECIST, RECOPT, RECPLT, RUNG, RECRED, and VARIAN. The purpose of each subroutine is listed below.

FINDSHK: Locate the region of shock fronts (rapidly changing stresses) in the record.

HORGAGE: Provide the calculation that represents smearing the stress history over the diameter of the gage.

MINMAX: Compute the minimum and maximum of the stress in a range of times.

RECIST: Construct the first trial stress history.

RECOPT: Determine the effect of varying some of the coordinate times and amplitudes, frequency and damping of the gage.

RECPLT: Plot graphs of the stress record and histories.

RUNG: Runge-Kutta integration of the one-degree-of-freedom equation of motion for the gage response to the trial stress history.

RECRED: Read the gage record.

VARIAN: Determine the variance between the actual record and a computed record.

The standard graphing routine GRAPH4 (and its associated routines GINITL, G PLOT, and JFRAME) is called by RECFIT and RECPLT. GRAPH4 is not provided because it has been implemented only on the SRI computers.

The main program RECFIT calls FINDSHK, HORGAGE, RECOPT, RECPLT, RECRED, RECIST, and RUNG. RECOPT calls HORGAGE, RUNG, and VARIAN. RECPLT calls only MINMAX. The other subroutines have no call statements to other subroutines listed here.
PROGRAM RECFIT

PROGRAM FOR PROCESSING RECORDS FROM GAGES TO ELIMINATE
THE FREQUENCY AND DAMPING CHARACTERISTICS OF THE GAGES.
FOR GAGES IN WHICH THE WAVE SWEEPS OVER THE GAGE FACE, THE
PROGRAM CAN ALSO REMOVE THE SWEEPING EFFECT.

WRITTEN BY BONNIE LEW OF SRI IN MARCH, 1984 FOR W. E. S.

TACTL  TIME OF THE ORIGINAL RECORD, AT UNIFORM INCREMENTS
OF -DT-
YACTL  ORIGINAL RECORD
YHORGG RECORD BASED ON SMEARING A TRIAL STRESS HISTORY OVER
A HORIZONTAL GAGE
YHIST  ESTIMATED STRESS HISTORY
THIST  TIME OF ESTIMATED STRESS HISTORY, NON UNIFORM -DT-
YRCOMP RECORD COMPUTED BY APPLYING THE ESTIMATED STRESS
HISTORY TO THE GAGE
YVELOC VELOCITY COMPUTED FROM ACCELERATION
YACTL, YRCOMP, AND YHORGG ARE ALL AT THE TIMES GIVEN BY TACTL

MODIFIED FEB, 1986 BY FJL

FILE NUMBERS USED:
1 - INPUT CONTAINING ORIGINAL RECORD
3 - RESTART FILE
4 - OUTPUT CONTAINING RECFIT DATA
5 - INPUT FROM TERMINAL
6 - OUTPUT TO SCREEN
8 - RECORD OF INTERACTIVE SESSION
9 - SCRATCH FILE CONTAINING SMEARING FUNCTION FROM HORGAGE

IMPLICIT REAL*4 (A-H,O-Z)
CHARACTER IDENT*50,IDAT*10
CHARACTER*80 TITLE(3)
CHARACTER*20 FILENAME,FILENAME3,FILENAME4,NAME,FILENAME7
CHARACTER*9 LABEL(9),STATUS
CHARACTER*1 IANS,IANSH,IANSA
DIMENSION TACTL(5001),YACTL(5001),YHORGG(5001),YRCOMP(5001)
DIMENSION ISHOCK(2),DELT5(2),VAO(9),VA(9),DEL(9),V(9)
DATA LABEL,' THIST(0)','THIST(1)',' THIST(2)',' THIST(3)'
@ ' YHIST(1)'),' YHIST(2)'),' YHIST(3)'),' DAMP'),' TAU'/
DATA PI/3.14159265/
OPEN (8,FILE='INTERACTIVE',STATUS='NEW')
OPEN (9,STATUS='SCRATCH')
CALL GINITL(0)
CALL DATE(IDAT)
STATUS = 'NEW'
WRITE (8,1000)
WRITE (6,1000)

1000 FORMAT(/'***** RECFIT, AN INTERACTIVE RECORD FITTING'@
', 'PROGRAM')

IBUG = 0
XMIN = 0.
XMAX = 0.
LS = 0

**************

GET FILENAME AND SET UP OUTPUT FILENAMES

**************

PROGRAM RECFIT
C **************

20 WRITE (6,9015)
WRITE (8,9015)

9015 FORMAT(//' ENTER FILE NAME CONTAINING ORIGINAL GAGE DATA')
READ (5,9020,ERR=20) FILENAME
WRITE (8,9019) FILENAME

9019 FORMAT ('->',1X,A20)

9020 FORMAT(A40)
K-INDEX(FILENAME,'.')-1
NAME=FILENAME(1:K)
FILENAME3=NAME(1:K)//'///RST'
FILENAME4=NAME(1:K)//'///GUI'
OPEN (4,FILE=FILENAME4,STATUS='NEW')

C **************

C CHECK FOR RESTART RUN
C **************

WRITE (8,1111)
WRITE (6,1111)

1111 FORMAT(//' IS THIS A RESTART RUN? ')
READ (5,1002) IAMS
WRITE (8,4002) IAMS

4002 FORMAT ('->',1X,A1)
IF (IAMS .EQ. 'N') STATUS = 'OLD'
OPEN (3,FILE=FILENAME3,STATUS=STATUS,ERR=9999)
IF (IAMS .EQ. 'N') GO TO 125

C **************

C READ IN RESTART FILE FROM XXX.X.RST (FILENAME3)
C **************

READ (3,1008) IDUM
READ (3,1021) NMIST,F,TAU,TH,TU,NHIST,IB,RADIUS,BSP
READ (3,1019) (THIST(I),YMIST(I),I=1,NMIST)

C **************

C CALL -RECRED- TO READ THE FILE CONTAINING THE GAGE RECORD
C **************

125 CALL RECRED (LS,IDENT,IDENT,DT,YACTL,TACTL,FILDAMF)
IF (LS .EQ. 10) GO TO 950
IF (IAMS .EQ. 'Y') GO TO 140

C **************

C BEGIN CALCULATIONS TO CONSTRUCT A NEW STRESS HISTORY
C **************

135 WRITE (6,1135)
WRITE (8,1135)

1135 FORMAT(//' ENTER PERIOD OF THE GAGE (SEC) AND FRACTION OF'
@ ' DAMPING',/5X,'EXAMPLE: 2.5E-5,0.05')
READ (5,*) TAU,F
WRITE (8,4135) TAU,F

4135 FORMAT ('->',1X,1PE7.1,1PE7.1,'OPF4.1')

C **************

C HORIZONTAL GAGE
C **************

WRITE (6,1138)
WRITE (8,1138)

1138 FORMAT(//' ARE THE DATA FROM A HORIZONTAL GAGE?' )
READ (5,1002) IAMS
WRITE (8,4002) IAMS

C **************

140 TWINDO = 0.5*TAU
VA0(6)=F
VA0(9)=TAU
IF (IAMS .EQ. 'Y') GO TO 150

PROGRAM RECFIT (continued)
CALL RECIST TO CONSTRUCT THE FIRST ESTIMATED STRESS HISTORY

150 FORMAT(/' DO YOU WANT A PLOT OF ACTUAL RECORD AND TRIAL'
@ ', ' RECORD? ')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .EQ. 'N') GO TO 270
LS = -1
CALL RECPLT (LS, NPT, TACTL, YACTL, NNIST, THIST, YHIST, YHORGG, YRCMP, @ IDENT, XMIN, XMAX)

1205 FORMAT(/' WANT TO MODIFY RECORD? ', /, @ ' N- EXITS WITHOUT WRITING ANY OUTPUT FILES')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .EQ. 'N') GO TO 300
270 IF (IANS NE. 'Y') GO TO 300
CALL MORGAGE(0, THIST, YHIST, NNIST, THIST, DT, TACTL, YHORGG, 1, NPT, RADIUS, SSP)
WRITE (8,1275)
WRITE (6,1275)

