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AN OBJECTIVE WAVEFORM COMPARISON TECHNIQUE

by

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20. ABSTRACT (Continued).

The objective discrepancy measures are incorporated into a computer program, named WCT*, which processes digitized data tapes containing measured or calculated waveforms or both. The computer program is used to statistically analyze selected data from the DISC Test I event and objectively compare particle velocity measurements made in DISC Test II with expected value waveforms obtained from probabilistic prediction calculations.

Appendix A of this report presents a flow chart and user's guide for the computer program WCT.

It is recommended that the objective discrepancy measures be used whenever comparisons of two or more waveforms are made. It is also recommended that the technique be extended to objectively quantify differences in laboratory- and field-generated material property test results.

* Waveforms Comparison Technique.

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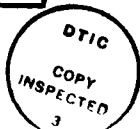
PREFACE

The investigation reported herein was conducted by personnel of the Geomechanics Division (GD), Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES). It was sponsored by the Defense Nuclear Agency under Task Y99QXSB, "Ground Shock Predictions," Work Unit 00020, "Waveform Comparison Techniques."

The study was conducted and this report prepared and written by Dr. G. Y. Baladi and Mr. D. E. Barnes (GD) during the period October 1981-October 1982 under the general direction of Mr. Bryant Mather, Chief, SL, and Dr. J. G. Jackson, Jr., Chief, GD.

COL Tilford C. Creel, CE, was Commander and Director of WES during the investigation and publication of this report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY
UNITS OF MEASUREMENT

Metric (SI) units of measurement used in this report can be converted to
U. S. customary units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
centimetres	0.3937007	inches
centimetres per millisecond	0.3937007	inches per millisecond
metres	3.280839	feet
metres per millisecond	3.280839	feet per millisecond
newtons	0.2248089237	pounds (force)
megapascals	0.01	kilobars
megapascals	145.0377439	pounds (force) per square inch
grams per cubic centimetre	62.42797	pounds (mass) per cubic foot
kilograms	2.204622476	pounds (mass)

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

It has been and still is customary to analyze explosion-generated ground shock waveforms (measured, computed, or both) subjectively. This is accomplished by comparing two or more waveforms and verbalizing their compatibility through the aid of statements such as "the peaks are within a factor of two" or "the overall agreement is pretty good." Each analyst, however, has his own opinion about what "pretty good" may mean, and their opinions quite often differ greatly. Consequently, subjective discrepancy measures have probably produced as much confusion and controversy as they have enlightenment on a host of ground shock issues.

It is time to minimize the confusion and controversy. Waveforms should be compared objectively, using discrepancy measures that are rooted in statistical theory. This report treats two such measures and recommends them for adoption by the ground shock calculation/measurement community.

Within the framework of the theory of probability there are two approaches that can be taken to develop objective waveform discrepancy measures. The first approach involves straightforward application of statistical concepts to obtain ensemble average (mean), mean square, standard deviation, etc., for a given instant of time. To use this approach, however, it is necessary to have information about the probability distribution of a ground shock parameter throughout the time history of its response or at least a large number of individual responses or measurements obtained at the same location. The second approach involves the use of temporal averages and

temporal mean squares in order to compare two response histories and make an objective judgement on their agreement or disagreement throughout a given period of time or "time window."

Using the second approach, T. L. Geers (Reference 1) developed two objective discrepancy measures for comparing transient response histories; these were the temporal root mean square and the correlation error history measure. The objective discrepancy measures developed in this report closely parallel Geers' development.

1.2 OBJECTIVE

The primary objective of this study was to develop and document objective waveform discrepancy measures for comparing arbitrary transient response histories. Secondary objectives were (a) to incorporate the newly-developed waveform discrepancy measures into a computer program which can read digitized measured or calculated waveforms and produce objective waveform comparisons and perform probabilistic analyses on a given number of response time histories, and (b) to demonstrate the potential utility of the computer program using the results of recent field experiments and code calculations.

1.3 SCOPE

The theoretical development behind statistical objective discrepancy measures is presented in Chapter 2. Chapter 3 demonstrates the application of the objective discrepancy measures through the use of simple analytic sinusoidal waveforms. To demonstrate the capabilities of the computer program WCT (Waveforms Comparison Technique), statistical analyses of measured data and examples of how calculated response histories can be compared to measurements are given in Chapter 4. Chapter 5 summarizes the report and presents recommendations.

Appendix A contains a flow chart and user's guide for the computer program WCT which reads digitized measured or calculated waveforms, produces objective waveform comparisons, and performs probabilistic analyses on a given number of response time histories.

CHAPTER 2

STATISTICAL METHOD FOR COMPARISON OF TRANSIENT RESPONSE HISTORIES

2.1 INTRODUCTION

In general, a waveform is characterized by its amplitude and its frequency. Thus, the comparison of two waveforms must be approached with these features in mind. In addition, phase shifts must be considered.

Historically, the shock and vibrations community has characterized individual waveforms by assigning them an average amplitude and by decomposing their frequency content to obtain a mean square spectral density function (References 2, 3, and 4). The average amplitude most commonly employed has been the root mean square value. Similar concepts and parameters are used in the following sections to develop objective waveform discrepancy measures.

2.2 BASIC EQUATIONS

2.2.1 Single Waveform

Let $P(t)$ be a periodic function of period T . Under very general conditions, $P(t)$ may be represented by a superposition of sinusoids using the following exponential Fourier series (Reference 5):

$$P(t) = \sum_{n=-\infty}^{\infty} C_n \exp (inw_0 t) \quad (2.1)$$

where $i = \sqrt{-1}$ is a complex number, $w_0 = 2\pi/T$ is the fundamental angular frequency, and C_n is Fourier coefficients that can be evaluated directly from the relation

$$C_n = \frac{1}{T} \int_{-T/2}^{T/2} P(t) \exp (-inw_0 t) dt \quad (2.2)$$

Using Equation 2.1 and Parseval's theorem (Reference 5), it can be shown that

$$\frac{1}{T} \int_{-T/2}^{T/2} P^2(t) dt = \sum_{n=-\infty}^{\infty} |c_n|^2 \quad (2.3)$$

Note that the left-hand side of Equation 2.3, called the temporal mean square of $P(t)$, equals the sum of the squares of the absolute values of the Fourier coefficients. Hence, the temporal mean square is indicative of the amplitude of $P(t)$.

2.2.2 Two Waveforms

Let $P_1(t)$ and $P_2(t + \phi)$ be two identical waveforms except for a constant phase shift between them (equal to ϕ). Such waveforms are correlated; Reference 3 defines this correlation as the temporal autocorrelation function $\chi(\phi)$, where

$$\chi(\phi) = \frac{1}{T} \int_{-T/2}^{T/2} P_1(t) P_2(t + \phi) dt \quad (2.4)$$

Note that when $\phi = 0$, $P_1(t) = P_2(t) = P(t)$, and Equation 2.4 reduces to the temporal mean square of $P(t)$.

Because $\chi(\phi)$ is related to the mean square spectral density function (Reference 3) which determines the frequency decomposition of a given waveform, Equation 2.4 is indicative of the frequency content of waveforms as well as their phase shifts.

2.3 OBJECTIVE DISCREPANCY MEASURES

Based on Equations 2.3 and 2.4, T. L. Geers (Reference 6) suggested three objective discrepancy measures for comparing two (numerically or experimentally generated) waveforms.

Consider $R_1(t)$ to be an errorless or true response function and $R_2(t)$ to be a similar response history, but they differ somewhat in amplitude, frequency, and phasing. Geers defined two correlation factors to characterize the differences between R_1 and R_2 in terms of (a) magnitude (i.e., amplitude), and (b) phase and frequency; namely,

$$M_{cf}(t) = \frac{\left[\int_0^t R_2^2(\tau) d\tau \right]^{1/2}}{\left[\int_0^t R_1^2(\tau) d\tau \right]^{1/2}} \quad (2.5)$$

and

$$P_{cf}(t) = \frac{\left| \int_0^t R_1(\tau) R_2(\tau) d\tau \right|}{\left[\int_0^t R_1^2(\tau) d\tau \right]^{1/2} \left[\int_0^t R_2^2(\tau) d\tau \right]^{1/2}} \quad (2.6)$$

Here, $M_{cf}(t)$ is the magnitude correlation factor, and $P_{cf}(t)$ is the phase-and-frequency correlation factor. Note the distinct preservation of the above fundamental character of Equations 2.3 and 2.4 in the above expressions.

Geers also defined a combined correlation factor to enfold the magnitude correlation factor and the phase-and-frequency correlation factor into one expression, i.e.,

$$C_{ef}(t) = \left\{ \left[M_{cf}(t) - 1 \right]^2 + \left[P_{cf}(t) - 1 \right]^2 \right\}^{1/2} \quad (2.7)$$

Finally, the magnitude error, phase-and-frequency error, and combined error were defined by Geers as

$$E_{\text{mag}}(t) = M_{\text{cf}}(t) - 1 \quad (2.8)$$

$$E_{\text{phs}}(t) = 1 - P_{\text{cf}}(t) \quad (2.9)$$

$$E_{\text{com}}(t) = \text{SIGN}[E_{\text{mag}}(t)] \left\{ [E_{\text{mag}}(t)]^2 + [E_{\text{phs}}(t)]^2 \right\}^{1/2} \quad (2.10)$$

Equations 2.8 through 2.10 represent powerful measures for quantifying temporal discrepancies between given waveforms; however, because they all involve time integrations, they are discrepancy measures throughout a given time window rather than time-discrete measures. This offers certain advantages because the quality of waveforms throughout their time histories is what is important in designing a structure to sustain such waveforms.

Note that the definition of $E_{\text{com}}(t)$ in Equation 2.10 capitalizes on the orthogonality of $E_{\text{mag}}(t)$ and $E_{\text{phs}}(t)$, as shown in Figure 2.1 and defined by Equations 2.8 and 2.9. Also, in keeping with Figure 2.1, it can be easily shown (using Equations 2.5 and 2.6) that

$$0 \leq E_{\text{phs}}(t) \leq 1 \quad (2.11)$$

2.4 ENSEMBLE AVERAGING

Quite often, situations arise in which several waveforms need to be compared as a group; e.g., when redundant field records and/or multiple calculations are available. The above error concepts can readily be extended to cover these situations by "ensemble averaging."

For N records in a set (either calculated or measured), average or mean error factors may be defined as

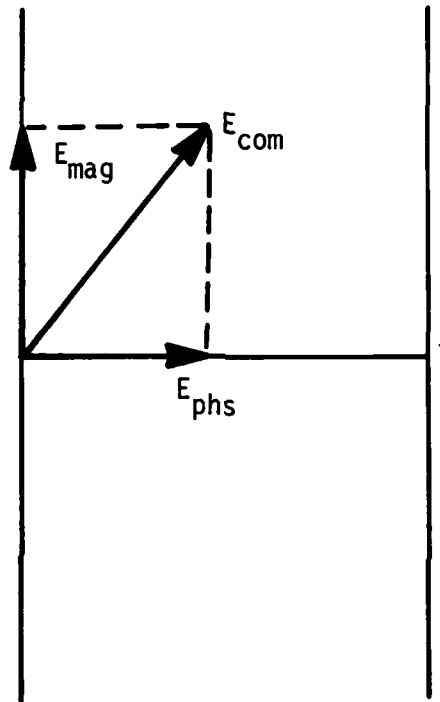


Figure 2.1 Orthogonality relationship for $E_{\text{mag}}(t)$, $E_{\text{phs}}(t)$ and their relation to $E_{\text{com}}(t)$.

$$\text{MEAN} \left[E_{\text{mag}}(t) \right] = \frac{\sum_{n=1}^N \left[E_{\text{mag}}(t) \right]_n}{N} \quad (2.12)$$

$$\text{MEAN} \left[E_{\text{phs}}(t) \right] = \frac{\sum_{n=1}^N \left[E_{\text{phs}}(t) \right]_n}{N} \quad (2.13)$$

and

$$\text{MEAN} \left[E_{\text{com}}(t) \right] = \text{SIGN} \left\{ \text{MEAN} \left[E_{\text{mag}}(t) \right] \right\} \frac{\sum_{n=1}^N \left[E_{\text{com}}(t) \right]_n}{N} \quad (2.14)$$

A great advantage occurs in using Equation 2.14 (rather than straightforward statistical methods) to compute the mean combined error; i.e., one avoids the calculation of standard deviations (and other statistical measures) for $E_{\text{mag}}(t)$ and $E_{\text{phs}}(t)$. This is due to the vector magnitude aspect of $E_{\text{com}}(t)$; i.e., $\pm E_{\text{mag}}(t)$ or $\pm E_{\text{phs}}(t)$ produces the same $E_{\text{com}}(t)$.

In Chapter 3 we demonstrate the utility of Equations 2.8 through 2.10 and Equations 2.12 through 2.14 by applying them to analyses of simple sinusoidal waveforms.

CHAPTER 3

ANALYTIC EXPOSITION OF OBJECTIVE DISCREPANCY MEASURES

3.1 INTRODUCTION

In this chapter the statistical measures described in Chapter 2 (Equations 2.8 through 2.10) are examined analytically using three pairs of contrived sinusoidal waveforms. In Section 3.2, two undamped waveforms are used to demonstrate the objective description of phase and magnitude discrepancies; Section 3.3 extends this analysis to include a frequency discrepancy. Section 3.4 adds the further complication of slight damping.

3.2 EXAMPLE 1; UNDAMPED SINUSOIDAL RESPONSE; PHASE AND MAGNITUDE DIFFERENCES

Consider the following two sinusoidal responses (Figure 3.1):

$$R_1(t) = \sin 2\pi t \quad (3.1)$$

and

$$R_2(t) = (1 + \epsilon_m) \sin (2\pi t + \phi) \quad (3.2)$$

where t is time in milliseconds. Assume that $R_1(t)$ is an errorless base or true response while $R_2(t)$ is a comparable response history with an error in magnitude equal to ϵ_m , and an error in phase equal to ϕ . Substitution of Equations 3.1 and 3.2 into Equations 2.8 and 2.9 leads to

$$E_{\text{mag}}(t) = \frac{\left[1 - \frac{\sin 2\pi t}{2\pi t} \cos (2\pi t + 2\phi) \right]^{1/2}}{\left[1 - \frac{\sin 2\pi t}{2\pi t} \cos 2\pi t \right]^{1/2}} \left| 1 + \epsilon_m \right| - 1 \quad (3.3)$$

and

$$E_{\text{phs}}(t) = 1 - \frac{\left| \cos \phi - \frac{\sin 2\pi t}{2\pi t} \cos (2\pi t + \phi) \right|}{\left[1 - \frac{\sin 2\pi t}{2\pi t} \cos (2\pi t + 2\phi) \right]^{1/2} \left[1 - \frac{\sin 2\pi t}{2\pi t} \cos 2\pi t \right]^{1/2}} \quad (3.4)$$

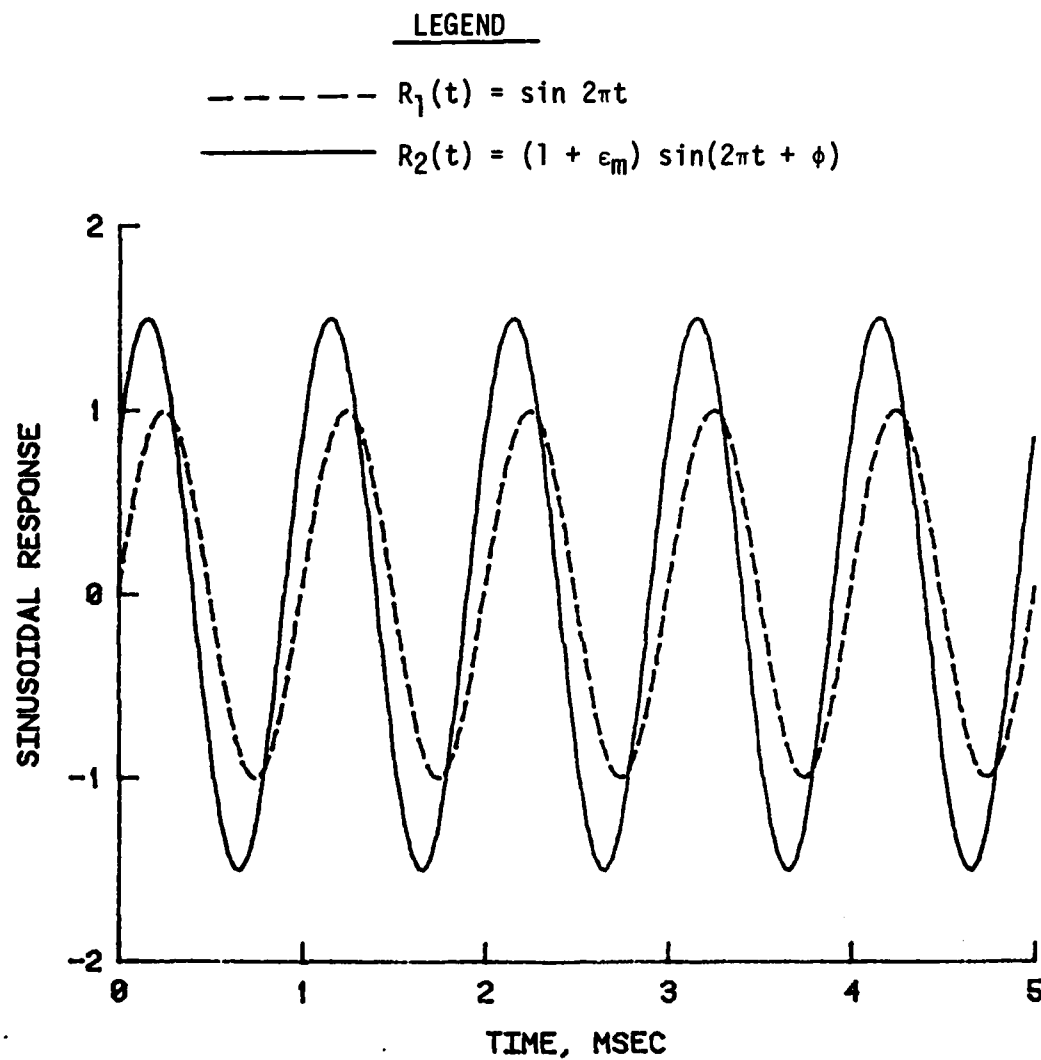


Figure 3.1 Example 1: Time histories of two undamped, identical frequency, sinusoidal responses; $\epsilon_m = 0.5$ and $\phi = 0.6$ radian.

The combined error can be calculated directly using Equation 2.10 and the results of Equations 3.3 and 3.4.

Note that for large values of t ($t > 2$ in this problem), Equations 3.3 and 3.4 rapidly approach limits, i.e., they become

$$E_{\text{mag}}(t) \approx |1 + \epsilon_m| - 1 \quad (3.5)$$

and

$$E_{\text{phs}}(t) \approx 1 - |\cos \phi| \quad (3.6)$$

respectively. Consequently, Equation 2.10 also approaches a limit. These limits are indicated on Figures 3.2 through 3.5 which illustrate the behavior of Equations 2.10, 3.3, and 3.4 for this example (in which $\epsilon_m = 0.5$ and $\phi = 0.6$ radian). It is clear from these figures that within a very short time the objective discrepancy measures have essentially captured the correct values of the magnitude and phase errors and therefore improve their acquisition with time.

As a final note, if $\phi = 0$ and $\epsilon_m \geq -1$, Equations 3.3 and 3.4 (as well as Equations 3.5 and 3.6) reduce to

$$E_{\text{mag}}(t) = \epsilon_m \quad (3.7)$$

and

$$E_{\text{phs}}(t) = 0 \quad (3.8)$$

Moreover, for $t > 2$, Equation 3.5 can be rewritten as

$$\left. \begin{aligned} E_{\text{mag}}(t) &= \epsilon_m & \text{for } \epsilon_m \geq -1 \\ E_{\text{mag}}(t) &= -(\epsilon_m + 2) & \text{for } \epsilon_m \leq -1 \end{aligned} \right\} \quad (3.9)$$

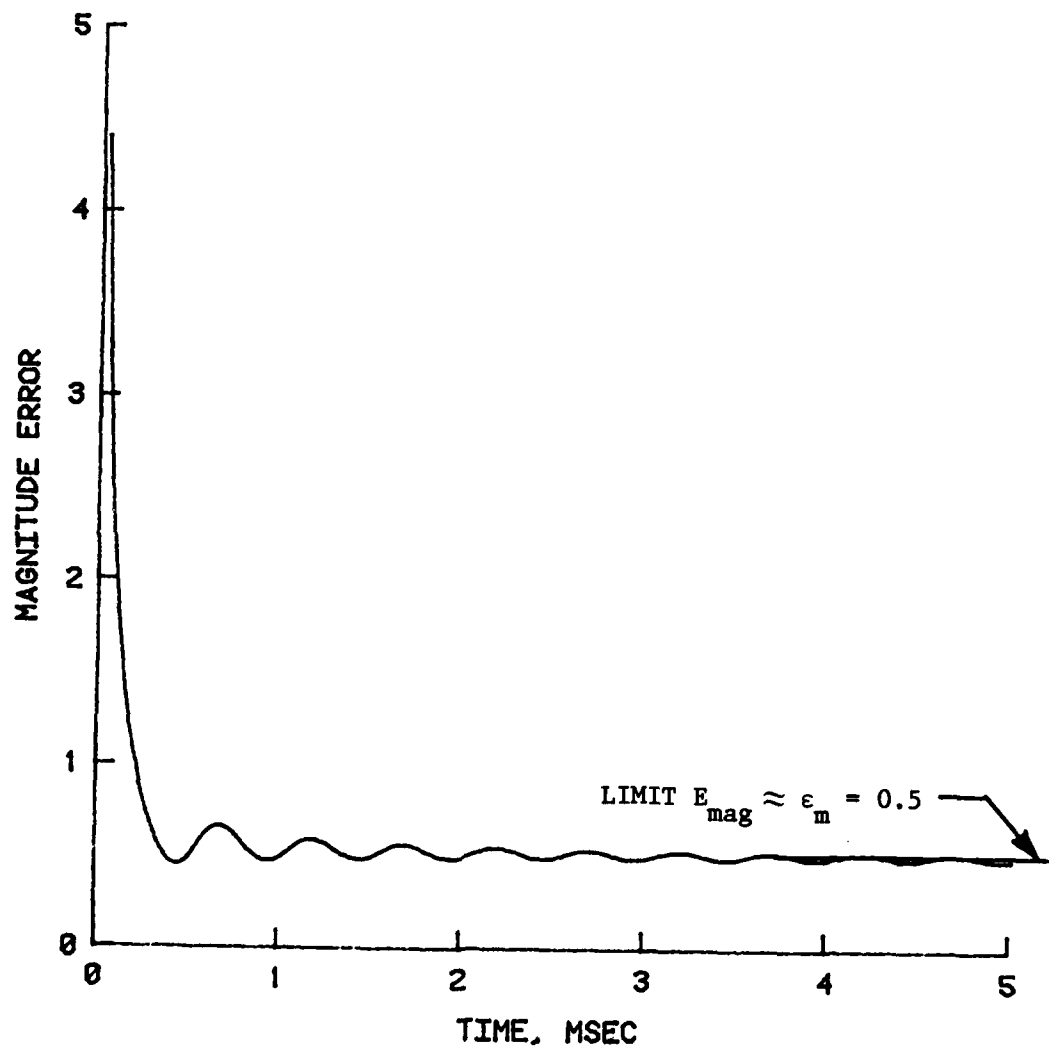


Figure 3.2 Time history of magnitude error for example 1.