1275 FORMAT(/' WANT TO PLOT ACTUAL RECORD AND STRESS HISTORY', /, @ ' OBTAINED FROM HORIZONTAL GAGE DATA? ')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS EQ 'N') GO TO 300
GRAPH THE SMEARED RECORD
LS = 2
CALL RECPLT (LS, NPT, TACTL, YACTL, NNIST, THIST, YHIST, YHORGG, YRCMP, @ IDENT, XMIN, XMAX)

CALL RECPLT (LS, NPT, TACTL, YACTL, NNIST, THIST, YHIST, YHORGG, YRCOMP)

PROGRAM RECIST (continued)
C **********
C BEGIN MODIFICATION OF ESTIMATED STRESS HISTORY.
C SELECT ONE SHOCK REGION AT A TIME.
C **********

400 FORMAT(/' WANT TO EXAMINE AND MODIFY RECORD IN DETAIL?
@ /','-N- WRITES OUTPUT FILE AND PREPARES TO EXIT')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .EQ. 'N') GO TO 795

C **********
C REQUEST PLOT RECORD, TRIAL STRESS HISTORY, COMPUTED RECORD
C **********

410 WRITE (6,1310)
WRITE (8,1310)
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .NE. 'Y') GO TO 440

415 LS = 3
CALL RECPIT (LS,NPT,TACTL,YACTL,NHIST,THIST,YHIST,YHORGG,YRCOMP,
@ IDENT,XMIN,XMAX)
WRITE (8,1417)
WRITE (6,1417)

1417 FORMAT(/' WANT TO REPLOT WITH DIFFERENT SCALES TO EXAMINE A'
@ ',' SMALL REGION? ')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .EQ. 'Y') GO TO 415

1418 FORMAT(/' IS RECORD FINISHED? WANT TO EXIT?')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .EQ. 'Y') GO TO 795

C **********
C FIND SHOCKS IN THE STRESS RECORD
C **********

440 TWF-TAU/6.
LS = 0
CALL FNDSHK(LS,NPT,TACTL,YACTL,NSHOCK,DELTS,ISHOCK,DT,TAU)
IF (LS .EQ. 10) GO TO 950

C **********
C DEFINE THE INTERVAL FOR EXAMINATION AND MODIFICATION
C **********

WRITE (8,1440)
WRITE (6,1440)

1440 FORMAT(/' ENTER TIME INTERVAL FOR CHANGING RECORD - TBEG,TEND'
@ ' (SEC)'/,'.7X,'THREE POINTS ARE USED, BEGINNING WITH TBEG')
READ (5,*) TBEG,TEND
WRITE (8,1440) TBEG,TEND

4440 FORMAT(' ->',/,'.1X,1PE7.1,'/.',E8.1)
C FIND WINDOW CORRESPONDING TO TBEG, TEND.
TEND = TBEG + 3.*TAU
IWINDO = (TBEG-TACTL(1))/DT +1.
JWINDO = (TEND-TACTL(1))/DT +2.
IF (IWINDO .GE. 1 .AND. IWINDO .LE. NPT-1) GO TO 450
WRITE (8,1445) IWINDO,TBEG,TEND,TACTL(1),TACTL(NPT)

PROGRAM RECPIT (Continued)
WRITE (6,1445) IWINDO, TBEG, TEND, TACTL(1), TACTL(NPT)
1445 FORMAT ('INAPPROPRIATE TIMES FOR WINDOW: IWINDO=',I5,
@ 'TBEG, TEND=', 1PE12.5, ' TIME RANGE OF RECORD IS FROM '
@ 'E12.5 TO ', E12.5)
GO TO 440
450 JWINDO = MIN(MAX(IWINDO+10, IWINDO), NPT)
IPLT=0
C ************
C FIND INDICES OF THIST POINTS THAT LIE IN THE INTERVAL FROM
C TBEG TO TEND
C ************
460 NHIST1 = NHIST-1
DO 460 N = 1, NHIST1
NB = N
IF (THIST(N+1).GT. TBEG) GO TO 465
CONTINUE
465 NB = MIN(NB, NHIST-4)
DO 470 N = NB, NHIST
NE = N
IF (THIST(N).GT. TEND) GO TO 475
CONTINUE
475 NE = MIN(NHIST, MAX(NE, NB+1))
DO 485 I = 1, 7
GO TO (478, 478, 478, 478, 478, 478, 478)
478 VAO(I) = THIST(NB+I-1)
GO TO 485
480 VAO(I) = YHIST(NB+I-4)
485 CONTINUE
C ************
C PLOT REQUEST FOR RECORD, ESTIMATED HISTORY, COMPUTED RECORD
C ************
490 WRITE (6,1310)
WRITE (8,1310)
WRITE (8,4002) IANS
READ (5,1002) IANS
IF (IANS .NE. 'Y') GO TO 600
LS = 13
IF (IPLT .EQ. 0) LS = LS-10
CALL RECPLT (LS, NPT, TACTL, YACTL, YHIST, THIST, YHOGG, YRCOMP, 
@ IDENT, KIN, DXAX)
IPLT = 1
C ************
C COMPUTE VARIANCE BETWEEN ACTUAL AND COMPUTED VALUES WITHIN WINDOW
C ************
600 CALL VARIAN(YACTL, YRCOMP, IWINDO, JWINDO, VO)
WRITE (8,1605) VO
WRITE (6,1605) VO
1605 FORMAT(' VARIANCE VO = ', 1PE12.3)
C WRITE (8,1620) FD, TAU
WRITE (6,1620) FD, TAU
1620 FORMAT('/' 'FR. DAMP = ', 1PE11.3, 2X, 'PERIOD = ', E11.3)
C ************
C CALL RECPFT TO DETERMINE THE EFFECT OF VARYING SOME OF THE
C COORDINATE TIMES AND AMPLITUDES, FREQUENCY AND DAMPING OF THE
C GAGE.
C ************
LS = 0
WRITE (8,1622) TBEG, TEND
WRITE (6,1622) TBEG, TEND

PROGRAM RECFIT (Continued)
1622 FORMAT ('/ FOR TIME INTERVAL(',1PE11.3,',',E11.3,')')
    CALL RECOPT (LS, IANSH, TBEG, TEND, TAU, FD, NPT, TACTL, YACTL,
               NHIST, THIST, YHIST, VO, LABEL, DT, YHORGG, YRCOMP)

C ********* ALTER THE ESTIMATED HISTORY, USING THE DERIVATIVE INFORMATION
C *********

WRITE (8,1661)
WRITE (6,1661)

1661 FORMAT (' WANT TO CHANGE THE WINDOW? ')
READ (5,1002) IANSA
WRITE (8,4002) IANSA
IF (IANSA .EQ. 'Y') GO TO 645
WRITE (8,1660)
WRITE (6,1660)

1660 FORMAT (' WANT TO CHANGE ANY VALUE OF TRIAL RECORD? ')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .EQ. 'Y') GO TO 700

645 DO 650 I=1,9
650 VA(I)=0.
GO TO 765

700 WRITE (6,1727)
WRITE (8,1727)

1727 FORMAT (' TO CHANGE ANY VALUE ENTER THE "I" VALUE FOR THE',
           'VARIABLE '/'7X,'0 - TO EXIT CHANGE LOOP')
READ (5,*)) I
WRITE (8,4727) I

4727 FORMAT (' ->',',IX,II)
IF (I .EQ. 0) GO TO 730

WRITE (8,1728)
WRITE (6,1728)

1728 FORMAT (' ENTER NEW VALUE OF VARIABLE BEING CHANGED')
READ (5,*) VA(I)
WRITE (8,4720) VA(I)

4720 FORMAT (' ->',',IX,1PE12.3)
WRITE (8,1720) (I,LABEL(I),VA0(I),VA(I),I=1,9)
WRITE (6,1720) (I,LABEL(I),VA0(I),VA(I),I=1,9)

1720 FORMAT (' I=','I2,2X,A6,'(ORIGINAL)='',1PE12.3,' (NEW)='',E12.3)  
GO TO 700

C ********* PUT CHANGED VALUES INTO ARRAY
C *********

730 DO 750 I=1,9
    IF (VA(I) .EQ. 0.) GO TO 750
    IF (I .LE. 4) THIST(NB+I-1)=VA(I)
    IF (I .GT. 4 .AND. I .LE. 7) YHIST(NB+I-4)=VA(I)
    IF (I .NE. 8) GO TO 740
    FD=VA(I)
    BETA=FD*2.*PI/TAU0

740 IF (I .NE. 9) GO TO 750
    TAU=VA(I)
    OMEGA=2.*PI/TAU

750 CONTINUE

C ********* COMPUTE RECORD BASED ON NEW VALUES OF YHIST AND THIST
C *********

IF (IANSH .NE. 'Y') GO TO 760
CALL HORGAGE(I,THIST,YHIST,NHIST,DT,TACTL,YHORGG,IWINDO,
               PROGRAM RECFIT (Continued)
CALL RUNG(IBUG,BETA,OMEGA,TACTL,YHORGG,NPT,DT,IWINDO, @ JWINDO,TACTL,YRCOMP)
GO TO 490
CALL RUNG(IBUG,BETA,OMEGA,THIST,YHIST,NHIST,DT,IWINDO, @ JWINDO,TACTL,YRCOMP)
GO TO 490
C *************** END OF ITERATION FOR EACH TIME INTERVAL IN THE RECORD C ***************
765 IF (IANSH .NE. 'Y') GO TO 770
CALL HORGAGE(1,THIST,YHIST,NHIST,DT,TACTL,YHORGG,1,NPT, @ RADIUS,SSP)
CALL RUNG(IBUG,BETA,OMEGA,TACTL,YHORGG,NPT,DT,1,NPT,TACTL, @ YRCOMP)
GO TO 790
770 CALL RUNG(IBUG,BETA,OMEGA,THIST,YHIST,NHIST,DT,1,NPT,TACTL, @ YRCOMP)
790 TAU0=2.*PI/OMEGA
C *************** WRITE RESTART FILE C ***************
REWIND (3)
WRITE (3,1008) IDENT
WRITE (3,1021) NHIST,FD,TAU0,SW,IANSH,RADIUS,SSP
WRITE (3,1019) (THIST(I),YHIST(I),I-1,NHIST)
IF (IANSA .EQ. 'Y') GO TO 440
C *************** C PLOT RECORD, ESTIMATED HISTORy, AND COMPUTED RECORD C ***************
WRITE (8,1312)
WRITE (6,1312)
1312 FORMAT ('/WANT TO PLOT STRESS RECORD, ESTIMATED HISTORY, AND' @ ' COMPUTED? ',/,' -N- SENDS TO END')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .EQ. 'N') GO TO 795
LS = 3
CALL RECPLT (LS,NPT,TACTL,YACTL,NHIST,THIST,YHIST,YHORGG,YRCOMP, @ IDENT,XMIN,XMAX)
WRITE (8,1800)
WRITE (6,1800)
1800 FORMAT ('/WANT TO GO BACK TO MODIFY RECORD FURTHER?' @ ',/,' -N- SEND TO END')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .EQ. 'Y') GO TO 410
C *************** C SAVE DATA FROM FINAL TRIAL RECORD ON FOR004 C ***************
795REWIND 4
WRITE (4,1008) IDENT
WRITE (4,1021) NHIST
WRITE (4,1020) (THIST(I),YHIST(I),I-1,NHIST)
C *************** C MAKE HARD COPIES OF PLOTTED RESULTS C ***************
830 WRITE (6,1830)
WRITE (8,1830)
PROGRAM RECFTT (Continued)
1830 FORMAT(' WANT HARD COPIES OF RESULTS?')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .EQ. 'N') GO TO 900
C CALL TO CLOSE OUT PLOTTING
CALL GPLOT(0.,0.,999)
C CALL TO INITIALIZE PLOTTING ON HARD COPY DEVICE
CALL GINITL(0)
C
850 LS = -3
CALL RECPLT (LS,NPT,TACTL,YACTL,NHIST,THIST,YHIST,YHORGG,YRCOMP, @ IDENT,XMIN,XMAX)
C LS = -6
IF (IANSH .EQ. 'Y') LS = -7
CALL RECPLT (LS,NPT,TACTL,YACTL,NHIST,THIST,YHIST,YHORGG,YRCOMP, @ IDENT,XMIN,XMAX)
WRITE (6,9860)
9860 FORMAT(' WANT MORE HARD COPIES WITH DIFFERENT SCALES?')
READ (5 1002) IANS
IF (IANS .EQ. 'N') GO TO 850
C CALL TO CLOSE PLOTTING HARD COPIES
CALL GPLOT(0.,0.,999)
C CALL TO INITIALIZE PLOTTING ON TERMINAL
CALL GINITL(1)
C ********
C INTEGRATE ACCELERATION RECORD FOR VELOCITY
C ********
900 WRITE (6,1905)
WRITE (8,1905)
1905 FORMAT(' DO YOU WANT TO CALCULATE VELOCITY?')
READ (5,1002) IANS
WRITE (8,4002) IANS
IF (IANS .NE. 'Y') GO TO 950
C CALCULATE VELOCITY FROM ACTUAL RECORD
YRCOMP(1) = 0.
DO 910 I=2,NPT
YRCOMP(I) = YRCOMP(I-1) + 0.5*DT*(YACTL(I-1) + YACTL(I))
910 CONTINUE
C CALCULATE VELOCITY FROM TRIAL RECORD
YVELOC(1) = 0.
DO 920 I=2,NHIST
YVELOC(I) = YVELOC(I-1) + 0.5*(THIST(I-1) - THIST(I-1)) * @ (YHIST(I-1) - YHIST(I))
920 CONTINUE
C LS = 5
CALL RECPLT (LS,NPT,TACTL,YACTL,NHIST,THIST,YHIST,YHORGG,YRCOMP, @ IDENT,XMIN,XMAX)
GO TO 950
9999 WRITE (6,997) FILENAME3
997 FORMAT(' ERROR IN OPENING ',A15)
950 CALL GPLOT(0.,0.,999)
CLOSE (2)
CLOSE (3)
CLOSE (4)
CLOSE (9)
STOP
C FORMATS
1002 FORMAT (A1)

PROGRAM RECFLR (Continued)
1008 FORMAT (A55)
1019 FORMAT (1P8E14.5)
1020 FORMAT (1P2E11.3)
1021 FORMAT (I5,3E12.5,4X,A1,2E12.5)
END
SUBROUTINE FNDSHK (LS, NPT, TIME, STRESS, NSHock, DELTS, IBEG, + DT, PERIOD)
*****
SUBROUTINE TO FIND SHOCK FRONT
*****
IMPLICIT REAL*4 (A-H,O-Z)
DIMENSION TIME(1), STRESS(1), DELTS(1), IBEG(1)
DIMENSION IBLOC(10), DSLOC(10)
*****
INITIALIZE
*****
LWINDO = 3.*PERIOD/DT + 1.
NSTEP = PERIOD/(4.*DT) + 1.
IBEGIN = 1
IBEGMX = 1
DELTAS = 0.0
NSHock = 0
*****
SEARCH FOR A SHOCK FRONT
*****
100 DS = STRESS(IBEGIN+NSTEP) - STRESS(IBEGIN)
   IF (DS .LE. DELTAS) GO TO 125
   DELTAS = DS
   IBEGMX = IBEGIN
125 IBEGIN = IBEGIN + 1
   IF (IBEGIN+NSTEP .LT. IBEGMX+LWINDO .AND. +
       IBEGIN+NSTEP .LT. NPT) GO TO 100
*****
STORE SHOCK FRONT DATA
*****
ISHK = 1
   IF (NSHock .EQ. 0) GO TO 200
   DO 175 IS = 1, NSHock
      IF (DSLOC(IS) .GE. DELTAS) GO TO 175
      ISHK = IS
   DO 150 I = IS, NSHock
      J = NSHock+IS-I
      DSLOC(J+1) = DSLOC(J)
      IBLOC(J+1) = IBLOC(J)
150 CONTINUE
   GO TO 200
175 CONTINUE
   IF (NSHock .GE. 10) GO TO 225
   ISHK = NSHock+1
200 DSLOC(ISHK) = DELTAS
   IBLOC(ISHK) = IBEGMX
   NSHock = MIN(NSHock+1, 10)
225 IF (IBEGIN+2*NSTEP .GE. NPT) GO TO 250
   IBEGIN = IBEGIN+NSTEP
   IBEGMX = IBEGIN
   DELTAS = 0.
   GO TO 100
*****
ASSEMBLE SHOCK DATA INTO FORMAL PARAMETERS
*****
250 WRITE (6,1025) (N, DSLOC(N), IBLOC(N), N = 1, NSHock)
250 NSHMax = MIN (NSHock, 2)
   DO 275 NS = 1, NSHMax
      DELTS(NS) = DSLOC(NS)
SUBROUTINE FNDSHK