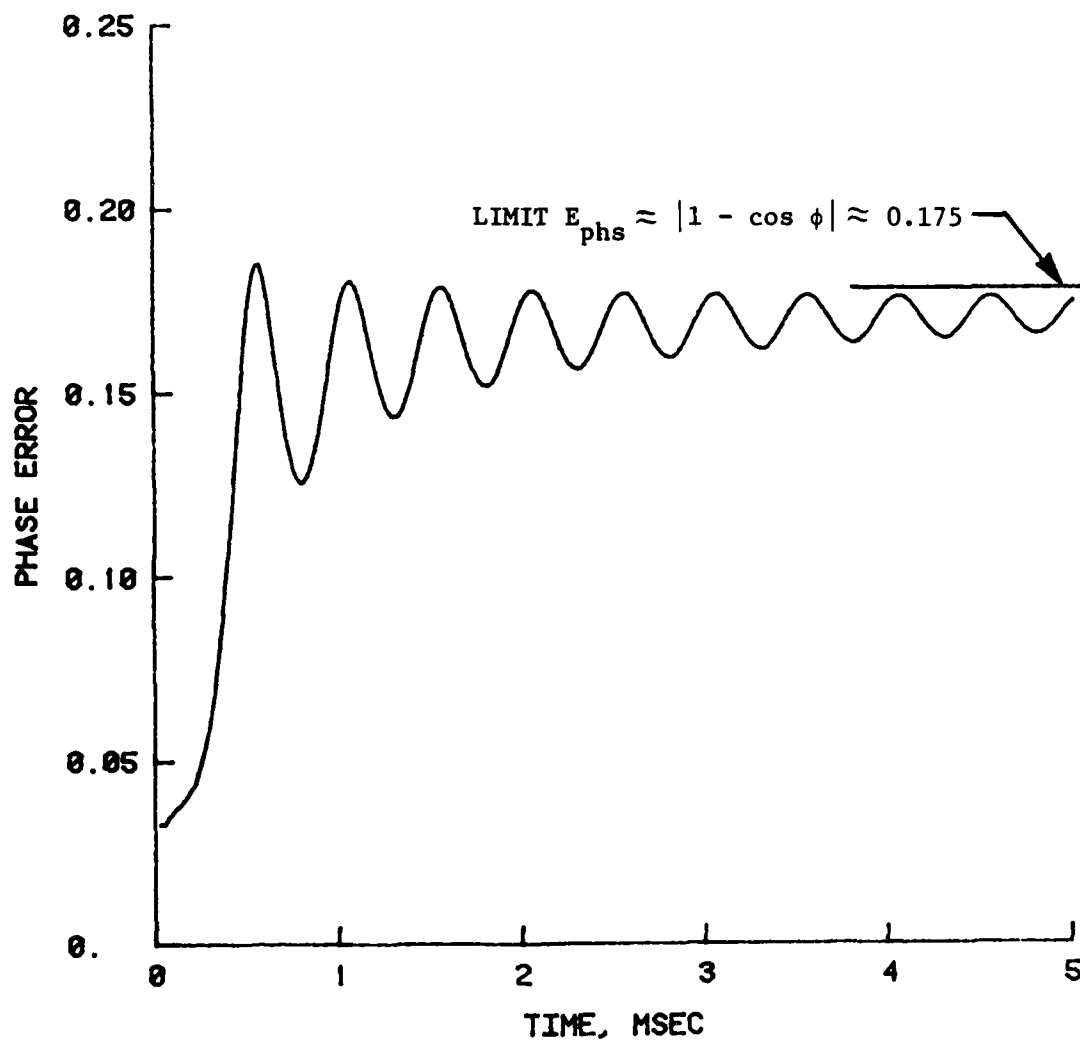


Figure 3.3 Time history of phase error for example 1.

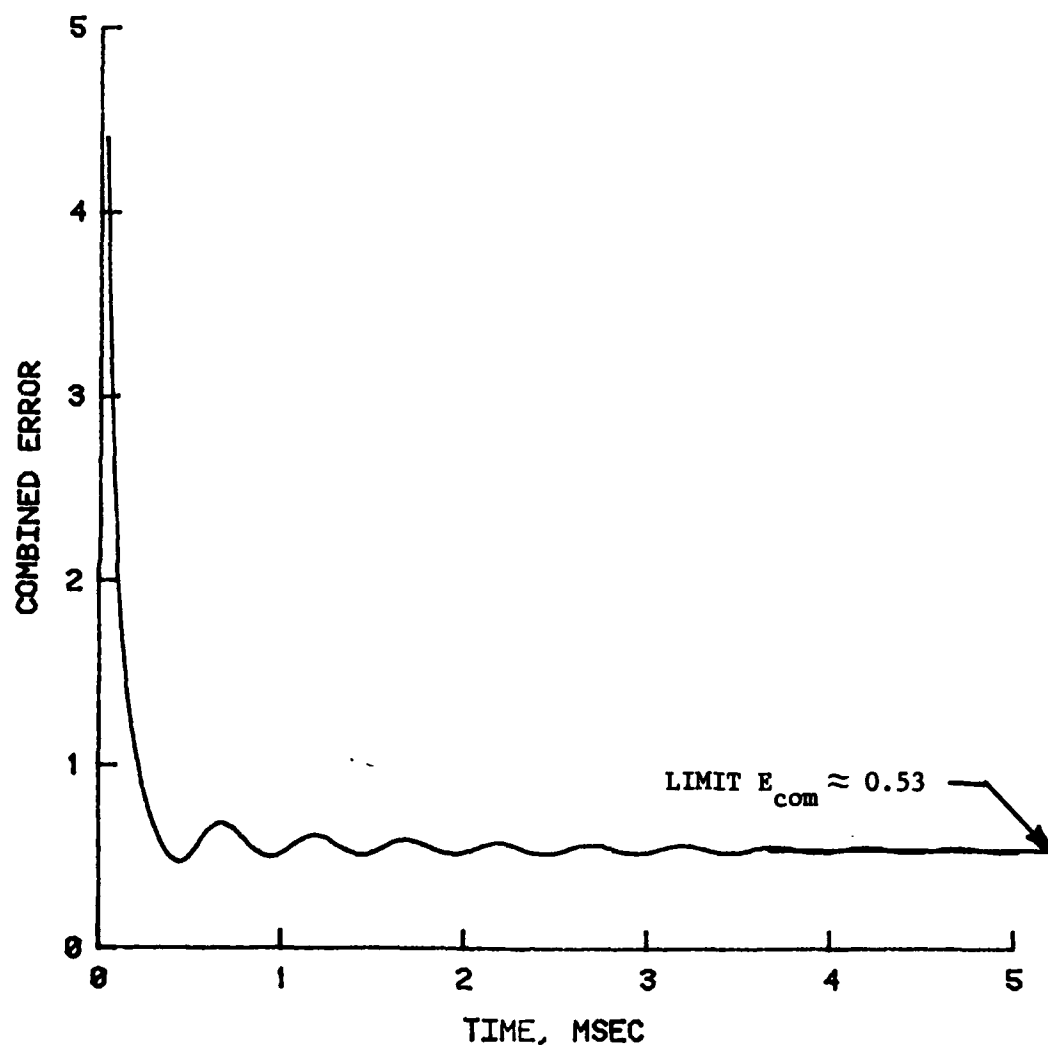


Figure 3.4 Time history of the combined error for example 1.

which leads to

$$-1 \leq E_{\text{mag}}(t) \leq \infty \quad (3.10)$$

Further, for $t > 2$, Equations 3.6 and 3.8 indicate that

$$0 \leq E_{\text{phs}}(t) \leq 1 \quad (3.11)$$

which is a conclusion that was previously stated in Equation 2.11.

And, finally, note that if the absolute value brackets were to be omitted from the numerator of the fraction in Equation 2.6, the present example problem would yield

$$E_{\text{phs}}(t) = 1 - \frac{1 + \epsilon_m}{|1 + \epsilon_m|} \cos \phi \quad (3.12)$$

which would make the phase error dependent upon ϵ_m . This, in turn, could lead to unreliable results. For example, if $\phi = 0$ and $\epsilon_m = -1 + \delta$, where δ is a small positive increment $\ll 1$, Equation 3.12 gives $E_{\text{phs}}(t) \approx 0$; yet for $\phi = 0$ and $\epsilon_m = -1 - \delta$, $E_{\text{phs}}(t) \approx 2$. This suggests that in practical cases with $|R_2(t)| \ll |R_1(t)|$, $E_{\text{phs}}(t)$ calculations (without the absolute value) might be unreliable.

3.3 EXAMPLE 2; UNDAMPED SINUSOIDAL RESPONSE; PHASE, FREQUENCY AND MAGNITUDE DIFFERENCES

In this example, the following sinusoidal responses are considered
(Figure 3.5)

$$R_1(t) = \sin 2\pi t \quad (3.13)$$

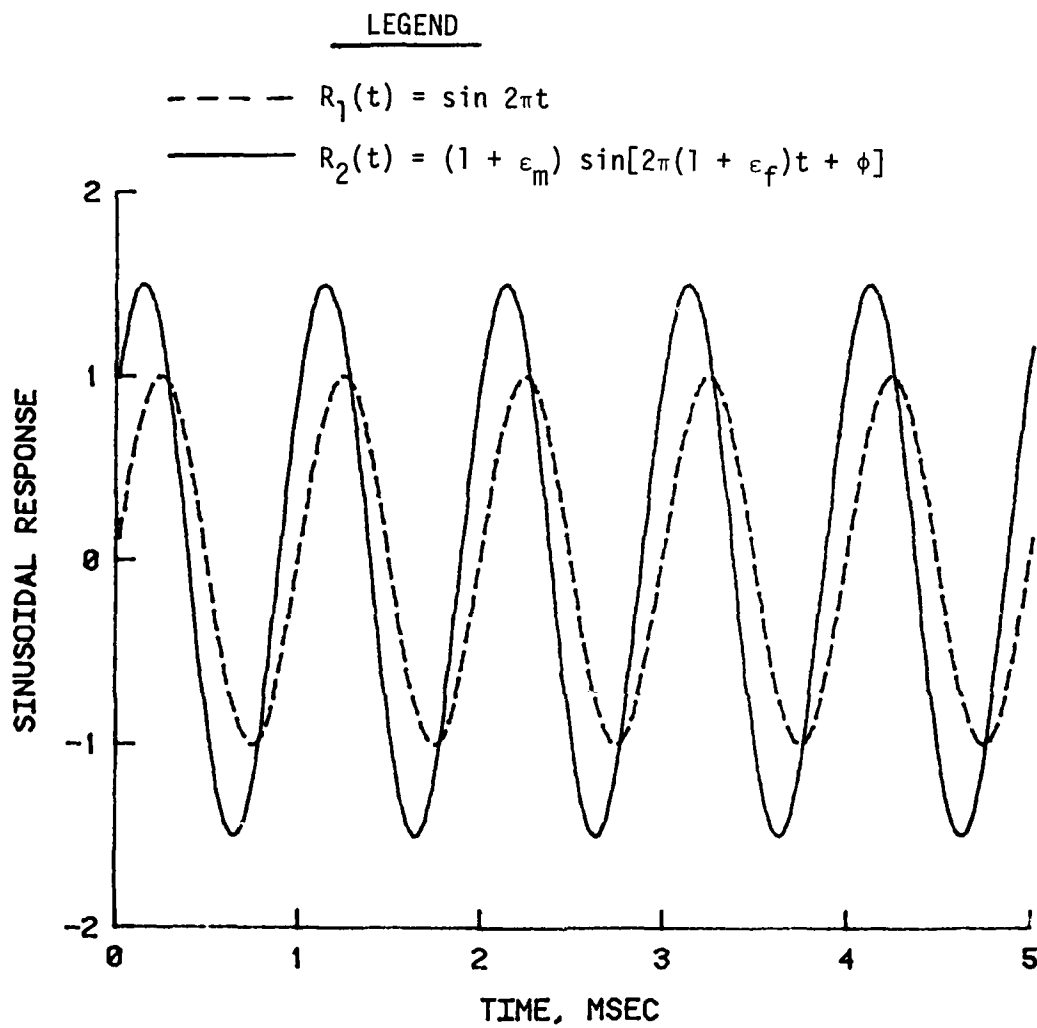


Figure 3.5 Example 2: Time histories of two undamped sinusoidal responses; $\epsilon_m = 0.5$, $\phi = 0.6$ radian, and $\epsilon_f = 0.005$.

$$R_2(t) = (1 + \epsilon_m) \sin \left[2\pi(1 + \epsilon_f) t + \phi \right] \quad (3.14)$$

Like the previous example, $R_1(t)$ is assumed to be an errorless base or true response while $R_2(t)$ is a comparable response history with error in magnitude equal to ϵ_m , error in frequency equal to ϵ_f , and error in phase equal to ϕ . For this example, $\epsilon_m = 0.5$, $\phi = 0.6$, and $\epsilon_f = 0.005$.

Substitution of Equations 3.13 and 3.14 into Equations 2.8 and 2.9 leads to

$$E_{\text{mag}}(t) = \frac{\left\{ 1 - \frac{\sin \left[2\pi(1 + \epsilon_f)t \right]}{2(1 + \epsilon_f)t} \cos \left[2\pi(1 + \epsilon_f)t + 2\phi \right] \right\}^{1/2}}{\left[1 - \frac{\sin 2\pi t}{2\pi t} \cos 2\pi t \right]^{1/2}} \left| 1 + \epsilon_m \right| - 1 \quad (3.15)$$

and

$$E_{\text{phs}}(t) = 1 - \frac{\left| \cos \phi \left[\frac{\sin 2\pi \epsilon_f t}{2\pi \epsilon_f t} - \frac{\sin 2\pi(2 + \epsilon_f)t}{2\pi(2 + \epsilon_f)t} \right] - \sin \phi \left[\frac{\sin^2 \pi \epsilon_f t}{\pi \epsilon_f t} - \frac{\sin^2 \pi(2 + \epsilon_f)t}{\pi(2 + \epsilon_f)t} \right] \right|}{\left[1 - \frac{\sin 2\pi t}{2\pi t} \cos 2\pi t \right]^{1/2} \left\{ 1 - \frac{\sin \left[2\pi(1 + \epsilon_f)t \right]}{2\pi(1 + \epsilon_f)t} \cos \left[2\pi(1 + \epsilon_f)t + 2\phi \right] \right\}^{1/2}} \quad (3.16)$$

and, as before, the combined error can be calculated using Equation 2.10 and the results of Equations 3.15 and 3.16. Figures 3.6 through 3.8 present the behavior of Equations 2.8 through 2.10 for this example (in which $\epsilon_m = 0.5$, $\phi = 0.6$, and $\epsilon_f = 0.005$).

For $t > 2$ and $\epsilon_f \ll 1$, Equations 3.15 and 3.16 reduce to (see Figures 3.6 through 3.8)

$$E_{\text{mag}}(t) \approx \left| 1 + \epsilon_m \right| - 1 \quad (3.17)$$

and

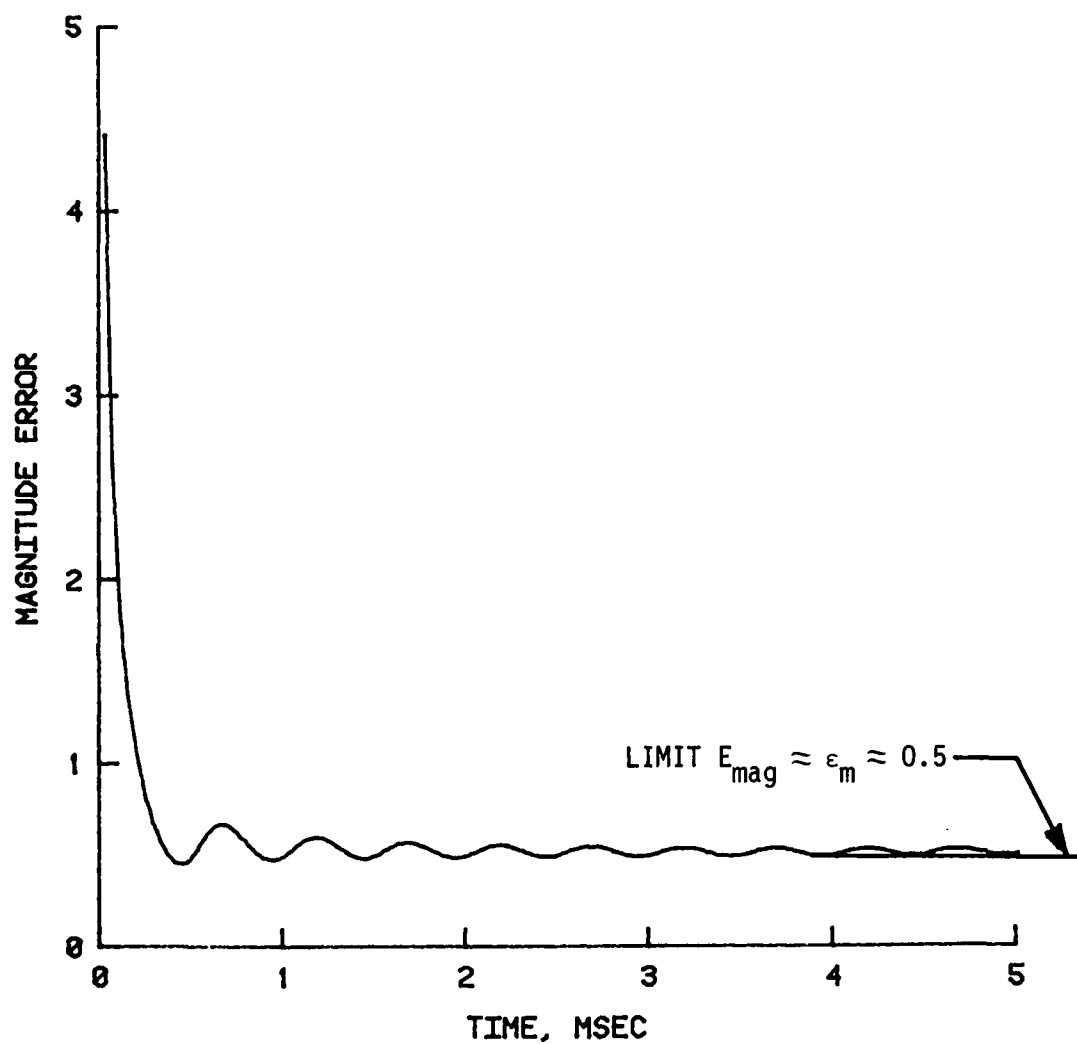


Figure 3.6 Time history of magnitude error for example 2.