C-11
275 IBEG(NS) = IBLOCL(NS)
L1 = IBEG(1)
L2 = IBEG(2)
WRITE (6,1027) TIME(L1),DELTS(1),TIME(L2),DELTS(2)
WRITE (8,1027) TIME(L1),DELTS(1),TIME(L2),DELTS(2)
RETURN

C FORMATS
1025 FORMAT (' N, DSLOCL(N), IBLOCL(N) = ',I3,1PE12.4,I8)
1027 FORMAT (' 1st SHOCK AT T = ',1PE12.4,' STRESS JUMP = ',E12.4/
     + ' 2nd SHOCK AT T = ',E12.4,' STRESS JUMP = ',E12.4)
END

SUBROUTINE FNDSHK (Concluded)
SUBROUTINE HORGAGE(NCALL, THIST, YNIST, NHIST, DT, TACTL, YHORGG, @ IWINDO, JWINDO, RADIUS.C)

CALCULATE STRESS HISTORY FROM GRADUAL LOADING ACROSS A CIRCULAR GAGE USING A STEP LOADING THAT MOVES ACROSS THE GAGE AT VELOCITY C

IMPLICIT REAL*4 (A-H,O-Z)
DIMENSION THIST(1), YHIST(1), YHORGG(1), F(50), TAUF(50), TACTL(1)

IF (NCALL .NE. 0) GO TO 60
WRITE (8,1002)
WRITE (6,1002)
1002 FORMAT(' ENTER GAGE RADIUS (CM)')
READ (5,*), RADIUS
WRITE (8,4004) RADIUS
4004 FORMAT(' -> ', 1X, F4.2)
WRITE (6,1004)
WRITE (8,1004)
1004 FORMAT(' ENTER SOUND SPEED (CM/SEC)')
READ (5,*), C
WRITE (8,4005) C
4005 FORMAT(' -> ', 1X, 1PE7.1)
ENTRY HRESTRT(NCALL, THIST, YNIST, NHIST, DT, TACTL, YHORGG, IWINDO.
1 JWINDO, RADIUS.C)
TWOPI=2.*3.14159265
TAUMX=0.885*RADIUS/C
NF=TAUMX/DT
NF2=2*NF+1
CON=C/(1.77*RADIUS)
TBAR=RADIUS/C
F1=0.
TAUF(1)=NF*DT
DO 50 J=1,NF2
IF (J .GT. 1) TAUF(J)=TAUF(J-1)+DT
FO=F1
F1=CON*TAUF(J)-SIN(TWOPI*(CON*TAUF(J)+0.5))/TWOPI
F(J)=0.
IF (J .GE. 1) F(J)=F1-FO
50 CONTINUE
WRITE(13,1040) (J, TAUF(J), F(J), J-1,NF2)
WRITE(9,1040) (J, TAUF(J), F(J), J-1,NF2)
1040 FORMAT(' J TAUF F'/(I5,1P2E11.3))

ENTRY HRESTRT(NCALL, THIST, YNIST, NHIST, DT, TACTL, YHORGG, @ IWINDO, JWINDO, RADIUS.C)
TWOPI=2.*3.14159265
TAUMX=0.885*RADIUS/C
NF=TAUMX/DT
NF2=2*NF+1
CON=C/(1.77*RADIUS)
TBAR=RADIUS/C
F1=0.
TAUF(1)=NF*DT
DO 50 J=1,NF2
IF (J .GT. 1) TAUF(J)=TAUF(J-1)+DT
FO=F1
F1=CON*TAUF(J)-SIN(TWOPI*(CON*TAUF(J)+0.5))/TWOPI
F(J)=0.
IF (J .GE. 1) F(J)=F1-FO
50 CONTINUE
WRITE(13,1040) (J, TAUF(J), F(J), J-1,NF2)
WRITE(9,1040) (J, TAUF(J), F(J), J-1,NF2)
1040 FORMAT(' J TAUF F'/(I5,1P2E11.3))
IF (THIST(IT+1) - THIST(IT) .LE. 1.0E-6) WRITE (13,9914)
C
@ J, MF2, TAUF(J), IT, T
C
@ THIST(IT), THIST(IT+1), YHOMOGG(I), F(J), YHIST(IT), YHIST(IT+1)
9914 FORMAT ('**HORGAGE, J, MF2=', '215.,' TAUF(J)=', '1PE11.3,
@ ' IT =', '15. ' T=', 'E11.3/' THIST(IT),
@ THIST(IT+1)='2E11.3/' YHOMOGG(I), F(J)='2E11.3,
@ YHIST(IT), YHIST(IT+1)='2E11.3)
@ YHOMOGG(I)-YHOMOGG(I)+F(J)*YHIST(IT)+(T+TAUF(J)-THIST(IT))*
@ (YHIST(IT+1)-YHIST(IT))/(THIST(IT+1)-THIST(IT))
100 CONTINUE
200 CONTINUE
C
RETURN
END

SUBROUTINE HORGAGE (Concluded)
SUBROUTINE MINMAX (YACTL, NPT, YMIN, YMAX)
DIMENSION YACTL(1)
YMIN = 2.E10
YMAX = -2.E10
DO 610 I=1, NPT
IF (YACTL(I) .GT. YMAX) YMAX = YACTL(I)
IF (YACTL(I) .LT. YMIN) YMIN = YACTL(I)
610 CONTINUE
RETURN
END
SUBROUTINE RECOPT (LS, IANSH, TBEG, TEND, TAU, FD, NPT, TACTL, YACTL, @ NHIST, THIST, YHIST, YG, LABEL, DT, YHORGG, YRCOMP)
C
VARY ONE AT A TIME THE S,T COORDINATES OF POINTS IN THE ESTIMATED
STRESS HISTORY, AND FREQUENCY AND DAMPING OF THE GAGE; COMPUTE
THE STRESS RECORDS FROM THE MODIFIED HISTORIES, AND THE
VARIANCES FROM THE ACTUAL RECORD. COMPUTE THE FINITE DIFF-
ERENCE APPROXIMATIONS TO THE DERIVATIVES OF THE VARIANCE WITH
RESPECT TO THE CHANGE IN THE ALTERED VARIABLE.
C
IMPLICIT REAL*4 (A-H,O-Z)
CHARACTER*1 IANSH
CHARACTER*9 LABEL(9)
DIMENSION THIST(1), YHIST(1), TACTL(1), YACTL(1), VALUE(2,9), @
DEL(2,9), DER(2,9), VARNCE(2,9), YHORGG(1), YRCOMP(1), DELMIN(9)
DATA PI/3.14159265/
DATA DELMIN /4*1.E-6, 3*100., 2*0./
IBUG = 0
DELFAC = 0.1
ICHUZ = 0
ISIGN = 1
VMIN = VO
OMEGA = 2.*PI/TAU
BETA = FD*OMEGA
IWINDO = (TBEG-TACTL(1))/DT +1.
JWINDO = (TEND-TACTL(1))/DT +2.
IF (IWINDO .GE. 1 .AND. IWINDO .LE. NPT-1) GO TO 100
WRITE (8,1005) IWINDO, TBEG, TEND, TACTL(1), TACTL(NPT)
WRITE (6,1005) IWINDO, TBEG, TEND, TACTL(1), TACTL(NPT)
1005 FORMAT ('INAPPROPRIATE TIMES FOR WINDOW. IWINDO=',I5, @
' TBEG,TEND=',1P2E12.5/' TIME RANGE OF RECORD IS FROM ' @
'E12.5,' TO ',E12.5) LS=-1
RETURN
C
WRITE (13,4150)
C
4150 FORMAT ('RECOPT START :'
@ ' THIST(I),YHIST(I), I=320,350')
100 JWINDO = MIN(MAX(IWINDO+10, JWINDO), NPT)
C
WRITE (13,4100) IWINDO, JWINDO
C
4100 FORMAT ('IWINDO, JWINDO=',I2,16, ' TACTL(I),I=IWINDO,JWINDO')
C
4110 FORMAT (IP6E13.5)
DO 200 I = 2, NHIST
IHIST = I-1
IF (THIST(I) .GT. TBEG) GO TO 210
200 CONTINUE
210 IHIST = MIN (IHIST, NHIST-4)
DO 240 I = IHIST, NHIST
JHIST = I
IF (THIST(I) .GT. TEND) GO TO 250
240 CONTINUE
250 JHIST = MIN (JHIST, MAX (JHIST, IHIST+1))
C
IWINDO = NPT
C
IF (LS .LE. 0) GO TO 300
IWINDO = IWINDO
JWINDO = JWINDO
300 DO 395 MINPLU = 1,2
DO 390 I=1,9
IF (LS .LE. 1) GO TO 310
SUBROUTINE RECOPT