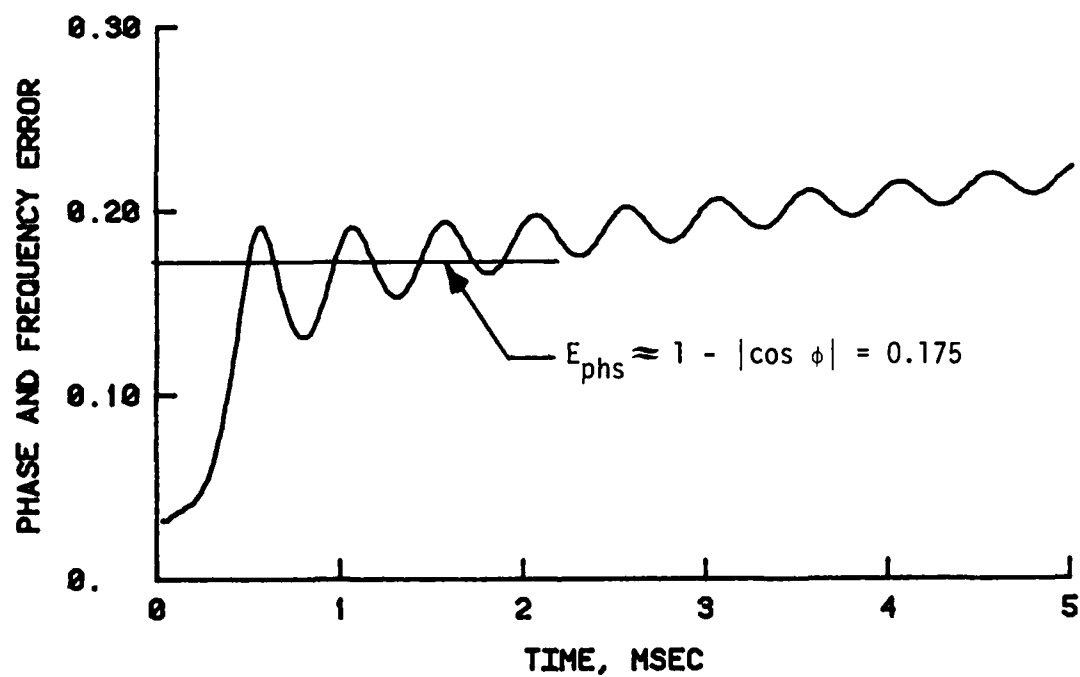
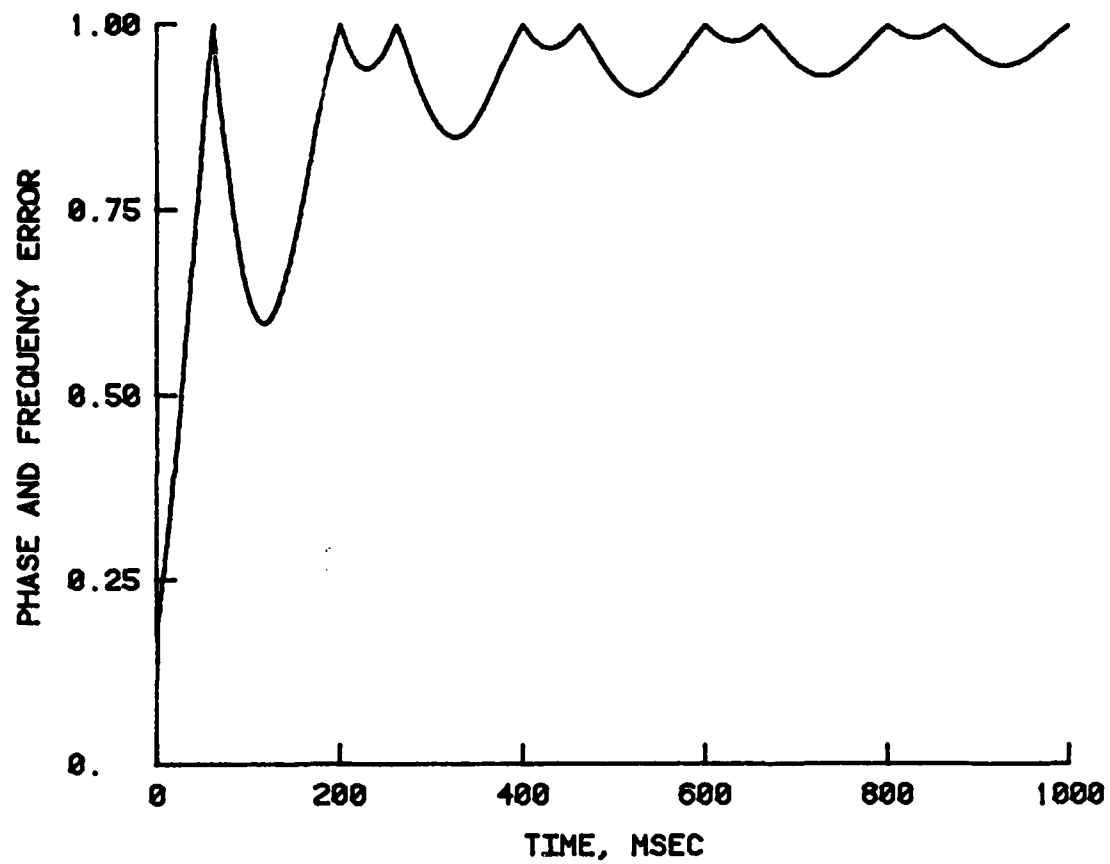


Figure 3.7 Time history of phase-and-frequency error for example 2.

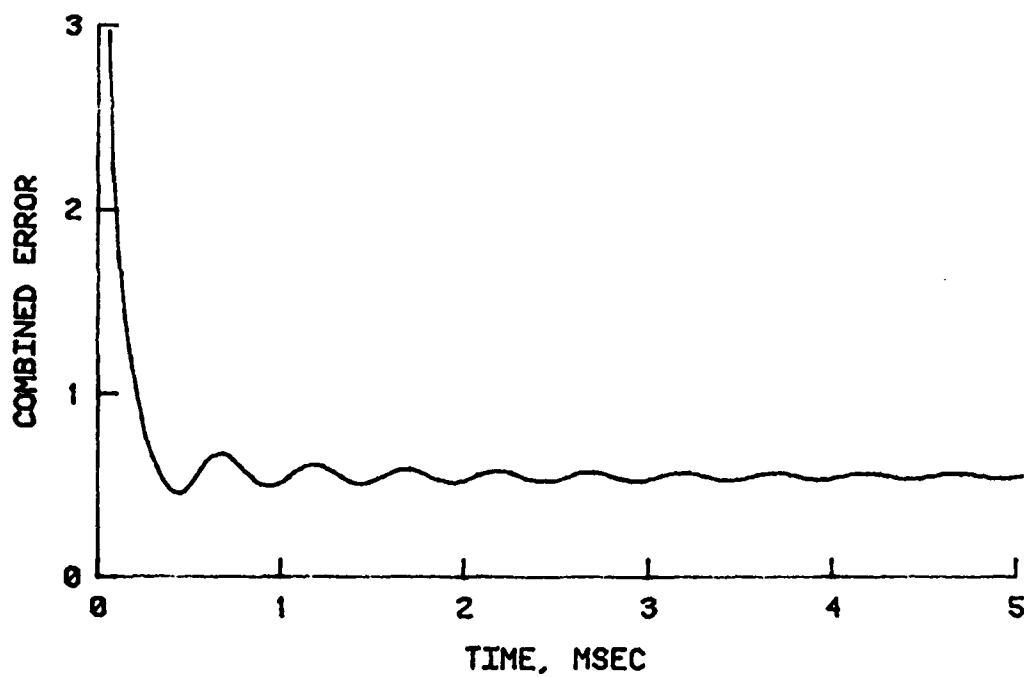
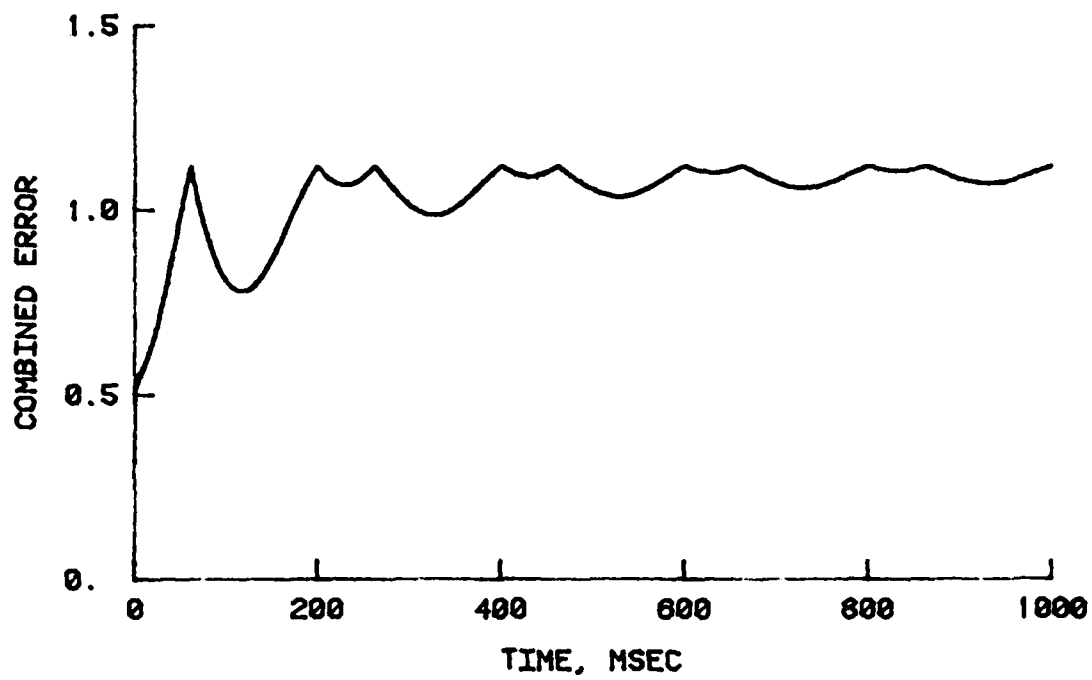


Figure 3.8 Time history of the combined error for example 2.

$$E_{\text{phs}}(t) \approx 1 - \left| \frac{\sin \pi \epsilon_f t}{\pi \epsilon_f t} \cos (\phi + \pi \epsilon_f t) \right| \quad (3.18)$$

Note that Equation 3.17 is identical to the corresponding result for the previous example (Equation 3.5). Note too that if $2 < t \ll (\pi \epsilon_f)^{-1}$, Equation 3.18 is essentially identical to its earlier counterpart (Equation 3.6); i.e., $E_{\text{phs}}(t) \approx 1 - |\cos \phi|$; however, for $t \gg (\epsilon_f)^{-1}$ $E_{\text{phs}} \approx 1$ (see Figure 3.7).

From this example we conclude that frequency error, as embodied in the term ϵ_f , has a negligible, if any, effect on $E_{\text{mag}}(t)$, yet has a profound effect on $E_{\text{phs}}(t)$. In order to put this into proper context, however, the effects of damping must be considered.

3.4 EXAMPLE 3; LIGHTLY DAMPED SINUSOIDAL RESPONSE; PHASE, FREQUENCY AND MAGNITUDE DIFFERENCES

In this example the effects of damping on the sinusoidal responses of the second example (i.e., Equations 3.13 and 3.14) are considered. We rewrite Equations 3.13 and 3.14 (with damping) as (Figure 3.9)

$$R_1(t) = \sin (2\pi t) \exp (-\beta t) \quad (3.19)$$

and

$$R_2(t) = (1 + \epsilon_m) \sin [2\pi(1 + \epsilon_f)t + \phi] \exp [-(1 + \epsilon_d)\beta t] \quad (3.20)$$

where ϵ_m , ϕ , and ϵ_f are as before, β is the damping factor (0.4 msec^{-1} in this example) and ϵ_d is the error in damping (assumed to be 0.1 for this example). The effects of the damping in Equations 3.19 and 3.20 can be clearly seen by comparing Figures 3.9 and 3.5.

Substitution of Equations 3.19 and 3.20 into Equations 2.8 and 2.9 leads to

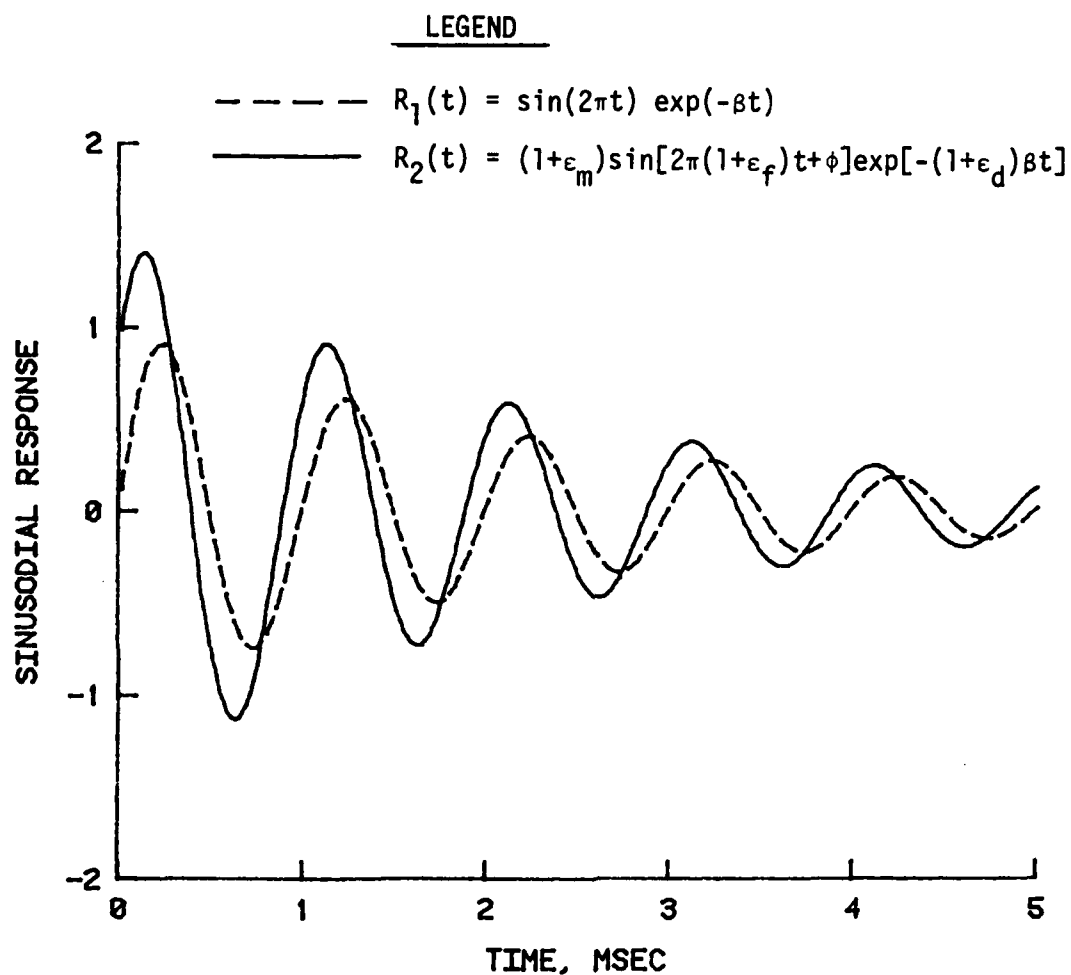


Figure 3.9 Example 3: Time histories of two lightly damped sinusoidal responses; $\epsilon_m = 0.5$, $\phi = 0.6$ radian, $\epsilon_f = 0.005$, $\epsilon_d = 0.1$, and $\beta = 0.4 \text{ (msec)}^{-1}$.

$$E_{\text{mag}}(t) = \frac{\sqrt{A}}{\sqrt{B}} - 1 \quad (3.21)$$

and

$$E_{\text{phs}}(t) = 1 - \frac{|C|}{\sqrt{A} \sqrt{B}} \quad (3.22)$$

where

$$A = \frac{(1 + \epsilon_m)^2}{4\beta(1 + \epsilon_d)} \left\{ 1 - \frac{a \sin 2\phi + a^2 \cos 2\phi}{1 + a^2} - \left[1 - \frac{a \sin (2bt + 2\phi) + a^2 \cos (2bt + 2\phi)}{1 + a^2} \right] \exp (2abt) \right\} \quad (3.23)$$

$$B = \frac{1 - e^{-2\beta t} \left[2 \left(\frac{\beta}{2\pi} \right)^2 \sin^2 2\pi t + \frac{\beta}{2\pi} \sin 4\pi t + 1 \right]}{4\beta \left[1 + \left(\frac{\beta}{2\pi} \right)^2 \right]} \quad (3.24)$$

$$C = \frac{(1 + \epsilon_m)}{2} \left\{ \frac{-(2 + \epsilon_d) \beta \cos (2\pi\epsilon_f t + \phi) + 2\pi\epsilon_f \sin (2\pi\epsilon_f t + \phi)}{[(2 + \epsilon_d)\beta]^2 + (2\pi\epsilon_f)^2} \right. \\ + \frac{(2 + \epsilon_d) \beta \cos [2\pi(2 + \epsilon_f)t + \phi] - 2\pi(2 + \epsilon_f) \sin [2\pi(2 + \epsilon_f)t + \phi]}{[(2 + \epsilon_d)\beta]^2 + [2\pi(2 + \epsilon_f)]^2} \left. \right\} \exp [-(2 + \epsilon_d)\beta t] \quad (3.25) \\ + \frac{(1 + \epsilon_m)}{2} \left\{ \frac{(2 + \epsilon_d)\beta \cos \phi - 2\pi\epsilon_f \sin \phi}{[(2 + \epsilon_d)\beta]^2 + (2\pi\epsilon_f)^2} - \frac{(2 + \epsilon_d)\beta \cos \phi - 2\pi(2 + \epsilon_f) \sin \phi}{[(2 + \epsilon_d)\beta]^2 + [2\pi(2 + \epsilon_f)]^2} \right\}$$

and

$$\left. \begin{aligned} a &= - \frac{(1 + \epsilon_d)\beta}{2\pi(1 + \epsilon_f)} \\ b &= 2\pi(1 + \epsilon_f) \end{aligned} \right\} \quad (3.26)$$

The combined error (Equation 2.10) becomes

$$E_{\text{com}}(t) = \frac{\sqrt{A} - \sqrt{B}}{|\sqrt{A} - \sqrt{B}|} \left\{ \frac{A}{B} - 2\sqrt{\frac{A}{B}} + \frac{C^2}{AB} - \frac{2|C|}{\sqrt{AB}} + 2 \right\}^{\frac{1}{2}} \quad (3.27)$$

Figures 3.10 through 3.12 present the behaviors of Equations 3.21, 3.22, and 3.27.

For $t \rightarrow \infty$, Equations 3.21 and 3.22 become

$$E_{\text{mag}}(t) \Big|_{t \rightarrow \infty} = \left| 1 + \epsilon_m \right| \left\{ \frac{1 + \left(\frac{\beta}{2\pi} \right)^2}{1 + \epsilon_d} \left[1 - \frac{a \sin 2\phi + a^2 \cos 2\phi}{1 + a^2} \right] \right\}^{1/2} - 1 \quad (3.28)$$

and

$$E_{\text{pha}}(t) \Big|_{t \rightarrow \infty} = 1 - \frac{\frac{\beta}{2\pi} \left\{ \frac{\left(1 + \frac{\epsilon_d}{2} \right) \frac{\beta}{2\pi} \cos \phi - \frac{\epsilon_f}{2} \sin \phi}{\left[\left(1 + \frac{\epsilon_d}{2} \right) \frac{\beta}{2\pi} \right]^2 + \left(\frac{\epsilon_f}{2} \right)^2} - \frac{\left(1 + \frac{\epsilon_d}{2} \right) \frac{\beta}{2\pi} \cos \phi - \left(1 + \frac{\epsilon_f}{2} \right) \sin \phi}{\left[\left(1 + \frac{\epsilon_d}{2} \right) \frac{\beta}{2\pi} \right]^2 + \left(1 + \frac{\epsilon_f}{2} \right)^2} \right\}}{\frac{1}{\left[1 + \left(\frac{\beta}{2\pi} \right)^2 \right]^{1/2} \left[1 + \epsilon_d \right]^{1/2}} \left\{ 1 - \frac{a \sin 2\phi + a^2 \cos 2\phi}{1 + a^2} \right\}^{1/2}} \quad (3.29)$$

Equations 3.21 and 3.22 or Equations 3.28 and 3.29 indicate that both the magnitude error and the phase-and-frequency error are dependent on the damping parameter $\beta/2\pi$. However, the phase-and-frequency error is independent of ϵ_m .

Note that if $\epsilon_m^2 \ll 1$, $\epsilon_d^2 \ll 1$, $\epsilon_f^2 \ll 1$, $\phi^2 \ll 1$, $\beta < 1$, and $(2\pi\epsilon_f/\beta) < 1$, Equations 3.28 and 3.29 become

$$E_{\text{mag}}(t) \Big|_{t \rightarrow \infty} \approx \epsilon_m - \frac{1}{2} \epsilon_d \quad (3.30)$$

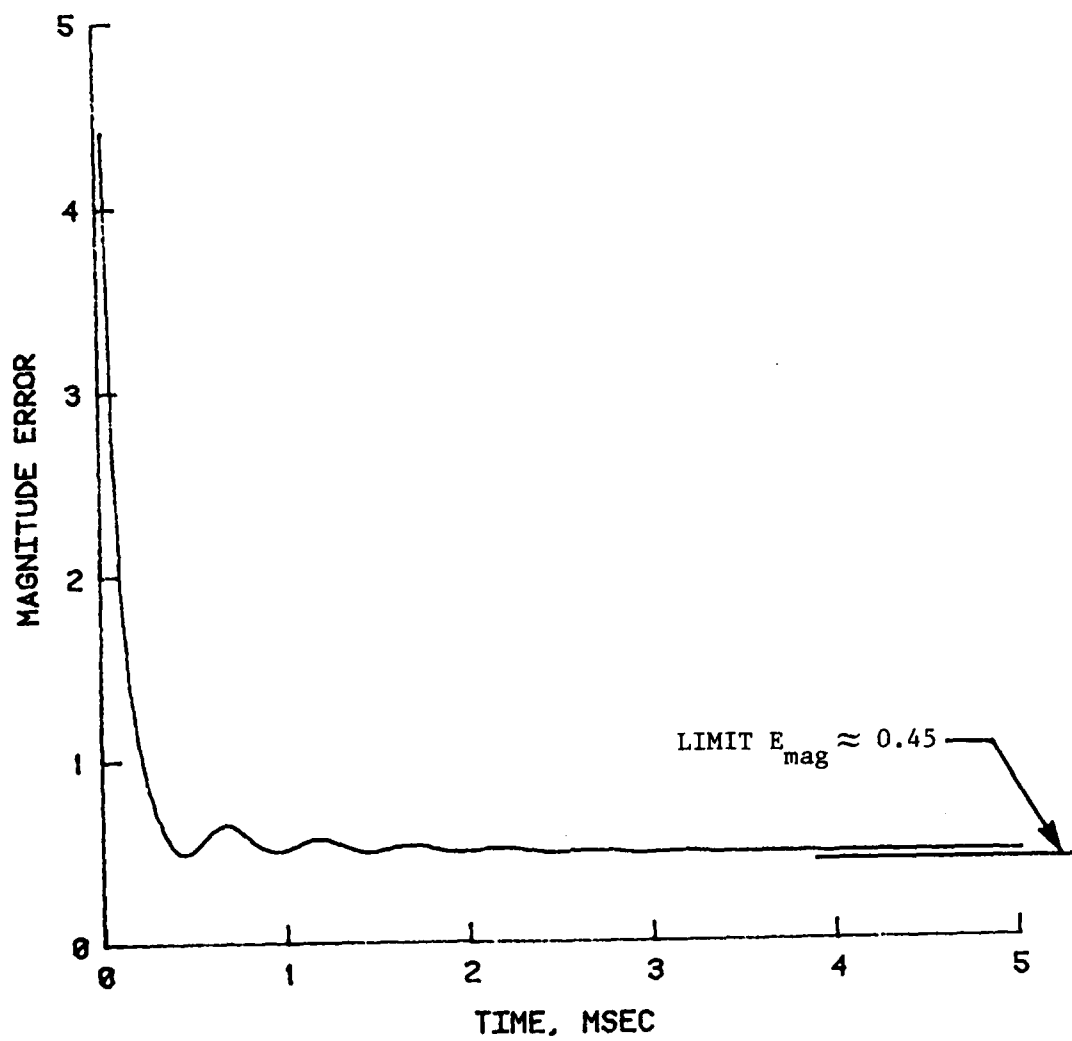


Figure 3.10 Time history of magnitude error for example 3.

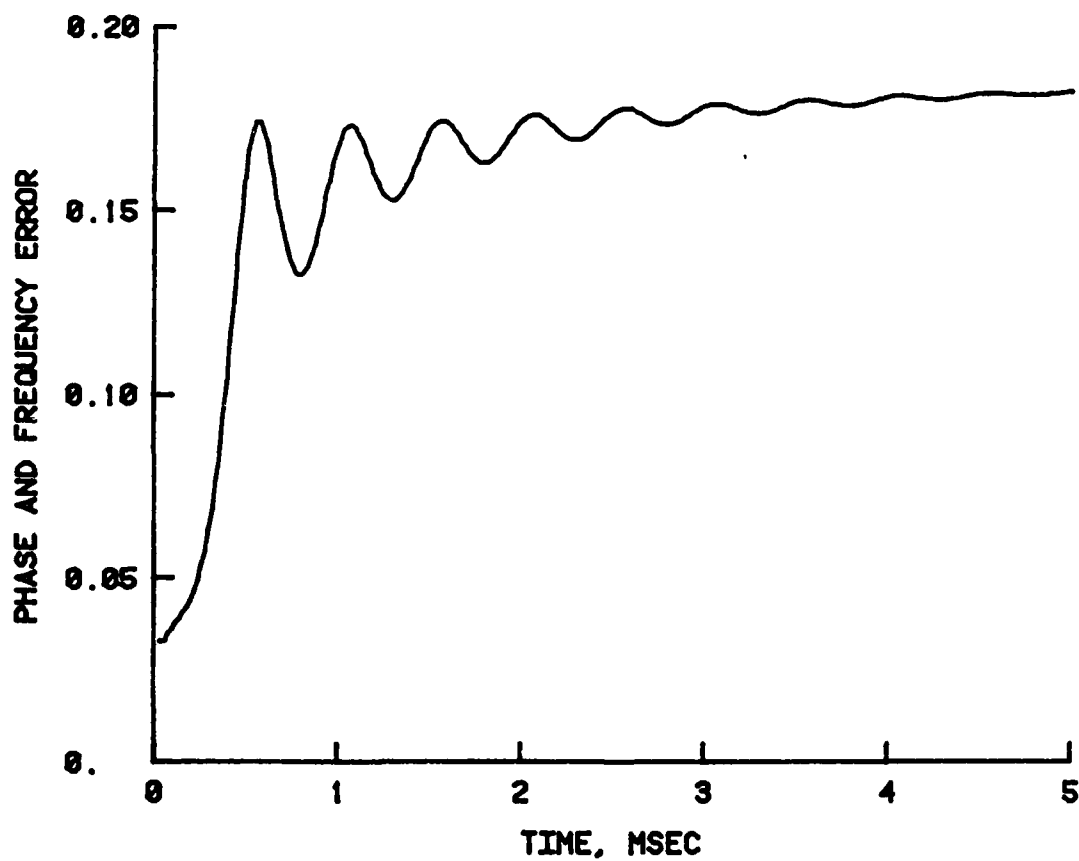
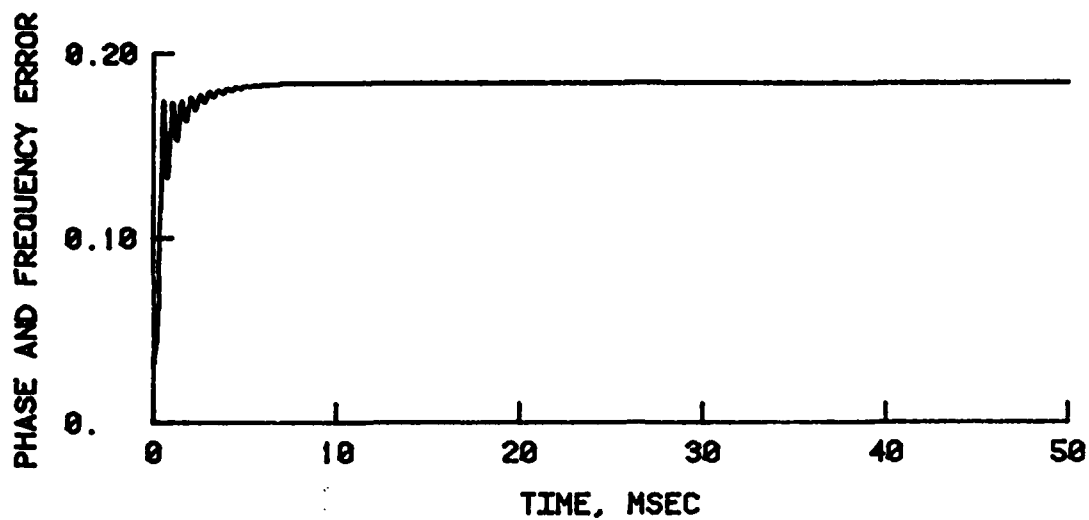


Figure 3.11 Time history of phase-and-frequency error for example 3.

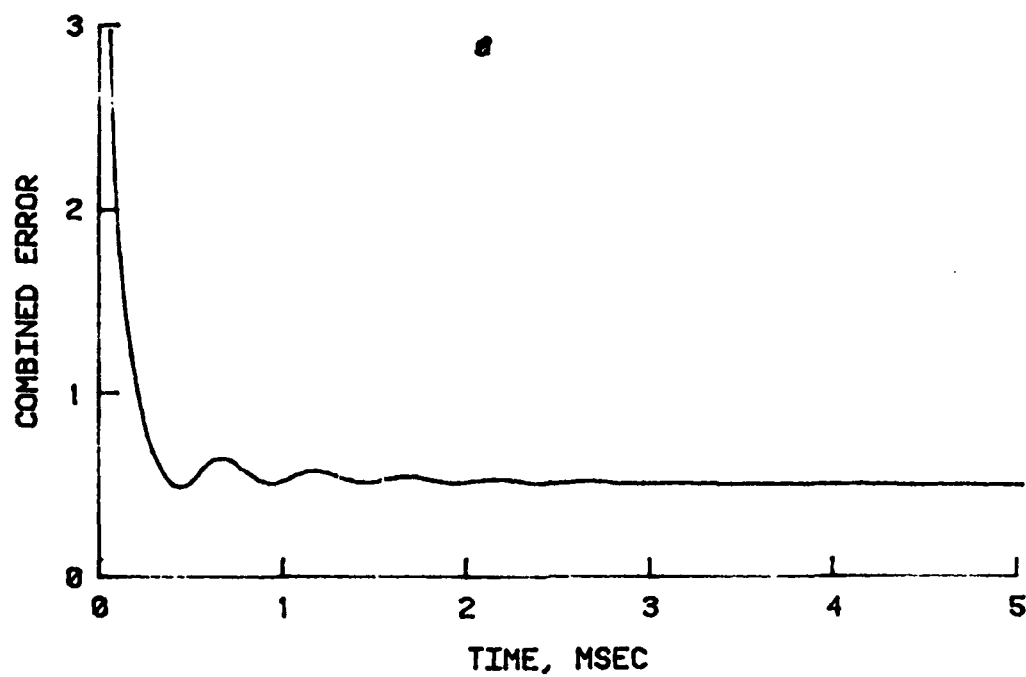
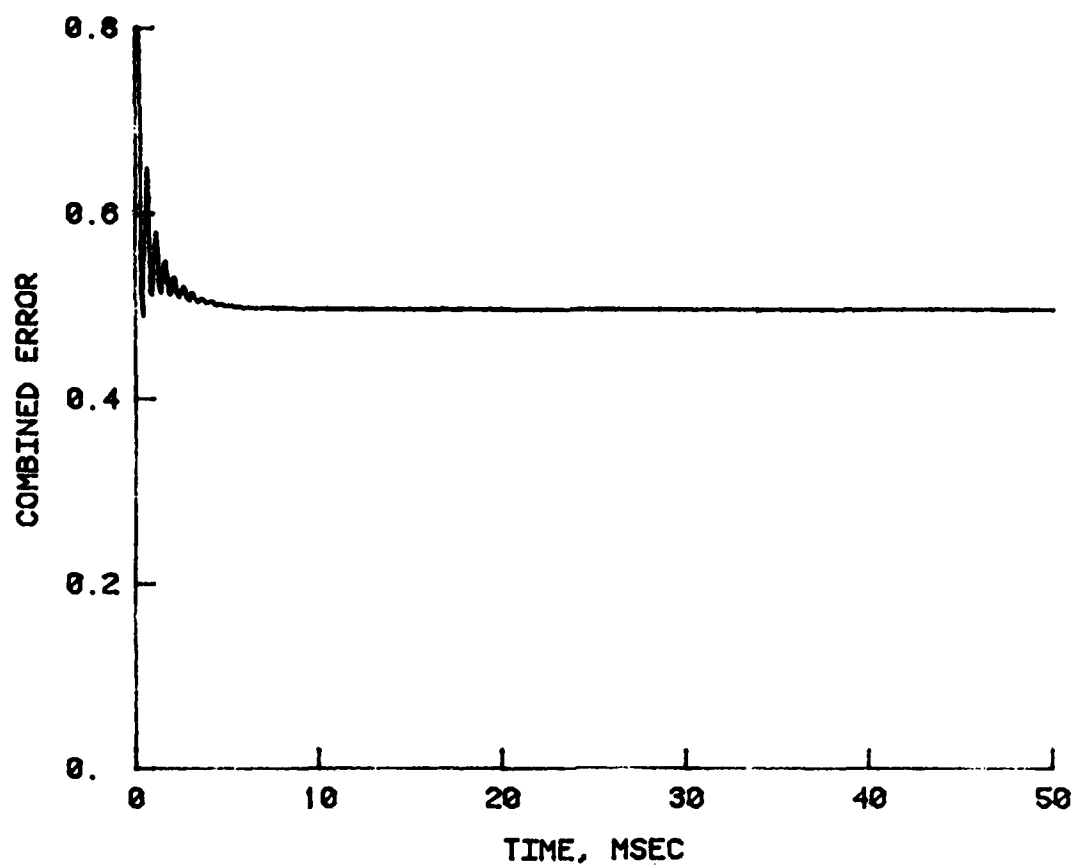


Figure 3.12 Time history of combined error for example 3.

and

$$E_{\text{phs}}(t) \Big|_{t \rightarrow \infty} \approx 1 - \left| \frac{\cos \phi - \frac{\pi \epsilon_f}{\beta} \sin \phi + \frac{\beta}{2\pi} \sin \phi}{\left[1 + \frac{\beta \sin 2\phi}{2\pi} \right]^{1/2}} \right| \quad (3.31)$$

In this case, the magnitude error depends only on ϵ_m and ϵ_d ; and the phase-and-frequency error depends on ϵ_f , ϕ , and the damping parameter $\beta/2\pi$.

The previous three examples demonstrated the application of the objective discrepancy measures. The potential utility of the computer program WCT is demonstrated in the next chapter through statistical analyses of measured data and examples of how calculated response histories can be compared to measurements.

CHAPTER 4

APPLICATIONS

4.1 INTRODUCTION

The objective discrepancy measures established in Chapter 2 (Equations 2.5 through 2.13) were incorporated into a computer program named WCT. The listing of WCT, its flow chart, and its user's guide are included in Appendix A. The computer program WCT is capable of processing digitized data tapes containing either measured or calculated waveforms to produce (a) the mean value and standard deviation at each time-step of any set of transient response histories, and (b) time histories of the objective discrepancy measures established in Chapter 2 (Equations 2.5 through 2.13) for any pair of waveforms. To demonstrate this capability, WCT was used to analyze selected free-field data recorded on the DISC Test I and II events (References 7 and 8), which were High Explosive Simulation Technique (HEST) experiments performed in the desert alluvium of Ralston Valley, Nevada.

4.2 STATISTICAL ANALYSIS OF MEASURED DATA

Figure 4.1 presents nine cavity pressure measurements and their integrals recorded for DISC Test I. These cavity pressure measurements were input to the WCT code which integrated them and produced the mean integral and its standard deviation bounds, as shown in Figure 4.2. The mean integral was then differentiated to obtain the mean cavity pressure waveform (also shown in Figure 4.2). This mean cavity pressure-time history and its standard deviation bounds were subsequently used as airblast pressure drivers for one-dimensional ground shock calculations of the DISC Test II event, as reported in Reference 9.

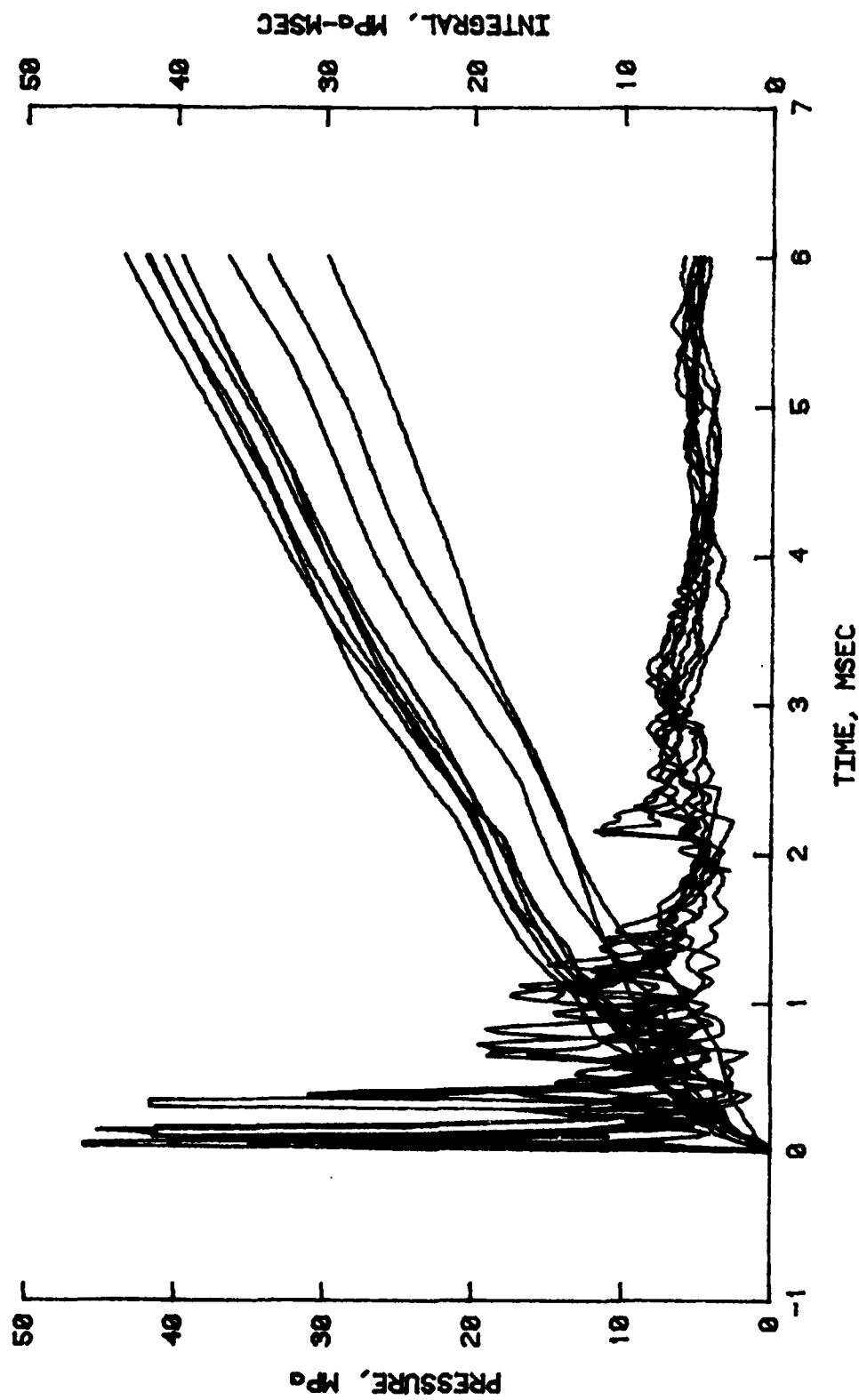


Figure 4.1 Early-time cavity pressure measurements and integrals; DISC Test I event.

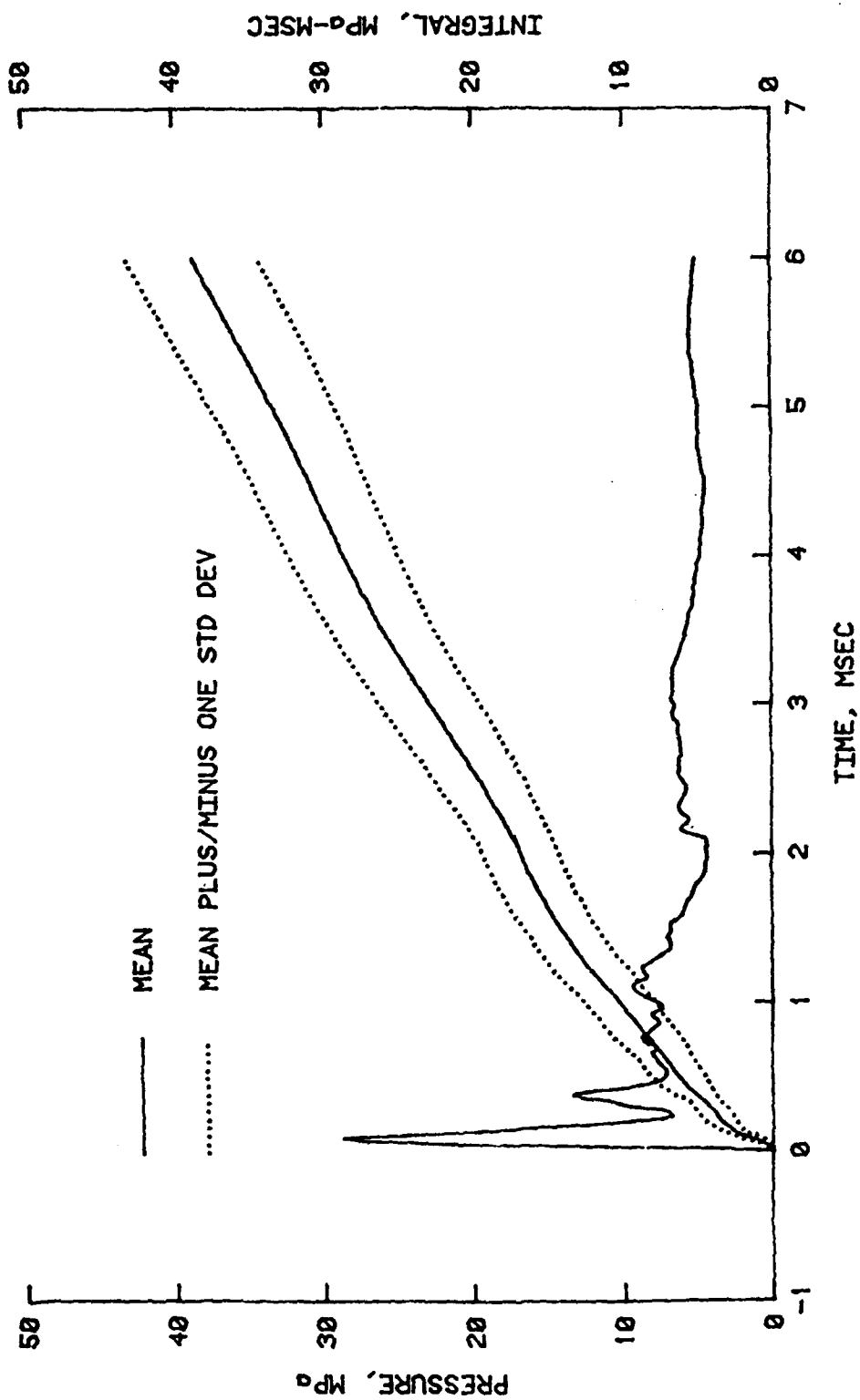


Figure 4.2 Early-time histories of mean cavity pressure and integral with standard deviation bounds for integrals; DISC Test I event.