C-16
IF (1 .LE. 1 .OR. 1 .EQ. 1 .OR. 1 .EQ. 9) GO TO 390
310 GO TO (320, 320, 320, 320, 320, 320, 330, 330, 340, 350) I
320 VALUE(MINPLU, I) = THIST(INIST + I - 1)
   IF (INIST + I .GT. 2) DELTAT = THIST(INIST + I - 1) - THIST(INIST + I - 2)
   IF (INIST + I .LE. NIST) DELTAT = MIN(DELTAT, THIST(INIST + I - 1)
   1) THIST(INIST + I - 1))
   DELTAT = MAX(DELMIN(I), DELTAT)
   DEL(MINPLU, I) = DELFA*DELTAT
   THIST(INIST - 1) = THIST(INIST - 1) + DEL(MINPLU, I)
   GO TO 360
330 VALUE(MINPLU, I) = YHIST(INIST + I - 4)
   DELTAY = YHIST(INIST + I - 4) - YHIST(INIST + I - 5)
   IF (INIST + I .LE. NIST) DELTAY = MIN(DELTAY, YHIST(INIST + I - 3)
   1) YHIST(INIST + I - 4))
   DELTAY = MAX(DELTAY, DELMIN(I))
   DEL(MINPLU, I) = DELFA*DELTAY
   YHIST(INIST + I - 4) = YHIST(INIST + I - 4) + DEL(MINPLU, I)
   GO TO 360
340 VALUE(MINPLU, I) = FD
   DEL(MINPLU, I) = DELFA*FD
   FD = FD + DEL(MINPLU, I)
   BETA = FD*2.*PI/TAU
   GO TO 360
350 VALUE(MINPLU, I) = TAU
   DEL(MINPLU, I) = DELFA*TAU
   TAU = TAU + DEL(MINPLU, I)
   OMEGA = 2.*PI/TAU
   BETA = FD*2.*PI/TAU
360 CONTINUE
C *********
C COMPUTE RECORD AND VARIANCE FOR EACH PARAMETER VARIATION
C IF (IANSH .NE. 'Y') GO TO 361
C WRITE (13, 4350)
4350 FORMAT (' RECOPT BEFORE CALL TO HORGAGE:
   THIST(K), YHIST(K), K = 320, 350')
C WRITE (13, 4360) (THIST(K), YHIST(K), K = 320, 350)
4360 FORMAT (1P2E13.5)
   CALL HORGAGE(2, THIST, YHIST, NIST, DT, TACTL, YHORG, IW, JWIN,
   @ RADIUS, SSP)
   CALL RUNG(IBUG, BETA, OMEGA, TACTL, YHORG, NPT, DT,
   @ IW, JWIN, TACTL, YRCOMP)
   GO TO 362
361 CALL RUNG(IBUG, BETA, OMEGA, THIST, YHIST, NIST, DT,
   @ IW, JWIN, TACTL, YRCOMP)
362 CALL VARIAN(TACTL, YRCOMP, IWINDO, JWINDO, VARNCE(MINPLU, I))
   DER(MINPLU, I) = 0.
   IF (VARNCE(MINPLU, I) .NE. V0)
   @ DER(MINPLU, I) = V0/((V0 - VARNCE(MINPLU, I))/DEL(MINPLU, I))
   IF (VARNCE(MINPLU, I) .GT. VMIN-1.) GO TO 364
   VMIN = VARNCE(MINPLU, I)
   ICHU = I
   ISIGN = MINPLU
C RETURN TO ORIGINAL VALUES OF EACH PARAMETER
364 GO TO (365, 365, 365, 365, 370, 370, 370, 370, 370, 380) I
365 THIST(INIST + I - 1) = VALUE(MINPLU, I)
   GO TO 390
370 YHIST(INIST + I - 4) = VALUE(MINPLU, I)
   GO TO 390
375 FD = VALUE(MINPLU, I)
   BETA = FD*2.*PI/TAU
SUBROUTINE RECOPT (Continued)
GO TO 390

TAU = VALUE(MINTLU, I)
OMEGA = 2. * PI / TAU
BETA = FD*2.*PI/TAU

CONTINUE
Delfac = -Delfac
CONTINUE

IF (LS .NE. 0) GO TO 397
WRITE (8,1053)
WRITE (6,1053)

1053 FORMAT (/" I',2X,'LABEL(I)',4X,'VALUE(I)',4X,'DEL(1)',5X,
@ 'DEL(2)',5X,'VARIANCE(1)',1X,'VARIANCE(2)'/)
WRITE (8,1054) (I,LABEL(I),VALUE(I),DEL(I),DEL(2),
@ VARIANCE(I),VARIANCE(2),1-1,9)
WRITE (6,1054) (I,LABEL(I),VALUE(I),DEL(I),DEL(2),
@ VARIANCE(I),VARIANCE(2),1-1,9)

1054 FORMAT (1X,I2,1X,A9,1X,1P5E12.3)

C COMPLETION FOR LS=0, ADVISORY CHANGE INFORMATION ONLY
RETURN

C ********
C ALTER ONE PARAMETER OF THE ESTIMATED HISTORY
C ********

397 IF (ICHUZ .EQ. 0) GO TO 430
GO TO (400,400,400,400, 408,408,408, 415, 418) ICHUZ

400 THIST(IHIST+ICHUZ-1) = THIST(IHIST+ICHUZ-1)+DEL(ISIGN, ICHUZ)
GO TO 425

408 YHIST(IHIST+ICHUZ-4) = YHIST(IHIST+ICHUZ-4)+DEL(ISIGN, ICHUZ)
GO TO 425

415 FD = FD+DEL(ISIGN, ICHUZ)
BETA = FD*2.*PI/TAU
GO TO 425

418 TAU = TAU+DEL(ISIGN, ICHUZ)
OMEGA = 2. * PI / TAU

425 CONTINUE

430 DELFAC = ABS(DELFAC)
IF (DELFAC .LT. 0.01) GO TO 500
IF (ICHUZ .EQ. 0) DELFAC = 0.5*DELFAC
ICHUZ = 0
GO TO 300

C ********
C ENDING ROUTINE
C ********

500 IF (IANSH .NE. 'Y') GO TO 505
CALL HORGAGE(1, THIST, YHIST, NHIST, DT, TACTL, YHORGG, IWIN, JWINDO, RADIUS,
@ SSP)
CALL RUNG(IBUG, BETA, OMEGA, TACTL, YHORGG, NPT, DT,
@ JWIN,JWIN,TACTL, YRCOMP)
GO TO 510