4.3 COMPARISON OF MEASURED VERSUS CALCULATED RESPONSE HISTORIES

Using the statistical variations of cavity pressure and soil compressibility from DISC Test I as input, a series of probabilistic 1D ground shock calculations was performed to predict particle velocity at the 3-meter depth for the DISC Test II event (Reference 9). The expected value obtained from these calculations and three records of measured velocities are plotted in Figure 4.3. Subjectively the comparison looks "pretty good." But in order to obtain a more objective judgment of the degree of agreement or disagreement among these velocities, the waveforms of Figure 4.3 were input to the computer program WCT, using the expected value from the probabilistic 1D calculations as a base (truth) record. The time histories of the magnitude errors, the phase-and-frequency errors, and the combined errors are shown in Figures 4.4 through 4.6, respectively. The errors associated with two of the measured waveforms (the dotted and the dash-dotted curves) are uniformly small and essentially identical. The errors are larger for the dashed curve, but only during the initial 2- to 3-msec toe (or precursor). The ensemble averages of the individual errors in Figures 4.4 through 4.6 are shown in Figures 4.7 through 4.9. These are simply the mean values of the errors computed using Equations 2.12, 2.13, and 2.14. Comparison of Figures 4.7 and 4.8 indicates that the dominant errors in this case are the magnitude errors.

Figures 4.10 through 4.13 compare the mean of the three DISC Test II measurements (dashed curve) with the calculated expected value (solid line). The magnitude error has a plus-and-minus oscillation during the rise portion and then settles on a numerical value of minus 0.1. For all practical purposes, the phase-and-frequency error is essentially zero; consequently, the combined error is dominated by the magnitude error.

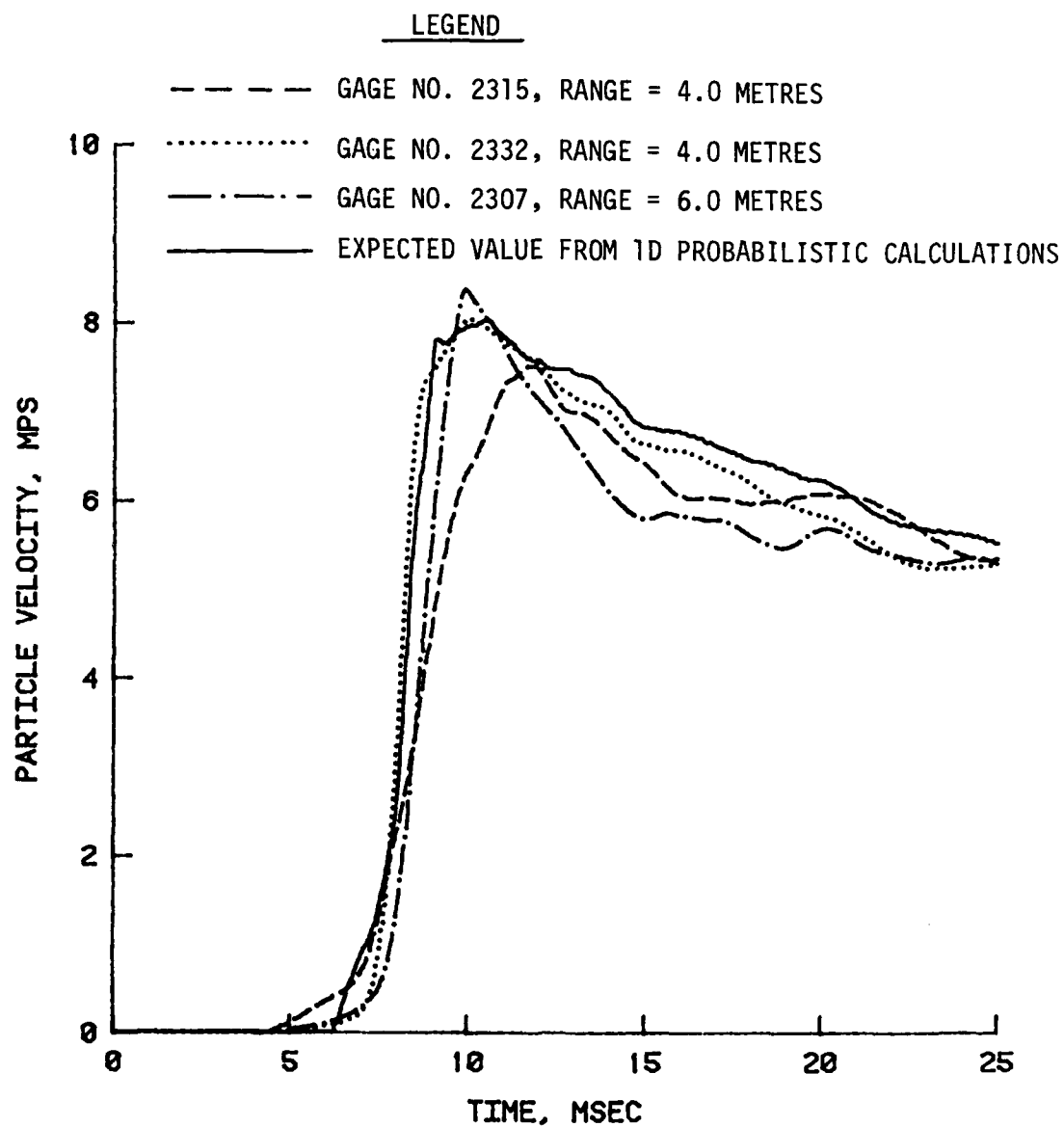


Figure 4.3 Comparison of calculated and measured particle velocity-time histories for DISC Test II event; depth = 3.0 metres.

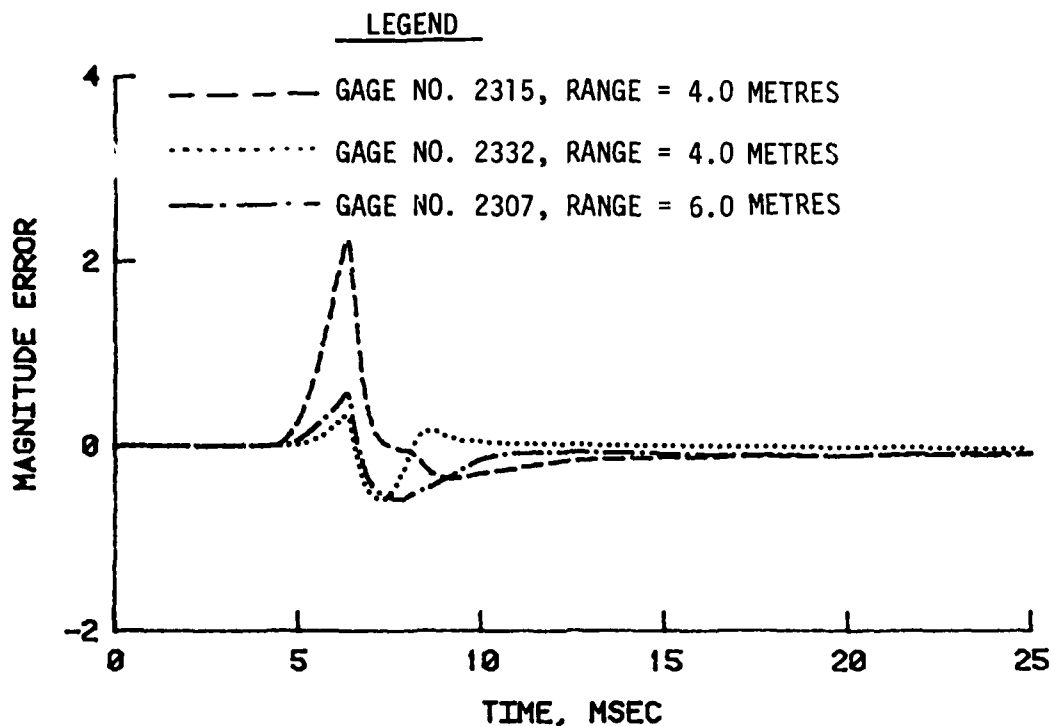


Figure 4.4 Time histories of magnitude errors between measured and calculated velocity waveforms; DISC Test II event, depth = 3.0 metres.

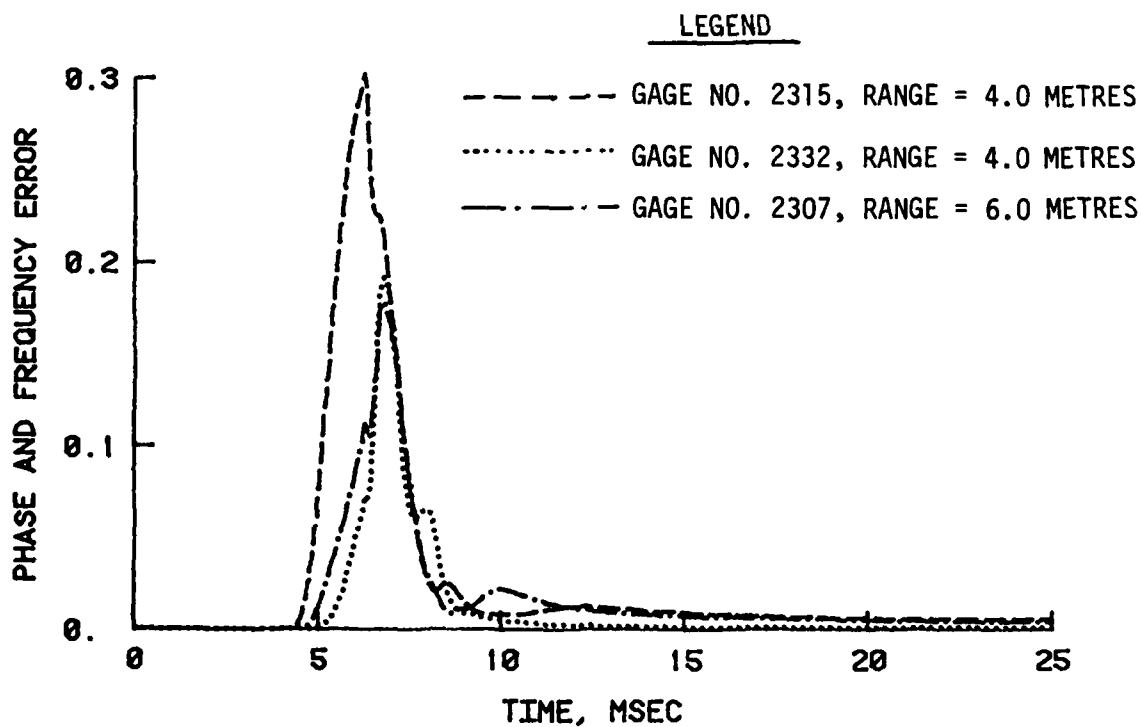


Figure 4.5 Time histories of phase-and-frequency errors between measured and calculated velocity waveforms; DISC Test II event, depth = 3.0 metres.

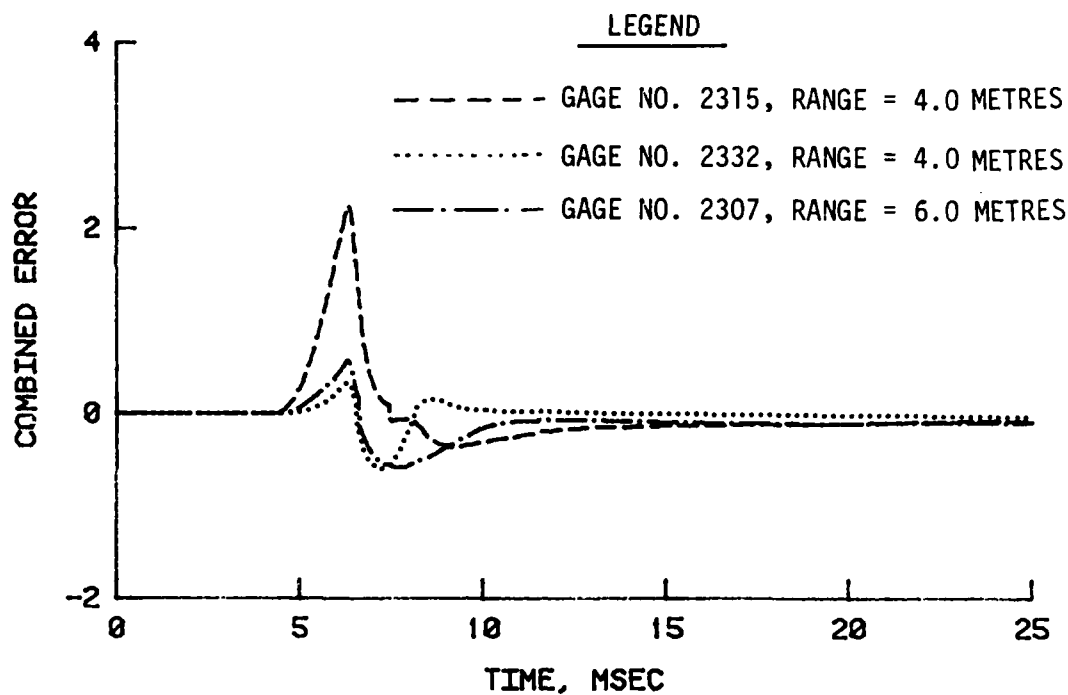


Figure 4.6 Time histories of combined error (magnitude, phase and frequency) for each measured velocity waveform relative to the calculated waveform; DISC Test II event, depth = 3.0 metres.

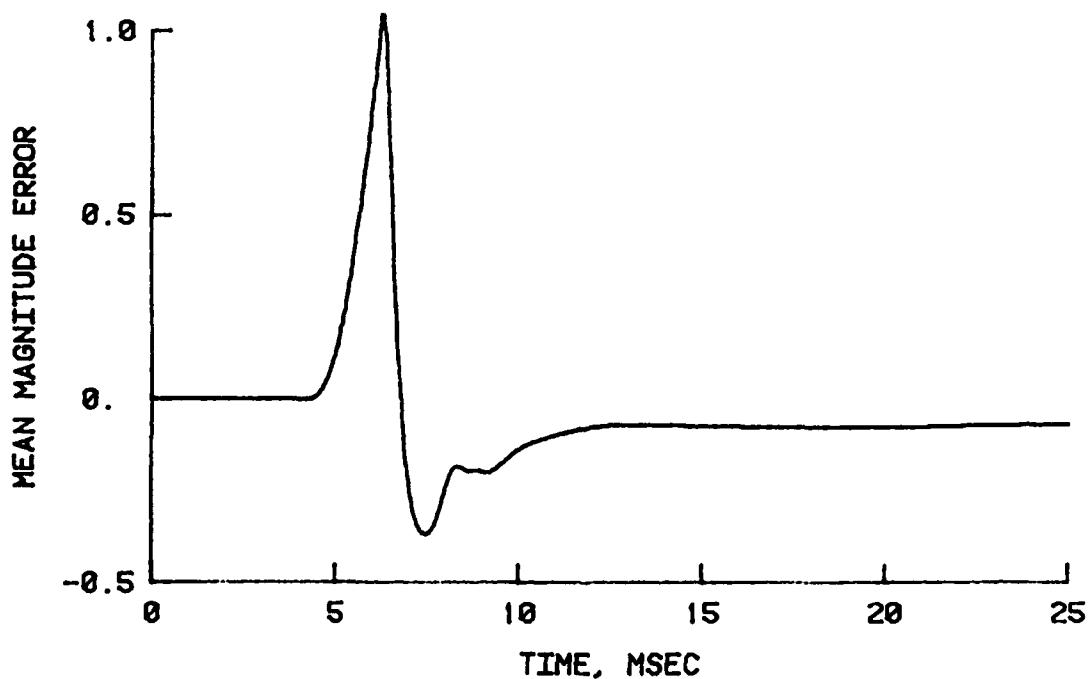


Figure 4.7 Time history of magnitude error between mean measured and calculated velocity waveforms; DISC Test II event, depth = 3.0 metres.

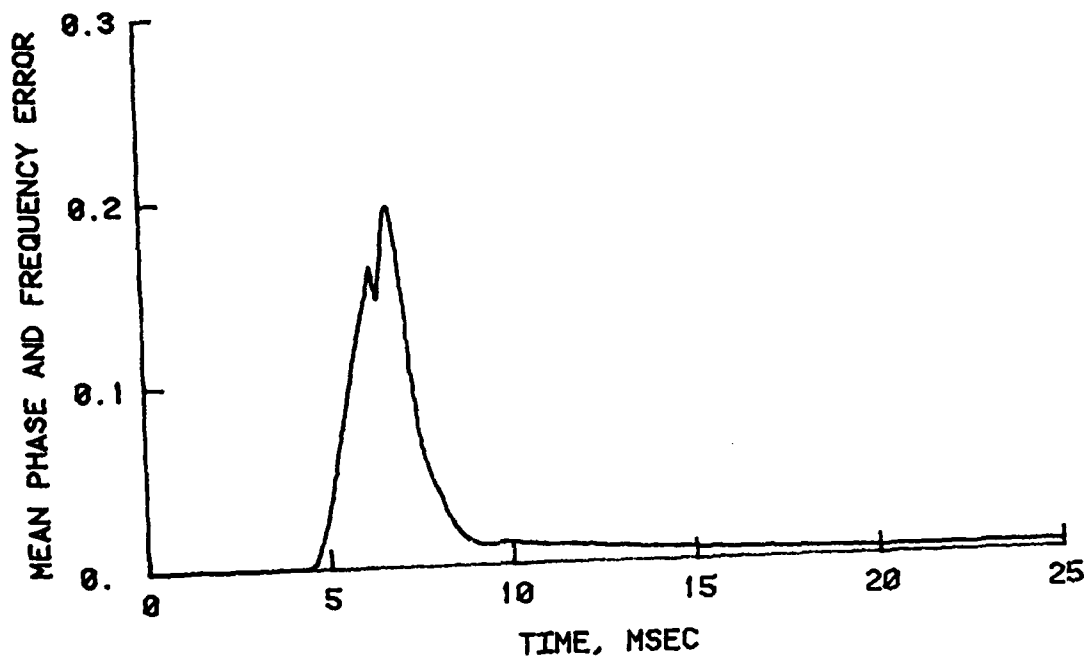


Figure 4.8 Time history of phase-and-frequency error between mean measured and calculated velocity waveforms; DISC Test II event, depth = 3.0 metres.

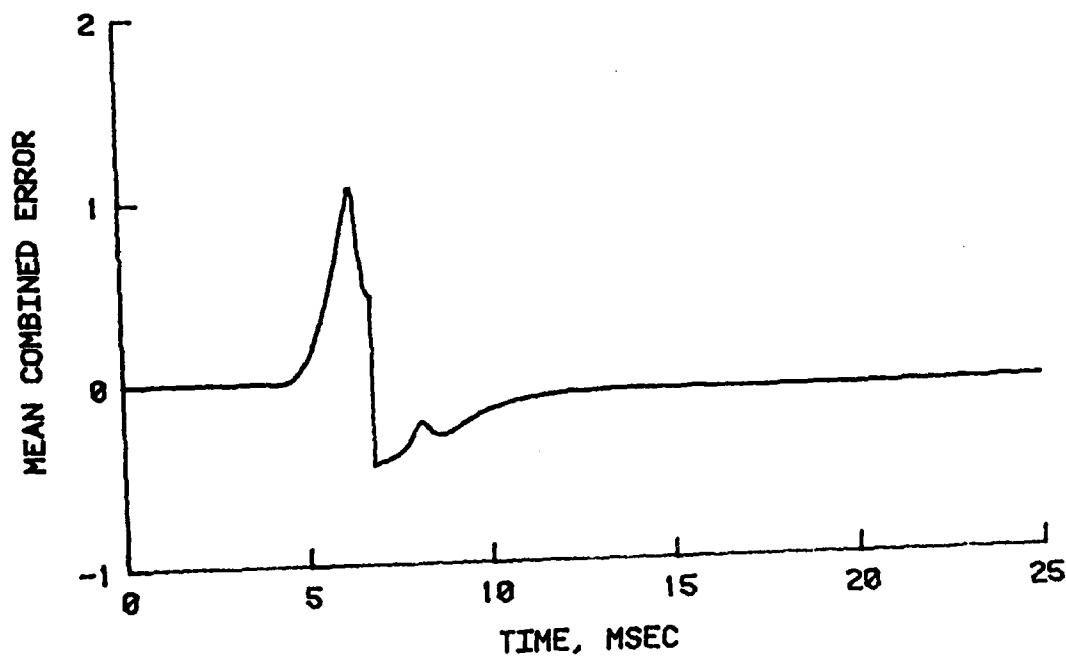


Figure 4.9 Time history of combined error (magnitude and phase-and-frequency) between mean measured and calculated velocity waveforms; DISC Test II event, depth = 3.0 metres.

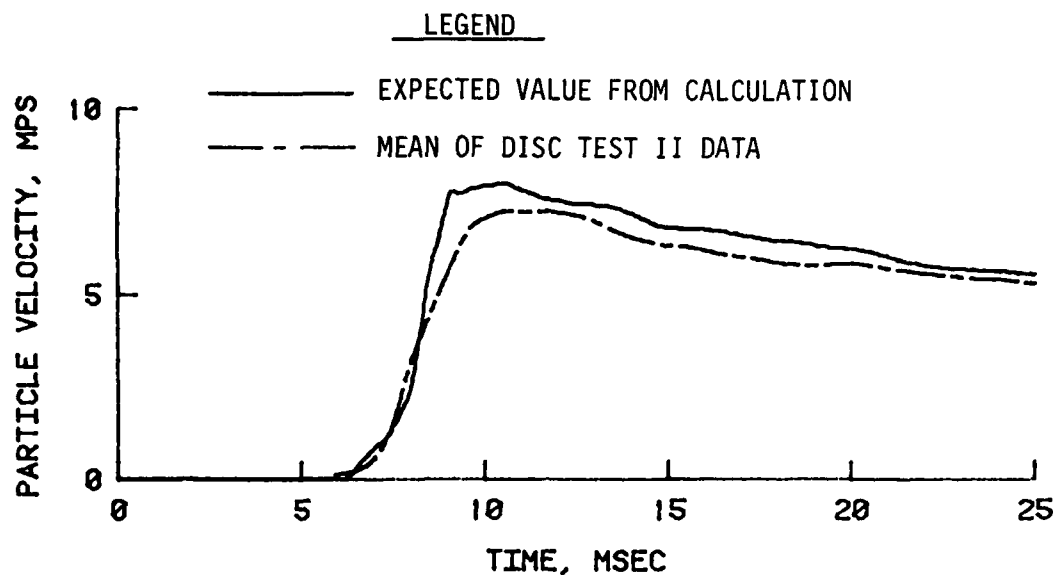


Figure 4.10 Time histories of mean measured and mean calculated velocity waveforms; DISC Test II event; depth = 3.0 metres.

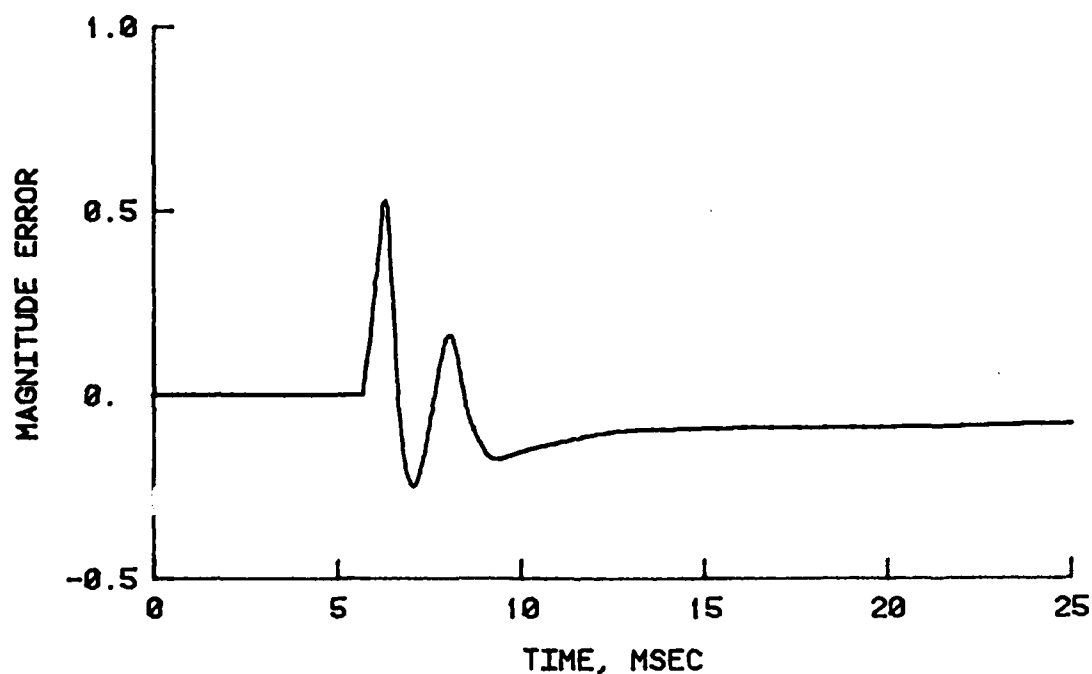


Figure 4.11 Time history of magnitude error between mean measured and mean calculated velocity waveforms; DISC Test II event, depth = 3.0 metres.

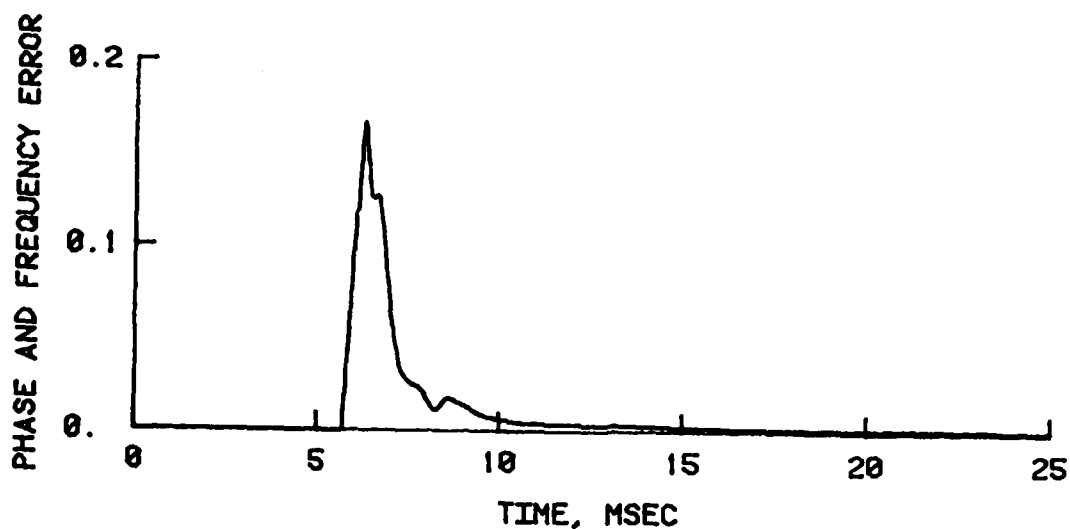


Figure 4.12 Time history of phase-and-frequency error between mean measured and mean calculated velocity waveforms; DISC Test II event, depth = 3.0 metres.

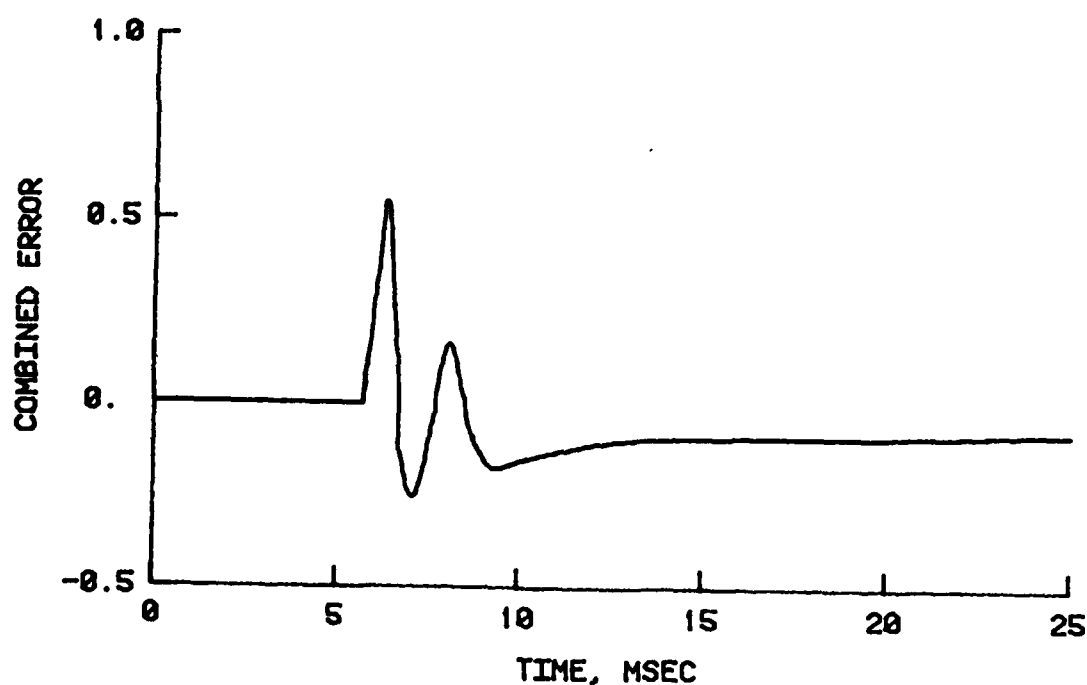


Figure 4.13 Time history of combined error (magnitude, phase-and-frequency) between mean measured and mean calculated velocity waveforms; DISC Test II event, depth = 3.0 metres.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY

A set of objective discrepancy measures for the comparison of transient response histories has been established. It consists of the magnitude correlation factor, the phase-and-frequency correlation factor, the magnitude error, the phase-and-frequency error, and the combined magnitude and phase-and-frequency errors. Their validity and behavior were checked and demonstrated for several simple sinusoidal responses.

The objective discrepancy measures were incorporated into a computer program named WCT which processes digitized data tapes containing measured or calculated waveforms or both.

As a demonstration of capability, the computer program was used to statistically analyze selected data from the DISC Test I event and objectively compare particle velocity measurements made in DISC Test II with the expected value waveform obtained from probabilistic prediction calculations.

5.2 RECOMMENDATIONS

It is recommended that the objective discrepancy measures examined in this report be used whenever comparisons of two or more waveforms are made. It is also recommended that the technique be extended to objectively quantify differences in laboratory- and field-generated material property test results.

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9. J. G. Jackson, Jr.; "Site Characterization for Probabilistic Ground Shock Predictions"; Miscellaneous Paper SL-82-8; July 1982; U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

APPENDIX A

USER'S GUIDE FOR COMPUTER PROGRAM WCT

A.1 INTRODUCTION

This user's guide for the computer program WCT describes typical input and output, contains a glossary of the variables, a flow chart, and a listing of the program, and presents sample tabulated output from two example runs. Program WCT has been coded in Honeywell Level 66 Fortran for the timesharing subsystem of the Honeywell DPS-1 digital computer currently operated at WES.

A.2 INPUT

The digitized waveforms for input to program WCT can be read directly from tapes or can be written to binary data files for subsequent access through the DPS-1 timesharing subsystem. Each input waveform consists of two records which are treated as one tape file by WCT. The first record contains the number of digitized data points, the digital time increment, and an identification (ID) label. For measured waveforms, this ID label consists of three 20-character alpha-numeric variables that contain all pertinent information about the gage and type of data; for calculated waveforms, the ID label consists of a title up to 60 characters in length. The record contains the digitized waveform as a single array of data points. All other input is in free-field format, and the program will call for the variables by name.

The first line of input variables contains the following information:

XFINAL-----Final time for calculations, msec.

DX-----Time increment, msec.

NTPLOT-----Type of calculations desired: For NTPLOT = 1, objective discrepancy measures (Equations 2.5 through 2.14 of Chapter 2) are computed;

for NTPLOT = 2, expected value and standard deviation are computed; and for NTPLOT = 3, expected value, standard deviation, and derivatives with respect to time for expected value and standard deviation are computed.

SEARV-----Search value for normalizing the arrival times of the records (about 1/2 percent of peak value of the data). If SEARV is input as zero, the data will be read from the beginning of the record.

ISKIP-----Print SKIP increment.

NIBASE-----Number of integrations for base record.

NICOMP-----Number of integrations for comparison records. (The base record is treated separately from the other records. This will allow a comparison of the base record to one, or more, measured or calculated waveforms.)

The second line of input contains the following variables which are required by the program for every record:

NSORCE----- = 0; no more waveforms to be read in.
 = 1; measured waveforms.
 = 2; calculated waveforms.

NFILE-----File number. If NFILE = 0, the program will ask for the name of a data file containing the waveform(s).

The third line of input is the name of the data file, called "FILE," containing the waveform. Finally, the program asks for the value of ANS, which gives the user options to obtain plots or tables or both, as described below.

A.3 OUTPUT

WCT output consists of optional time history plots or tabulated data or both. In addition, the input records can be plotted either before or after preprocessing or both. A table of maximum and minimum values is produced for all computations.

The type of output depends on the value of NTPLOT. For NTPLOT = 1, the output consists of the magnitude error (Equation 2.8), the phase-and-frequency error (Equation 2.9), and the combined error (Equation 2.10). If there is more than one comparison record, the mean of each error (i.e., ensemble averages, Equations 2.12, 2.13, and 2.14) is also computed. For NTPLOT = 2, the output consists of expected (or mean) values and standard deviation. If the arrival times of the records have been normalized, the expected waveforms can be plotted against the time associated with expected arrival time and the expected waveform plus or minus standard deviation can be plotted against the expected arrival time plus or minus the standard deviation, respectively. For NTPLOT = 3, the output consists of data identical to NTPLOT = 2, plus the derivatives with respect to time of (a) the expected value, (b) the expected value plus one standard deviation, and (c) the expected value minus one standard deviation.

A.4 GLOSSARY

A.4.1 Main Program

ANS	Character variable through which the types of outputs are chosen.
CEF	Combined error factor (Equation 2.7).
DE(I)	Derivative with respect to time of E(I) at the Ith time step.

DEM(I)	Derivative with respect to time of EM(I) at the Ith time step.
DEMAX	Maximum value of DE(I).
DEMIN	Minimum value of DEM(I).
DEP(I)	Derivative with respect to time of EP(I) at the Ith time step.
DEPMAX	Maximum value of DEP(I).
DT(J)	Time increment for the Jth record, msec.
DX	Time increment for calculations, msec.
DXI	1/DX.
DX02	DX/2.
E(I)	Expected value (mean of given set of records at the Ith time step).
ECMN(K)	Minimum value of ECOM(I,K) at the Kth record.
ECMX(K)	Maximum value of ECOM(I,K) at the Kth record.
ECOM(I,K)	Combined error between the Kth record and the base one at the Ith time step (Equation 2.10).
ECOMAV(I)	Mean combined error at the Ith time step (Equation 2.14).
EM(I)	E(I) Minus one standard deviation at the Ith time step.
EMAG(I,K)	Magnitude error between the Kth record and the base one at the Ith time step (Equation 2.8).

EMAGAV(I)	Mean magnitude error at the Ith time step (Equation 2.12).
EMAX	Maximum value of E(I).
EMIN	Minimum value of E(I).
EMMIN	Minimum value of EM(I).
EMMN(K)	Minimum value of EMAG(I,K) at the Kth record.
EMMX(K)	Maximum value of EMAG(I,K) at the Kth record.
EP(I)	E(I) plus one standard deviation at the Ith time step.
EPHS(I,K)	Phase-and-frequency error between the Kth record and the base one at the Ith time step (Equation 2.9).
EPHSAV(I)	Mean phase-and-frequency error at the Ith time step (Equation 2.13).
EPMAX	Maximum value of EP(I).
EPMN(K)	Minimum value of EPHS(I,K) at the Kth record.
EPMX(K)	Maximum value of EPHS(I,K) at the Kth record.
ES	Temporary variable for computing the expected value.
II(I)	Integral of the base record squared at the Ith time step.
ICM1	Number of records to be compared with the base record.
ICNT	Total number of records to be processed.
ISKIP	Print SKIP increment.

MAXC(K)	One plus maximum absolute value of the record at K.
MAXM	Maximum absolute of the base record.
MCF	Magnitude correlation factor (Equation 2.5).
N1	Parameter variable for setting the maximum number of comparison cases to be processed.
NC	Parameter variable for setting the maximum number of records to be processed.
NIBASE	Number of times for which the base record must be integrated.
NICOMP	Number of times for which the waveforms must be integrated.
NINT	Temporary counter for NIBASE and NICOMP.
NINVERS	$1/ICM1$.
NP	Parameter variable for setting the maximum number of time steps that can be processed.
NPOINT	Number of time steps to be used for given calculations.
NPIS(J)	Number of time steps in the Jth record.
NTPLOT	Variable determines the desired type of output.
PCF	Phase-and-frequency correlation factor (Equation 2.6).
PEF(K)	Peak error factor of the Kth record.
PLOT2	A subroutine for plotting on a Tektronix 4662 interactive digital plotter (Note: It is not the intent of this user's guide to explain the use of PLOT2).

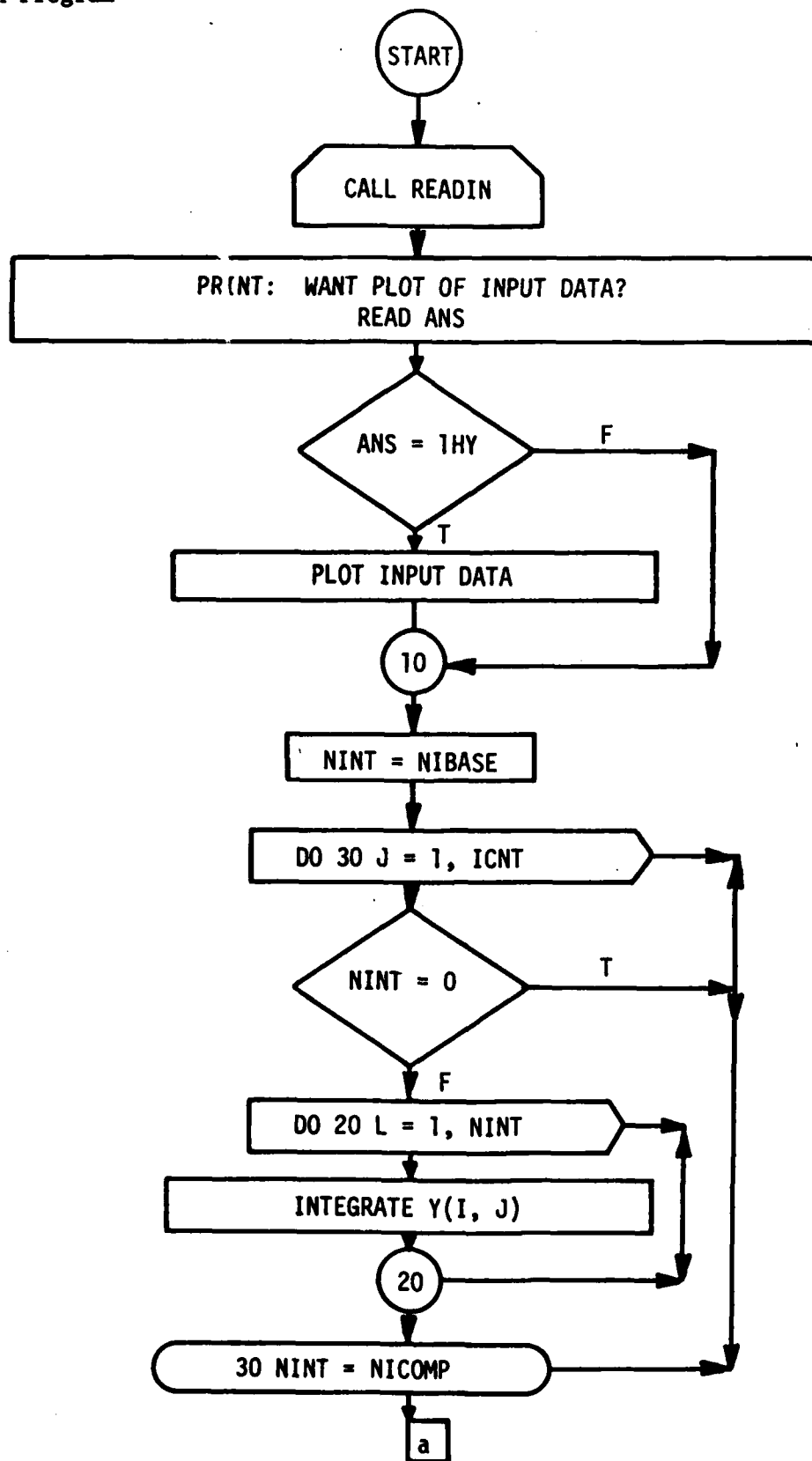
RICNT	$1./ICNT.$
RNM1	$1/(ICNT-1).$
SS	Variance.
ST	Standard deviation.
SUM1	Temporary variable for computing MCF.
SUM2	Temporary variable for computing PCF.
TAR(K)	Arrival time for the Kth record, msec.
TE(I)	Time associated with E(I) at the Ith time step, msec.
TE1	Expected arrival time of the given set of records, msec.
TITLE(K)	Title with up to 60 characters for identifying the Kth record.
TM(I)	Time associated with EM(I) at the Ith time step, msec.
TM1	TE1-ST.
TP(I)	Time associated with EP(I) at the Ith time step, msec.
TP1	TE1+ST.
X(J,K)	Time associated with the Kth record at the Jth time step, msec.
XCUR	Temporary variable used for interpolation.
XFINAL	The length of the calculation, msec.