505 CALL RUNG(IBUG, BETA, OMEGA, THIST, YHIST, NHIST, DT,
@ JWIN,JWIN,TACTL, YRCOMP)

510 CALL VARIAN(YACTL, YRCOMP, IWINDO, JWINDO, V0)

SUBROUTINE RECOPT (Concluded)
SUBROUTINE RECPLT (LS, NPT, TACTL, YACTL, THIST, YHIST, YHORGG, @ YRCOMP, IDENT, XMIN, XMAX)
C PLOT SEVERAL HISTORIES FOR THE RECFIT PROGRAM
C LS = 1 ACTUAL RECORD, AND TRIAL STRESS HISTORY
C LS = 2 SMEARED ESTIMATE OF HORIZONTAL STRESS HISTORY
C LS = 3 ACTUAL RECORD, TRIAL HISTORY, COMPUTED RECORD
C LS = 4 SMEARED HISTORY, TRIAL HISTORY, AND COMPUTED RECORD
C LS = 5 PLOT OF ACCELERATION AND VELOCITY
C LS = 6 PLOT OF ACTUAL RECORD AND COMPUTED RECORD
C LS = 7 PLOT OF ACTUAL RECORD, SMEARED HISTORY, AND COMPUTED RECORD
C
DIMENSION IA(7), TACTL(1), YACTL(1), THIST(1), YHIST(1), YHORGG(1), 1 YRCOMP(1)
CHARACTER TITLE(3)*80, IDENT*50
DATA TITLE(2)/'TIME -- *SEC$'/
DATA IA/-2.5*0,5/
YMIN=0.
YMAX=0.
TITLE(1) = IDENT
LSM=MOD(ABS(LS),10)
GO TO (100,200,300,400,500,600,700,800) LSM
100 TITLE(3) = 'STRESS - ACTUAL RECORD, TRIAL HISTORY'
IF (ABS(LS) .GT. 10) GO TO 190
WRITE (8,1022) XMIN,XMAX
WRITE (6,1022) XMIN,XMAX
READ (5,1002), IANS
WRITE (8,4100) IANS
4100 FORMAT (' ',',I1X,A1)
IF (IANS .EQ. 'N') GO TO 190
WRITE (8,1024)
WRITE (6,1024)
READ (5,'*'), XMIN,XMAX
WRITE (8,4024) XMIN,XMAX
4024 FORMAT (' ',',I1X,1P2E12.3)
190 IA(1) = 1
CALL JFRAME
CALL GRAPH4(TACTL, YACTL, NPT, 1, XMAX, XMIN, YMAX, YMIN, TITLE, IA)
C IA(2) = 4
IA(1) = 2
CALL GRAPH4(THIST, YHIST, NHIST, 1, XMAX, XMIN, YMAX, YMIN, TITLE, IA)
RETURN
C
LS = 2 PLOT OF SMEARED STRESS HISTORY
200 TITLE(3) = 'STRESS - ACTUAL AND SMEARED ESTIMATED HISTORY'
IF (ABS(LS) .GT. 10) GO TO 220
WRITE (8,1022) XMIN,XMAX
WRITE (6,1022) XMIN,XMAX
READ (5,1002), IANS
WRITE (8,4100) IANS
IF (IANS .EQ. 'N') GO TO 220
WRITE (8,1024)
WRITE (6,1024)
READ (5,'*'), XMIN,XMAX
WRITE (8,4024) XMIN,XMAX
220 CALL JFRAME
C220 IA(1) = 1
IA(3) = 0
CALL GRAPH4(TACTL, YACTL, NPT, 1, XMAX, XMIN, YMAX, YMIN, TITLE, IA)
SUBROUTINE RECPLT
SUBROUTINE RECPIT (Continued)
C-21

SUBROUTINE RECPLOT (Continued)
```fortran
IA(3) = 2
CALL GRAPH4(TACTL,YRCOMP,NPT,1,XMAX,XMIN,YMIN,YMAX,TITLE,IA)
GO TO 800
C
LS = 7
C
C PLOT OF STRESS RECORD, SMEARED HISTORY, AND COMPUTED
C RECORD
700 TITLE(3) = 'STRESS - ACTUAL, SMEARED, AND COMPUTED REC.'
IF (ABS(LS) .GT. 10) GO TO 720
IF (LS .LT. 0) GO TO 705
CALL MINMAX(YACTL,NPT,YMIN,YMAX)
WRITE (8,9700)
WRITE (6,9700)
9700 FORMAT(/'*** PLOTTING ACTUAL, SMEARED, AND COMPUTED'@
     ,',RECORDS')
705 WRITE (6,9102) XMIN,XMAX
WRITE (8,9102) XMIN,XMAX
READ (5,1002),IANS
WRITE (8,9100) IANS
IF (IANS.EQ. 'N') GO TO 720
WRITE (8,1024)
WRITE (6,1024)
READ (5,*) ,XMIN,XMAX
WRITE (8,4024) XMIN,XMAX
720 IA(1) = 1
IA(3)=0
CALL GRAPH4(TACTL,YACTL,NPT,1,XMAX,XMIN,YMIN,YMAX,TITLE,IA)
IA(3)=3
CALL GRAPH4(TACTL,YHORGG,NPT,1,XMAX,XMIN,YMIN,TITLE,IA)
IA(1)=2
IA(3)=1
CALL GRAPH4(TACTL,YRCP,NPT,1,XMAX,XMIN,YMIN,YMAX,TITLE,IA)
C
LS = 8
C
C PLOT FINAL ESTIMATED RECORD
C
800 TITLE(3) = 'STRESS - FINAL ESTIMATED RECORD'
IF (ABS(LS) .GT. 10) GO TO 820
IF (LS .LT. 0) WRITE (6,9800)
IF (LS .LT. 0) WRITE (8,9800)
9800 FORMAT(/'*** PLOTTING FINAL RECORD')
WRITE (8,9102) XMIN,XMAX
WRITE (6,9102) XMIN,XMAX
READ (5,1002),IANS
WRITE (8,9100) IANS
IF (IANS.EQ. 'N') GO TO 820
WRITE (8,1024)
WRITE (6,1024)
READ (5,*) ,XMIN,XMAX
WRITE (8,4024) XMIN,XMAX
820 IA(3)=0
IA(1)=2
CALL GRAPH4(THIST,YHIST,NHIST,1,XMAX,XMIN,YMIN,YMAX,TITLE,IA)
RETURN
1002 FORMAT (A1)
1022 FORMAT(/'XMIN,XMAX = ',1P2E11.3,' WANT TO CHANGE THEM? ')
1024 FORMAT(/'ENTER XMIN,XMAX')
END

SUBROUTINE RECPLOT (Concluded)

C-22
```
SUBROUTINE RECRED (LS, IDENT, IDAT, NPT, DT, YACTL, TACTL, FILENAME)
C READ THE FILE CONTAINING THE GAGE RECORD
IMPLICIT REAL*4 (A-H,O-Z)
DIMENSION TACTL(1), YACTL(1)
DIMENSION IVAR(5), IVARS(5)
DATA IVAR/'(S,', '2E16', '8);', ' '/
DATA IVARS/'(5E1', '6.8)', ' ', ' '/
CHARACTER IDENT*50,FILENAME*20, IDAT*10, IANS*I
C **********
C CHECK FOR FORMAT OF INPUT DATA
NLINES = 1
WRITE (8,1000)
WRITE (6,1000)
READ (5,1002) IANS
WRITE (8,4000) IANS
4000 FORMAT (' ->',1X,A1)
IF (IANS .EQ. 'Y') GO TO 100
C C PROVISION FOR DATA FILE NOT IN STANDARD FORM
WRITE (8,1004)
WRITE (6,1004)
READ (5,*) ,NLINES
WRITE (8,4005) NLINES
4005 FORMAT (' ->',1X,I3)
WRITE (8,1005)
WRITE (6,1005)
READ (5,1007) IVAR
WRITE (8,4007) IVAR
4007 FORMAT (' ->',1X,I4)
WRITE (8,1009)
WRITE (6,1009)
READ (5,1007) IVARS
WRITE (8,4007) IVARS
C FORMATS FOR PREPARATORY EFFORTS
1000 FORMAT(' FILE CONTAINING DATA IS IN FOLLOWING FORM:'//
@ 7X,'TITLE (A60)'//
@ 7X,'NO. OF POINTS (I5), TIME INCREMENT (E16.8)'//
@ 'INITIAL TIME (E16.8)'/7X,'AMPLITUDE (5E16.8)'///
@ IS THAT CORRECT?')
1002 FORMAT(A1)
1004 FORMAT(' LIST NUMBER OF LINF'S IN ALPHANUMERIC TITLE OF FILE'
1 '/' (ONLY FIRST LINE IS SAVED AS TITLE), NO. OF LINES?)
1005 FORMAT (' PROVIDE THE FORMAT FOR READING -NPT-, -DT-, T(1)'
1 ' FOR EXAMPLE, (I5,2E16.8)')
1007 FORMAT (5A4)
1009 FORMAT (' PROVIDE THE FORMAT FOR READING THE STRESS VALUES,'
1 ' FOR EXAMPLE, (5E16.8)')
C 100 OPEN(UNIT=1,FILE=FILENAME,STATUS='OLD',ERR=900)
C **********
C READ DATA
1008 FORMAT(A55)
IF (NLINES .GE. 1) READ (1,1008) IDENT
1008 FORMAT(A55)
IF (NLINES .EQ. 0) WRITE (6,1011)
1011 FORMAT (' ENTER TITLE FOR THE DATA')
IF (NLINES .EQ. 0) READ (5,1008) IDENT
IF (NLINES .LE. 1) GO TO 103
DO 102 NL = 2,NLINES
102 READ (1,1008) NOTES
103 IDENT-IDAT//IDENT(1:40)