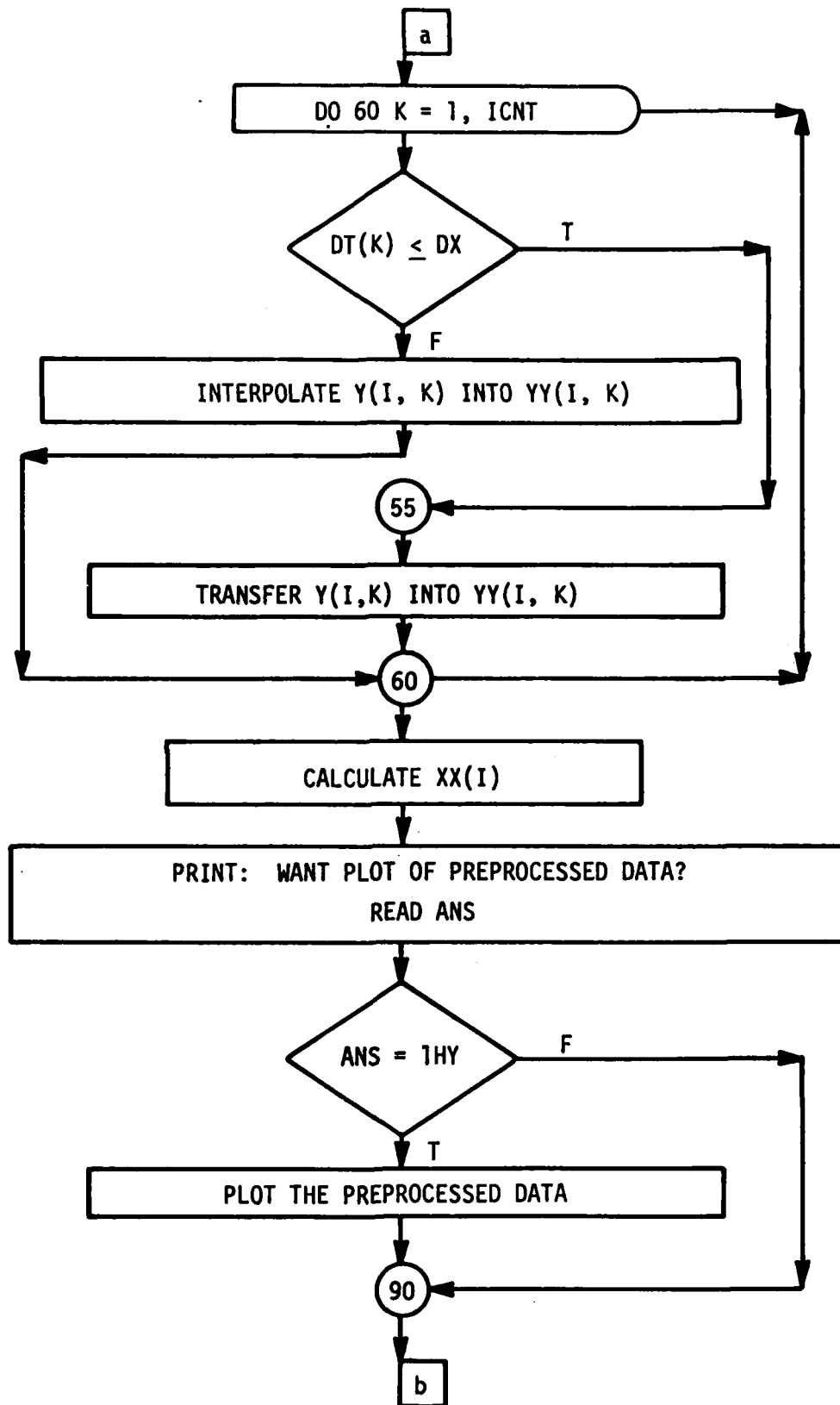
XX(I)	Time at the Ith time step, msec.
Y	An array for storing the input data.
YNEXT,YT	Temporary variables for integration.
YY	An array for storing the preprocessed data.
A.4.2 Subrouting READIN	
ATTACH	System subroutine for opening a permanent file.
BCDASC	System subroutine for converting from BCD to ASCII.
C1,C2,C3	Identification for measured data; BCD labels (converted to ASCII for title).
DETACH	System subroutine for closing a permanent file.
DT(ICNT)	Time increment (in seconds, converted to milliseconds) for the ICNT record.
DX	Time increment, msec.
FILE	Variable name for input file.
ICNT	Record counter.
ISKIP	Print SKIP increment.
N1,NC,NP	(See main program).
NFILE	Tape file number in the input file.
NIBASE, NICOMP	(See main program).

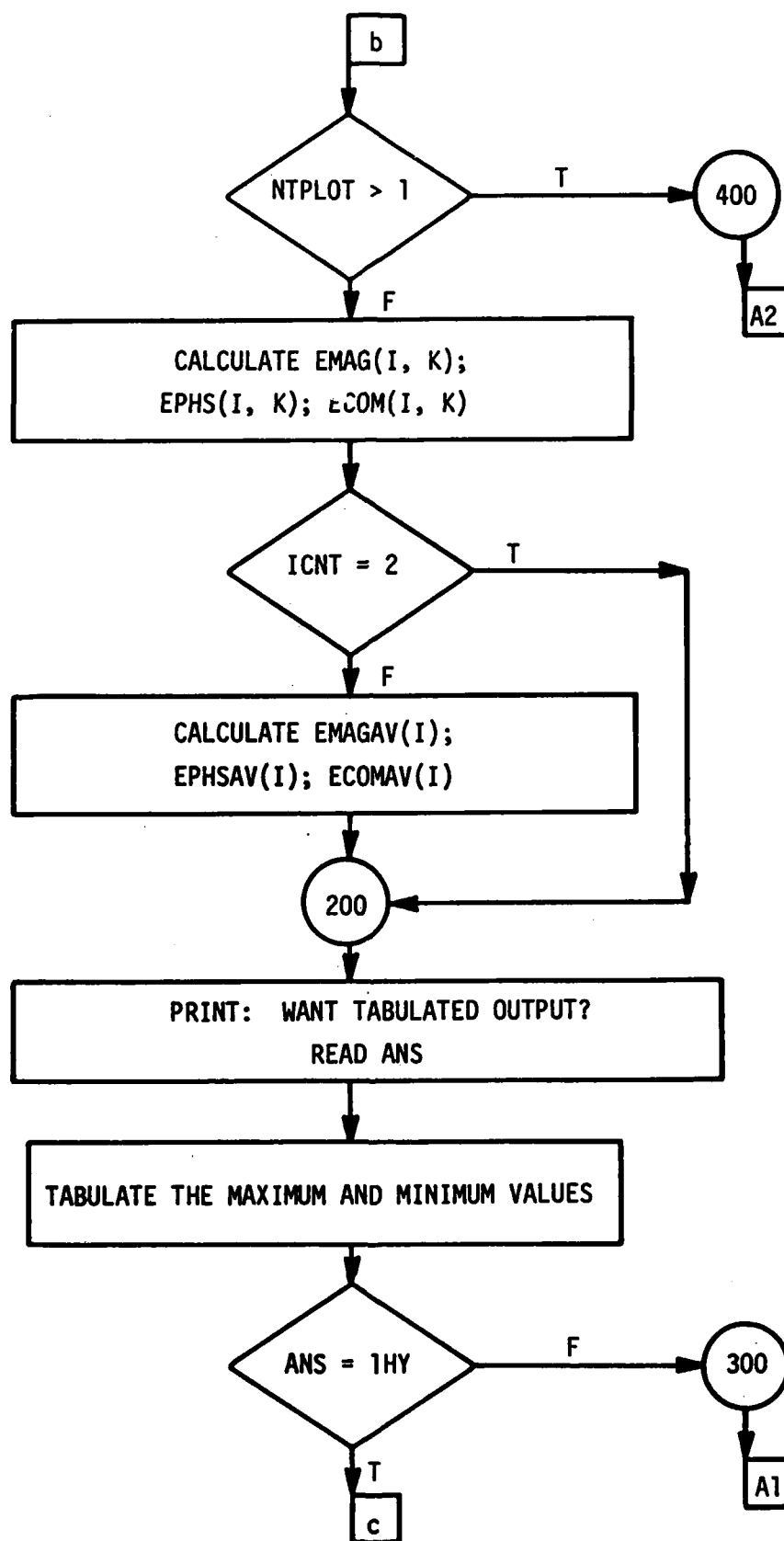
NPOINT	Number of points to be used for calculations. NPOINT will be reduced if any input record contains fewer than NPOINT data points (this would also reduce the value of XFINAL).
NPS	Maximum number of data points from an input record to be searched in order to obtain the arrival time.
NPT	Total number of data points to be read from an input record.
NPTX(ICNT)	(See main program.)
NSORCE	Origin of input data: NSORCE = 1 for measured data; NSORCE = 2 for calculated data.
NSTRT	The number of time steps at which the signal arrives.
NTPLOT	(See main program.)
SEARV	(See the input.)
TAR(ICNT)	Arrival time (in seconds, converted to milliseconds) for record number ICNT.
TDUM	Identification label. BCD label (converted to ASCII for title).
TITLE(ICNT)	(See main program.)
X,XFINAL,XX,Y,YY	(See main program.)