SUBROUTINE RECRED

C-23
WRITE (8, 4008) IDENT
4008 FORMAT (' ', A55)
WRITE (6, 1008) IDENT
READ (1, IVAR) NPT, DT, TACTL(1)
WRITE (8, 4010) NPT, DT, TACTL(1)
4010 FORMAT (' NPT = ', IS, ' DT = ', 1PE12.5, ' T(I) = ', E12.5)
WRITE (6, 1010) NPT, DT, TACTL(1)
1010 FORMAT (' NPT = ', IS, ' DT = ', 1PE12.5, ' T(1) = ', E12.5)
READ (1, IVARS, END=910) (YACTL(I), I=1, NPT)
DO 105 I=2, NPT
105 TACTL(I) = TACTL(I-1) + DT
RETURN
C
C ERROR FINISH -------------------------------
900 WRITE (6, 1090) FILENAME
1090 FORMAT (' ERROR IN OPENING ', A20)
GO TO 950
910 WRITE (6, 1092) FILENAME
1092 FORMAT (' END OF FILE ENCOUNTERED ON ', A20)
950 LS = 10
RETURN
END

SUBROUTINE RECRED (Concluded)
SUBROUTINE REC1ST (LS,NPT,DT,TWINDO,TACTL,YACTL,NHIST,THIST,YHIST)
C FIND LOCAL MINIMA AND MAXIMA IN THE -YACTL- RECORD. CONSTRUCT A
C RECORD FROM THESE MINIMA AND MAXIMA, STORING IT IN (YHIST, THIST).
C NPT IS THE NO. OF POINTS IN THE YACTL RECORD, NHIST IS THE NO. IN
C THE YHIST HISTORY.
C IMPLICIT REAL*4 (A-H,O-Z)
DIMENSION TACTL(1),YACTL(1),THIST(1),YHIST(1)
K=1
YHIST(1)=YACTL(1)
THIST(1)=TACTL(1)
YMN=YACTL(1)
YMX=YACTL(1)
IBEG=2
JEND = NPT
IX=0
IR=1
YMOLD=YACTL(1)
IXOLD=1
DO 160 I=IBEG,NPT
IF (I .LE. IXOLD) GO TO 160
IF (IR) 115,130,108
C MAXIMUM
108 IF (YACTL(I) .LE. YMX) GO TO 109
   YMX=YACTL(I)
   IX=I
   IR=1
   GO TO 160
109 IF (I-1 .NE. IX) GO TO 115
   M=TWINDO/DT+I-1
   JEND=MIN(M,NPT)
   I1=I
   I2=JEND
   DO 110 J=I,JEND
      IF (YACTL(J) .LE. YMX) GO TO 110
      YMX=YACTL(J)
      IX=J
110 CONTINUE
   YMN=YMX
   YM=YMX
   GO TO 150
C MINIMUM
115 IF (YACTL(I) .GE. YMN) GO TO 117
   YMN=YACTL(I)
   IX=I
   IR=1
   GO TO 160
117 IF (I-1 .NE. IX) GO TO 130
   M=TWINDO/DT+I-1
   JEND=MIN(M,NPT)
   DO 120 J=I,JEND
      IF (YACTL(J) .GE. YMN) GO TO 120
      YMN=YACTL(J)
      IX=J
120 CONTINUE
   YMX=YMN
   YM=YMN
   GO TO 150
C EQUAL
SUBROUTINE REC1ST
130 IF (YACTL(I) .ME. YMOLD .OR. (I-IHOLD)*DT .LT. TWINDO) GO TO 160
   K=K+1
   YNIST(K)=YACTL(I)
   TNIST(K)=(I-1)*DT+TACTL(1)
   IHOLD=I
   GO TO 160
150 K=K+1
   FRAC=0.5
   YNIST(K)=FRAC*(YM+YMOLD)
   TNIST(K)=FRAC*(DT*(IXOLD+IX-2)+2.*TACTL(1))
   YMOLD=YM
   IXOLD=IX
   IX=0
   IR=1
   IF (IXOLD .EQ. I-1) GO TO 108
160 WHIST=K
   NH=WHIST-50
   IF (WHIST .LE. 2001) RETURN
   WRITE (6,1094) WHIST
1094 FORMAT(' ***ERROR EXIT -- NO. OF ELEMENTS EXCEED ARRAY '/
1   'DIMENSION.'/5X, 'NO. OF ELEMENTS,WHIST =',IS/
2   'ARRAYS ARE DIMENSIONED 2001. ')
   LS = 10
   RETURN
END

SUBROUTINE RECIST (Concluded)
SUBROUTINE RUNG(IBUG,BETA,OMEGA,THIST,YHIST,NHIST,DT,IBEG,
@ ISTOP,TACTL,YRCOMP)
IMPLICIT REAL*4 (A-H,O-Z)
C ROUTINE FOR CONDUCTING A 4TH ORDER RUNGE-KUTTA INTEGRATION OF
C THE EQUATIONS OF MOTION OF A DAMPED ONE-DEGREE-OF-FREEDOM
C SYSTEM.
C BETA AND OMEGA ARE DAMPING FACTOR AND CIRCULAR FREQUENCY.
C THIST AND YHIST ARE THE INPUT TIME AND POSITION POINTS FOR THE
C FORCING FUNCTION.
C YRCOMP IS THE OUTPUT MOTION, DEFINED AT NHIST TIME STEPS (DT).
C NHIST IS THE NUMBER OF TIME STEPS IN THE FORCING FUNCTION.
C DT IS THE TIME INCREMENT IN THE DIGITIZED RECORDS.
C IBEG AND ISTOP DEFINE THE NUMBER OF DT TIME STEPS OVER WHICH
C THE INTEGRATION IS TO OCCUR.
C
DIMENSION THIST(1),YHIST(1),TACTL(1),YRCOMP(1),DYDT(4),DUDT(4)
C
ISTART = MAX(IBEG-5,2)
LI=1
U0=0.
Y0=0.
IF (IBEG .LE. 2) GO TO 200
Y0 = YRCOMP(ISTART-1)
U0 = (YRCOMP(ISTART+1)-Y0)/(2.*DT)
200 DO 250 I = ISTART,ISTOP
DO 210 L=LI,NHIST
KI = L
IF (THIST(L) .GT. (I-1)*DT+TACTL(1)) GO TO 220
210 CONTINUE
220 CONTINUE
LI = KI
YY=YHIST(LI-1)+(YHIST(LI)-YHIST(LI-1))*((I-1)*DT+TACTL(1)
@ -THIST(LI-1))/THIST(LI)-THIST(LI-1)
COEF=0.5
U=U0
Y=Y0
DO 230 J=1,4
IF (J .EQ. 3) COEF=1.
DYDT(J)=U
DUDT(J)=OMEGA**2*(YY-Y)-2.*BETA*U
U=U0+COEF*DUDT(J)*DT
Y=Y0+COEF*DYDT(J)*DT
230 CONTINUE
U=U0+DT/6.*(DUDT(1)+2.*(DUDT(2)+DUDT(3))+DUDT(4))
Y=Y0+DT/6.*(DYDT(1)+2.*(DYDT(2)+DYDT(3))+DYDT(4))
250 CONTINUE
RETURN
END
SUBROUTINE VARIAN(YA,YC,IWINDO,JWINDO,V)
IMPLICIT REAL*4 (A-H,O-Z)
C COMPUTE THE VARIANCES BETWEEN THE YA (ACTUAL) AND YC (COMPUTED)
C VALUES IN THE INTERVAL IWINDO TO JWINDO
DIMENSION YA(1),YC(1)
SUM=0.
DO 100 I=IWINDO,JWINDO
SUM=SUM+(YA(I)-YC(I))**2
100 CONTINUE
V=SUM
RETURN
END
DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Director
Defense Nuclear Agency
ATTN: SPST (Dr. K. L. Goering)
SPST (Mr. C. B. McFarland)
SPST (CPT M. A. Reed)
SPST (Dr. C. Canada)
SPST (MAJ M. Pelkey)
Technical Library
Washington, DC 20308-1000

Director
Defense Advanced Research Project Agency
ATTN: Technical Library
1400 Wilson Blvd.
Arlington, VA 22209

Director
Defense Intelligence Agency
ATTN: Technical Library
Washington, DC 20301

Defense Technical Information Center
Cameron Station
ATTN: TC (2 oya)
Alexandria, VA 22314

DEPARTMENT OF THE ARMY

Commander
US Army Corps of Engineers
ATTN: CERD-L (Ms. Sharon Vannucci)
CERD-M (Mr. B. O. Benn)
CEEC-ET (Mr. R. L. Wight)
CEIM-SL
Washington, DC 20314

Division Engineer
US Army Engineer Division, Huntsville
ATTN: Technical Library
P. O. Box 1500, West Station
Huntsville, AL 35807

District Engineer
US Army Engineer District, Omaha
ATTN: CEMRO-ED-S (Mr. Bob Kelly)
CEMRO-ED-SN (Mr. Bill Gauk)
215 N. 17th Street
Omaha, NE 68102-4978

Director
US Army Construction Engineering Research Laboratory
ATTN: Technical Library
P. O. Box 4005
Champaign, IL 61820

Commander/Director
US Army Cold Regions Research and Engineering Laboratory
ATTN: Technical Library
P. O. Box 282
Hanover, NH 03755

Commandant
US Army Engineer School
ATTN: Technical Library
Ft. Belvoir, VA 22060

Commander
US Army Laboratory Command
2800 Powder Mill Road
Adelphi, MD 20783-1145

Director
US Army Ballistic Research Laboratory
ATTN: Technical Library
Aberdeen Proving Ground, MD 21005

Commander
US Army Nuclear and Chemical Agency
ATTN: Technical Library
7500 Backlick Road, Bldg. 2073
Springfield, VA 22150

DEPARTMENT OF THE NAVY

Naval Civil Engineering Laboratory
ATTN: Technical Library
Port Hueneme, CA 93043

Naval Facilities Engineering Command
ATTN: Technical Library
200 Stovall Street
Alexandria, VA 22332

DEPARTMENT OF THE AIR FORCE

Air Force Institute of Technology
Air University
ATTN: Technical Library
Wright-Patterson Air Force Base, OH 45433

Air Force Office of Scientific Research
ATTN: Technical Library
Boiling Air Force Base, DC 20332

Air Force Weapons Laboratory (AFSC)
ATTN: NTE (Dr. M. A. Plamondon)
NTEE (Mr. J. M. Thomas)
NTEBG (CPT C. W. Felice)
NTEDE (Mr. J. Renick)
Technical Library
Kirtland Air Force Base, NM 87117

Air Force Engineering and Services Center (AFSC)
ATTN: Technical Library
Tyndall Air Force Base, FL 32403

Air Force Armament Laboratory (AFCS)
ATTN: Technical Library
Eglin Air Force Base, FL 32542

Commander
Ballistic Missile W. of C. (AFSC)
ATTN: ENFP (LT R. M. Coleman)
MYEB (LT D. M. Gage)
Technical Library
Norton Air Force Base, CA 92409
DISTRIBUTION LIST (CONTINUED)

DEPARTMENT OF ENERGY

Lawrence Livermore National Laboratory
ATTN: Technical Library
P. O. Box 500
Livermore, CA 94550

Los Alamos National Laboratory
ATTN: Technical Library
P. O. Box 1663
Los Alamos, NM 87545

Sandia National Laboratories
ATTN: Technical Library
P. O. Box 500
Albuquerque, NM 87185

DEPARTMENT OF DEFENSE CONTRACTORS

Mr. J. L. Bratton
300 San Mateo Blvd., NE, Suite A220
Albuquerque, NM 87110

Mr. J. D. Shinn
South Royalton, VT 05068

Mr. J. L. Drake
1204 Openwood Street
Vicksburg, MS 39180-2610

Dr. J. G. Trulio
930 S. LaBrea Avenue
Los Angeles, CA 90036

Technical Library
Boeing Aerospace Company
P. O. Box 3999
Seattle, WA 98124

Technical Library
California Research & Technology, Inc.
20943 Devonshire Street
Chatsworth, CA 91311-2376

Dr. D. L. Orshel
California Research & Technology, Inc.
5117 Johnson Drive
Pleasanton, CA 94566-3343

Dr. E. J. Reinhardt
California Research & Technology, Inc.
2017 Yale Blvd., SE
Albuquerque, NM 87106

Mr. J. Karagian
Karagian and Case Structural Engineers
1130 Fair Oaks Avenue
South Pasadena, CA 91030-3312

Technical Library
New Mexico Engineering Research Institute
University of New Mexico
Box 25, University Station
Albuquerque, NM 87131

Dr. R. T. Allen
Pacifico Technology
P. O. Box 148
Del Mar, CA 92014

Mr. J. G. Lewis
R&D Associates
P. O. Box 9695
Marina del Rey, CA 90291

Technical Library
R&D Associates
6940 S. Kings Highway, Suite 210
Alexandria, VA 22310

Technical Library
Science Applications International Corporation
P. O. Box 2551
La Jolla, CA 92038-2351

Dr. P. L. Coleman
Technical Library
S-Cubed
P. O. Box 1620
La Jolla, CA 92038-1620

Dr. Lynn Seaman (10 oya)
Dr. D. R. Curran
Dr. J. D. Colton
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Technical Library
Terra Tek, Inc.
420 Wakara Way
Salt Lake City, UT 84108

Mr. W. Lipner
Dr. M. G. Katona
Dr. R. J. Hoar
TRW Defense Systems Group
P. O. Box 3130
San Bernardino, CA 92402

Dr. D. J. Hess, Bldg. 134/W 1035
TRW Defense and Space Systems Group
One Space Park
Redondo Beach, CA 90278

Dr. I. S. Sandier
Weidlinger Associates
333 Seventh Avenue
New York, NY 10001

Dr. J. Eisenberg
Weidlinger Associates
620 Hansen Way, Suite 100
Palo Alto, CA 94304
END
9-87
Dtic