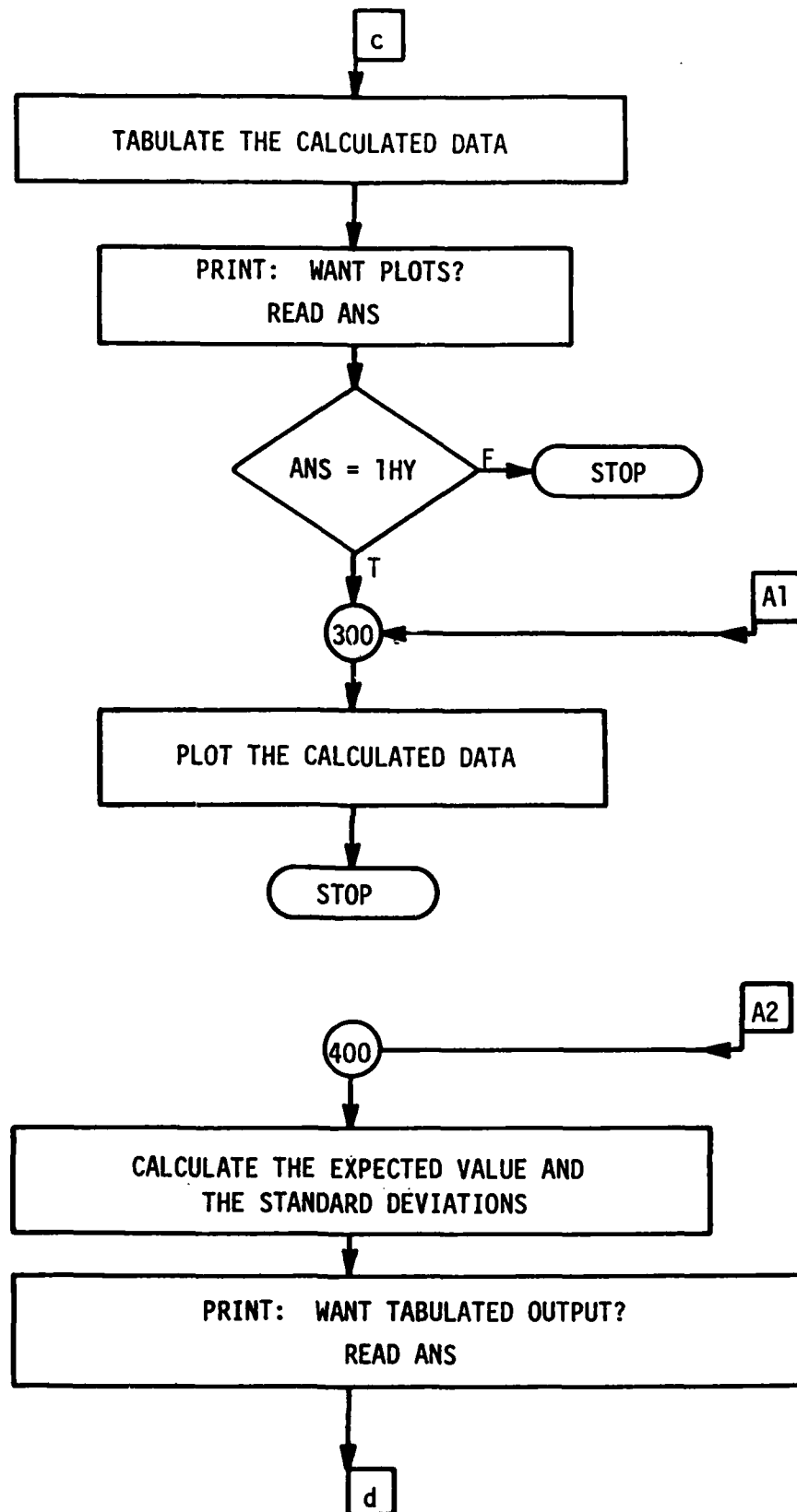
A.5 FLOW CHART

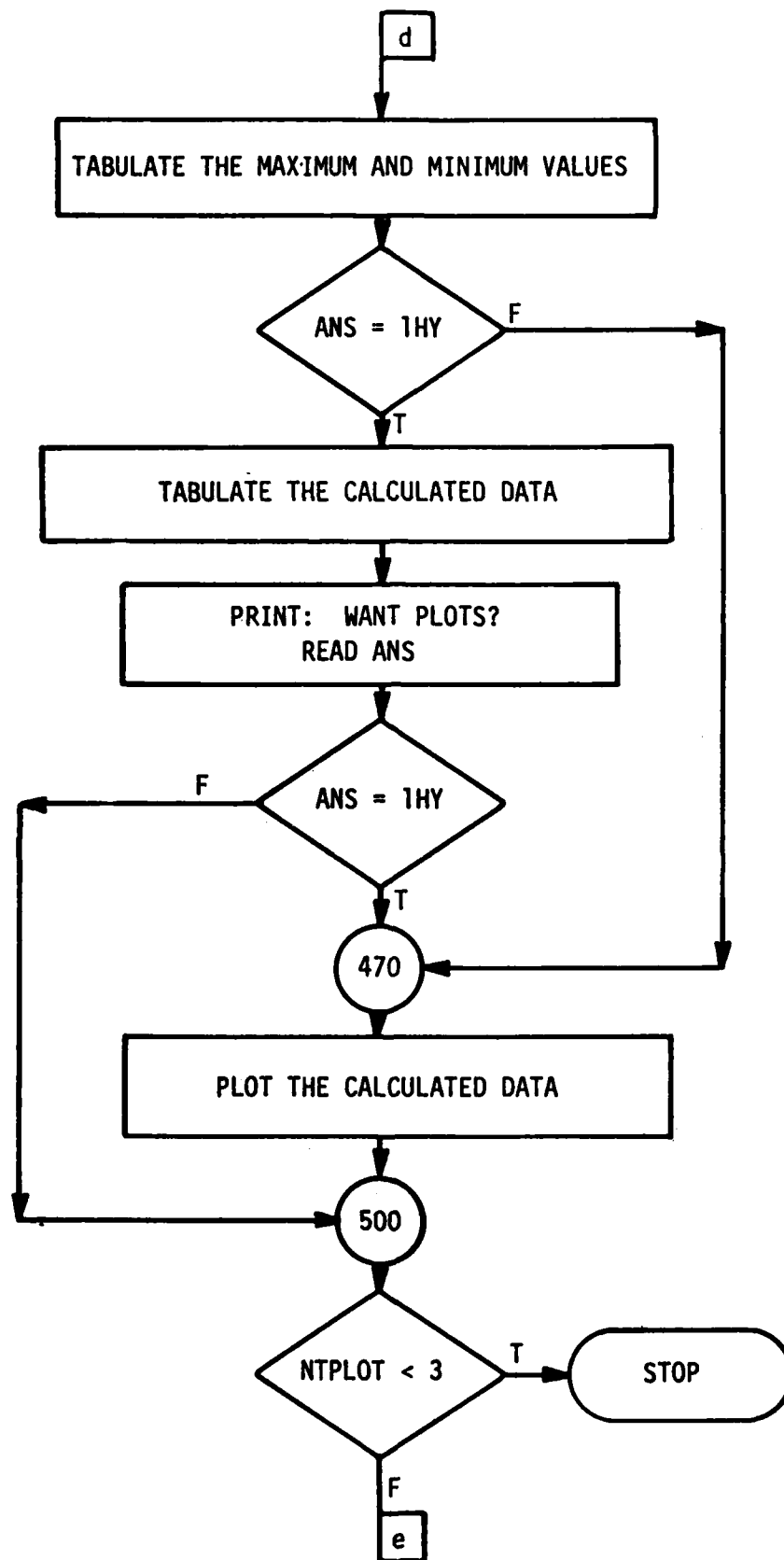
A.5.1 Main Program

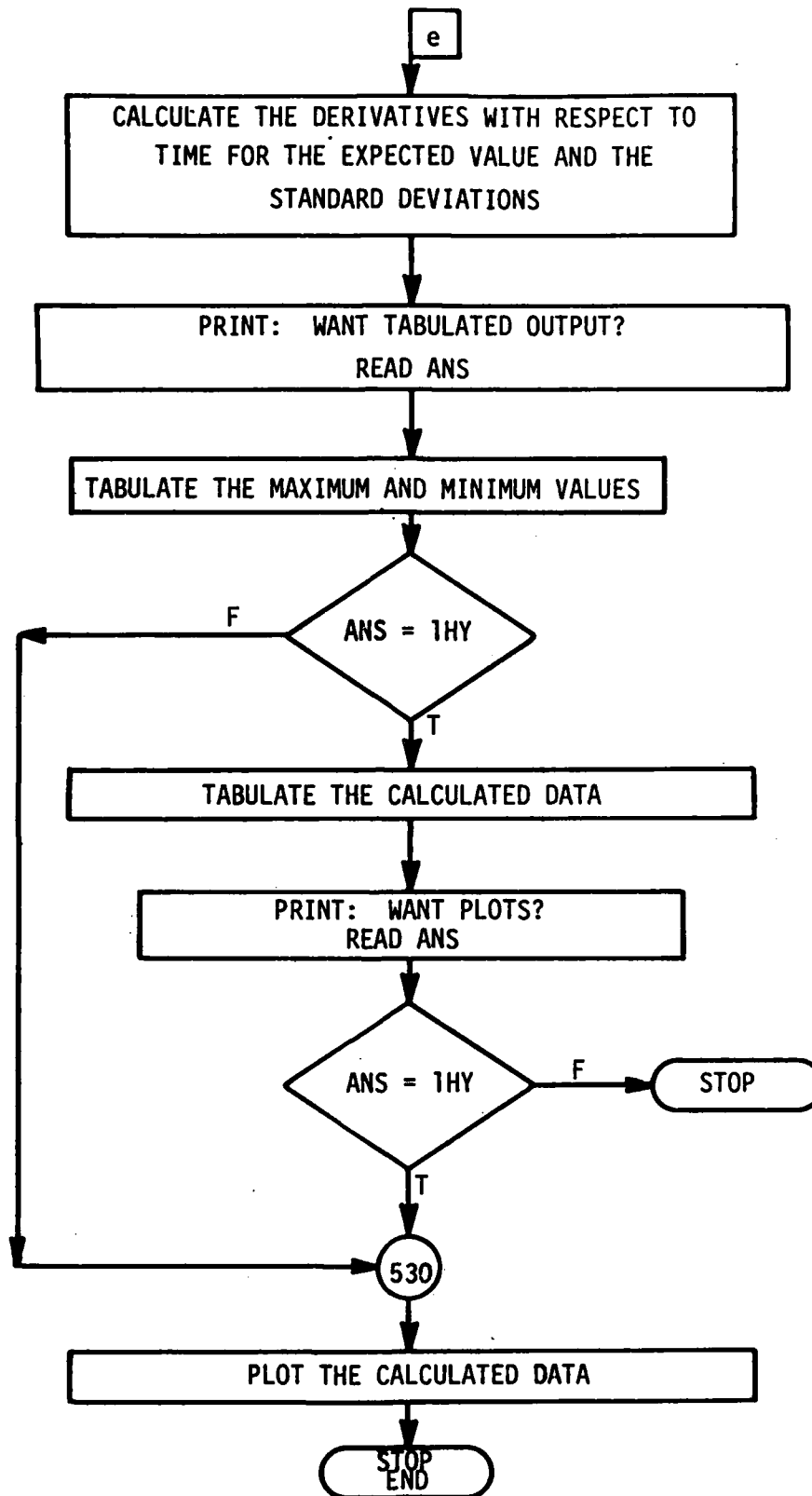




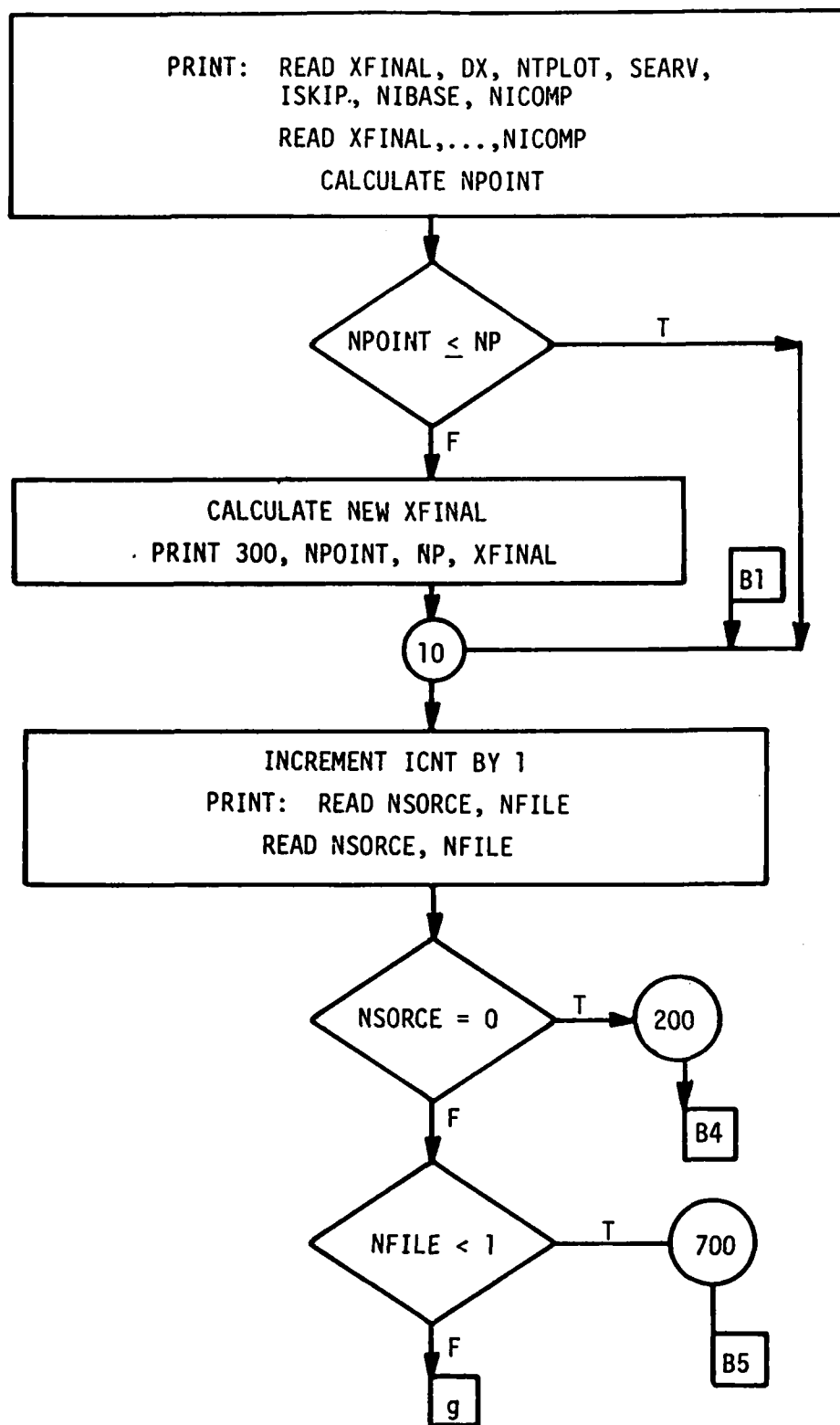


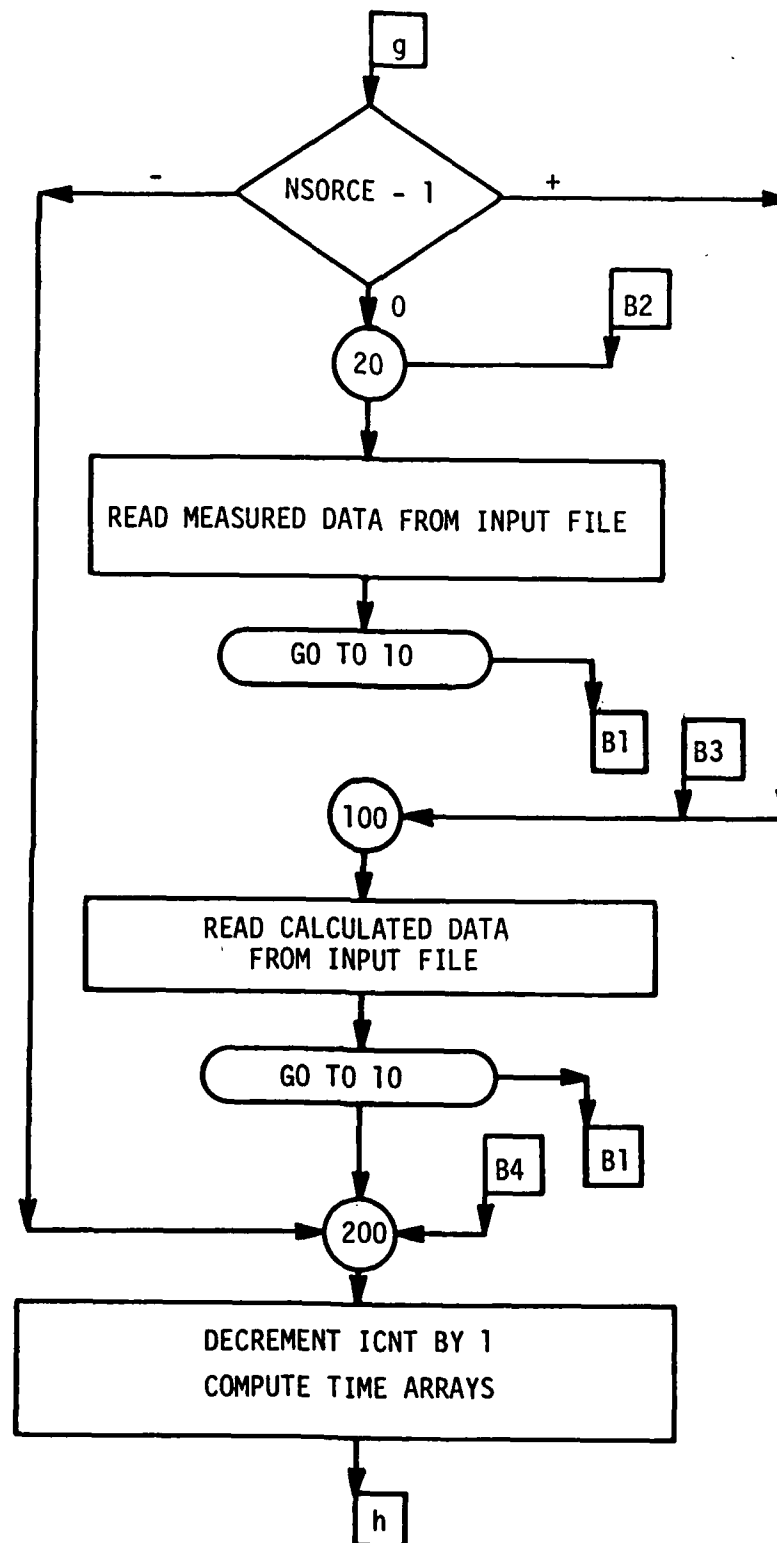


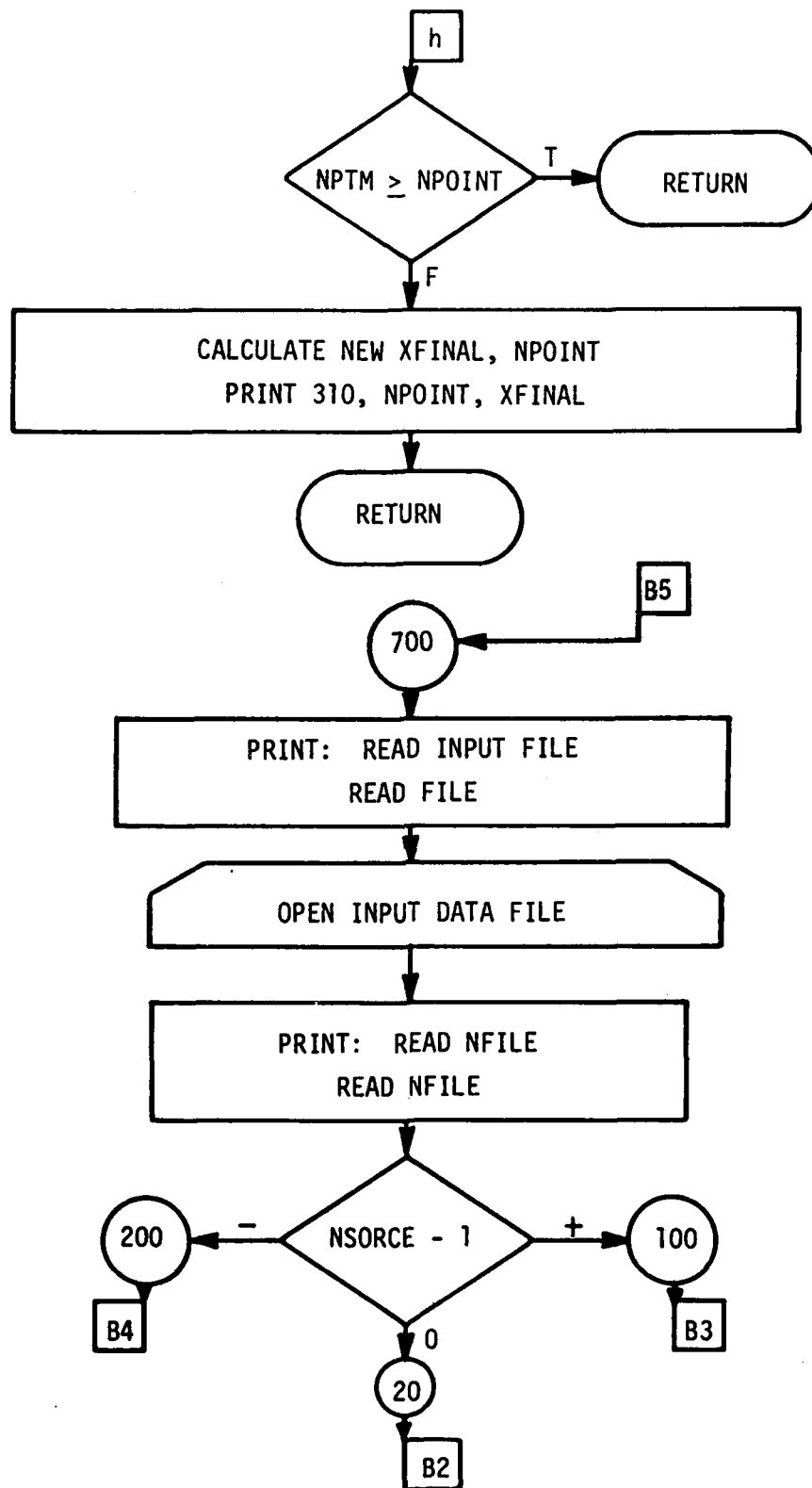




A.5.2 Subroutine READIN







A.6 EXAMPLES

OLD WCT
*FRN

12/08/82 21.070

READ XFINAL,DX,NTPLOT,SEARV,ISKIP,NIBASE,NICOMP

=7 .02 1 .5 50 0 0

NPOINT = 351

READ NSORCE,NFILE

=1 0

INPUT FILE ?

=ROSD222/OUTB1

READ NFILE

=1

READ NSORCE,NFILE

=1 2

READ NSORCE,NFILE

=1 5

READ NSORCE,NFILE

=1 3

READ NSORCE,NFILE

=0 0

WANT PLOT OF INPUT DATA?

=NO

WANT PLOT OF PREPROCESSED DATA?

=NO

WANT TABULATED OUTPUT ?

=YES

CASE	1	2	3
MAXC =	41.598	34.930	19.221
PEF =	-0.097	-0.241	-0.583
EMHX =	105.420	88.186	51.388
EMHN =	-0.460	-0.043	-0.321
EPHX =	0.987	0.995	0.991
EPHN =	0.	0.	0.
ECMX =	105.423	88.191	51.398
ECMN =	-0.777	-0.730	-0.704

BASE	3.5-0-0-AB	2-6	PRESSURE KPA	DISC TEST 1	0001
CASE	1 6-0-45-AB	2-7	PRESSURE KPA	DISC TEST 1	0002

I	EMAG	EPHS	ECOM
2	-0.460	0.626	-0.777
50	105.243	0.898	105.247
100	0.148	0.777	0.791
150	0.093	0.647	0.654
200	0.097	0.588	0.596
250	0.069	0.537	0.542
300	0.073	0.497	0.503
350	0.059	0.470	0.474

CASE	2 2-0-300-AB	2-10	PRESSURE KPA	DISC TEST 1	0010
------	--------------	------	--------------	-------------	------

I	EMAG	EPHS	ECON
2	0.589	0.577	0.824
50	85.993	0.931	85.998
100	0.000	0.733	0.733
150	-0.012	0.583	-0.583
200	-0.007	0.530	-0.530
250	-0.033	0.486	-0.487
300	-0.031	0.450	-0.451
350	-0.043	0.425	-0.427

CASE 3 4-0-90-AB 2-8 PRESSURE KPA DISC TEST 1 0003

I	EMAG	EPHS	ECON
2	3.910	0.592	3.955
50	43.846	0.876	43.854
100	-0.293	0.503	-0.582
150	-0.307	0.411	-0.513
200	-0.238	0.366	-0.437
250	-0.248	0.330	-0.413
300	-0.223	0.302	-0.375
350	-0.219	0.279	-0.355

I	EMAGAV	EPHSAV	ECONAV
2	1.347	0.598	1.852
50	78.360	0.902	78.366
100	-0.048	0.671	-0.702
150	-0.075	0.547	-0.583
200	-0.049	0.494	-0.521
250	-0.071	0.451	-0.481
300	-0.060	0.416	-0.443
350	-0.068	0.391	-0.419

WANT PLOTS ?

=NO

PTU-SEC = 1.85

*

FRN

12/08/82 21.100

READ XFINAL,DX,NTPLOT,SEARV,ISKIP,NIBASE,NICOMP

=7 .02 3 .5 50 1 1

NPOINT = 351

READ NSORCE,NFILE

=1 0

INPUT FILE ?

=ROSD222/OUTB291

READ NFILE

=1

READ NSORCE,NFILE

=1 2

READ NSORCE,NFILE

=1 5

READ NSORCE,NFILE

=1 3

READ NSORCE,NFILE

=0 0

WANT PLOT OF INPUT DATA?

=NO

WANT PLOT OF PREPROCESSED DATA?

=NO

WANT TABULATED OUTPUT ?

=YES

EMX	EMN	EPHX	EMMN
41.336	0.	44.986	-0.008

TE1	TP1	TH1
0.960	1.646	0.274

CASE	1	2	3	4
TAR =	0.	1.600	1.000	1.240

I	E	EP	EM
50	7.048	12.494	1.602
100	14.246	18.197	10.295
150	20.785	24.927	16.643
200	26.490	30.624	22.356
250	31.477	35.307	27.647
300	36.760	40.705	32.814
350	41.255	44.908	37.601

WANT PLOTS ?

=NO

WANT TABULATED OUTPUT ?

=YES

DEM X	DEM N	DEPM X	DEMM N
18.408	0.	31.840	-0.880

I	DE	DEP	DEM
50	5.085	7.980	2.191
100	5.531	3.717	7.346
150	5.895	6.848	4.943
200	5.044	5.001	5.086
250	5.045	5.330	4.760
300	5.202	4.839	5.565
350	4.068	3.818	4.319

WANT PLOTS ?

=NO

PTU-SEC = 1.26

*

A.7 PROGRAM LISTING

```

1000*#RUNH*#;ROSD441/PLOTS,R
1010C      PROGRAM WCT
1020C
1030C      CALCULATIONS OF STATISTICAL MEASURES FOR
1040C      COMPARISON OF WAVEFORMS
1050C
1060      PARAMETER NC = 10,N1 = NC-1,NP = 200
1070      REAL I1,MCF,MAXC,MAXM,NINURS
1080      CHARACTER TITLE #60,ANS*1
1090      DIMENSION I1(NP),EMAGAV(NP),EPHSAV(NP),ECOMAV(NP),
1100      &      EMAG(NP,N1),EPHS(NP,N1),ECOM(NP,N1),
1110      &      TE(NP),TP(NP),TH(NP),E(NP),EP(NP),EH(NP),
1120      &      DE(NP),DEP(NP),DEM(NP)
1130      COMMON /INPUT/ XFINAL,DX,NTPLOT,ISKIP,NIBASE,NICOMP,
1140      &      ICNT,NPOINT,DT(NC),TAR(NC),NPTS(NC)
1150      COMMON /ARRA1/ X(NP,NC),Y(NP,NC),XX(NP),YY(NP,NC),
1160      &      MAXC(N1),PEF(N1),EMMX(N1),EMMN(N1),EPHX(N1),
1170      &      EPHN(N1),ECMX(N1),ECMN(N1),TITLE(NC)
1180      EQUIVALENCE (EMAGAV(1),I1(1),X(1,NC)),(EMAG(1,1),X(1,1)),
1190      &      (EPHSAV(1),Y(1,NC)),(EPHS(1,1),Y(1,1)),
1200      &      (ECOMAV(1),YY(1,NC)),(ECOM(1,1),YY(1,1))
1210      EQUIVALENCE (TE(1),X(1,1)),(TP(1),X(1,2)),(TH(1),X(1,3)),
1220      &      (E(1),Y(1,1)),(EP(1),Y(1,2)),(EH(1),Y(1,3)),
1230      &      (DE(1),YY(1,1)),(DEP(1),YY(1,2)),(DEM(1),YY(1,3))
1240      CALL PTIME(PTI)
1250      CALL FPARAM(1,80)
1260C
1270      CALL READIN
1280C
1290      PRINT,'WANT PLOT OF INPUT DATA?'
1300      READ,ANS
1310      IF(ANS.NE.1HY) GO TO 10
1320      1 CONTINUE
1330      DO 5 K =1,ICNT
1340      CALL PLOT2(X(1,K),Y(1,K),NPTS(K))
1350      5 CONTINUE
1360      PRINT,'WANT REPLOT ?'
1370      READ,ANS
1380      IF(ANS.EQ.1HY) GO TO 1
1390      10 CONTINUE
1400C
1410C      PERFORM INTEGRATIONS AS NEEDED ON DATA TO OBTAIN
1420C      DESIRED QUANTITIES FOR COMPARISON
1430C
1440      NINT = NIBASE
1450      DO 30 J =1,ICNT
1460      IF(NINT.EQ.0) GO TO 30
1470      DO 20 L =1,NINT
1480      DX02 = .5*DT(J)
1490      YNEXT = Y(1,J) + Y(2,J)
1500      Y(1,J) = 0.

```

```

1510     Y(NPTS(J)+1,J) = 0.
1520     DO 20 I =2,NPTS(J)
1530     YT = YNEXT
1540     YNEXT = Y(I,J) + Y(I+1,J)
1550     Y(I,J) = Y(I-1,J) + DX02 * YT
1560 20 CONTINUE
1570 30 NINT = NCOMP
1580C
1590C     INTERPOLATE VERTICAL ARRAYS FOR SAME DX IF REQUIRED
1600C
1610     DO 60 K =1,ICNT
1620     IF(DT(K).LE.DX) GO TO 55
1630     YY(1,K) = Y(1,K)
1640     XCUR = DX
1650     I = 1
1660     DO 50 J =2,NPTS(K)
1670 40 IF(X(J,K).LT.XCUR) GO TO 50
1680     I = I + 1
1690     JM1 = J - 1
1700     YY(I,K) = Y(JM1,K) + (Y(J,K)-Y(JM1,K))*(XCUR-X(JM1,K))/
1710     &      (X(J,K)-X(JM1,K))
1720     XCUR = I * DX
1730     IF(I-NPOINT) 40,60,60
1740 50 CONTINUE
1750     GO TO 60
1760 55 CONTINUE
1770C
1780C     IF INTERPOLATION NOT REQUIRED TRANSFER Y ARRAY INTO YY ARRAY
1790C
1800     DO 58 I =1,NPOINT
1810 58 YY(I,K) = Y(I,K)
1820 60 CONTINUE
1830C
1840C     SET UP HORIZONTAL ARRAY
1850C
1860     DO 70 I =1,NPOINT
1870     XX(I) = DX * (I-1)
1880 70 CONTINUE
1890C
1900     PRINT,'WANT PLOT OF PREPROCESSED DATA?'
1910     READ,ANS
1920     IF(ANS.NE.1HY) GO TO 90
1930 80 CONTINUE
1940     DO 85 K =1,ICNT
1950     CALL PLOT2(XX,YY(1,K),NPOINT)
1960 85 CONTINUE
1970     PRINT,'WANT REPLOT ?'
1980     READ,ANS
1990     IF(ANS.EQ.1HY) GO TO 80
2000 90 CONTINUE
2010     IF(NTPLOT.GT.1) GO TO 400
2020C
2030C     FORM INTEGRALS FOR CORRELATIONS

```

```

2040C
2050     DX02 = 0.5*DX
2060     ICM1 = ICNT-1
2070     I1(1) = 0.
2080     MAXM = ABS(YY(1,1))
2090     DO 100 I =2,NPOINT
2100     MAXM = MAX(ABS(YY(I,1)),MAXM)
2110     I1(I) = I1(I-1) + DX02 * (YY(I,1)**2+YY(I-1,1)**2)
2120 100 CONTINUE
2130     K = 2
2140 110 KM1 = K - 1
2150     MCF = 1.0
2160     PCF = 1.0
2170     EMMX(KM1) = 0.
2180     EMMN(KM1) = 0.
2190     EPMX(KM1) = 0.
2200     EPMN(KM1) = 0.
2210     MAXC(KM1) = ABS(YY(1,K))
2220     PEF(KM1) = 0.
2230     EMAG(1,KM1) = 0.
2240     EPHS(1,KM1) = 0.
2250     SUM1 = 0.
2260     SUM2 = 0.
2270     DO 130 I =2,NPOINT
2280     MAXC(KM1) = MAX(MAXC(KM1),ABS(YY(I,K)))
2290     SUM1 = SUM1 + DX02 * (YY(I-1,K)**2+YY(I,K)**2)
2300     SUM2 = SUM2 + DX02 * (YY(I-1,1)*YY(I-1,K)+YY(I,1)*YY(I,K))
2310     MCF = SQRT(MAX(SUM1,.001)/MAX(I1(I),.001))
2320     PCF = MAX(ABS(SUM2),.001) / MAX(SQRT(SUM1*I1(I)),.001)
2330     EMAG(I,KM1) = (MCF-1.)
2340     EPHS(I,KM1) = (1.-PCF)
2350     EMMX(KM1) = MAX(EMMX(KM1),EMAG(I,KM1))
2360     EPMX(KM1) = MAX(EPMX(KM1),EPHS(I,KM1))
2370     EMMN(KM1) = MIN(EMMN(KM1),EMAG(I,KM1))
2380     EPMN(KM1) = MIN(EPMN(KM1),EPHS(I,KM1))
2390 130 CONTINUE
2400     PEF(KM1) = MAXC(KM1)/MAX(MAXM,.001)-1.
2410     K = K + 1
2420     IF(K.LE.ICNT) GO TO 110
2430     DO 140 K =1,ICM1
2440     ECMX(K) = 0.
2450     ECMN(K) = 0.
2460     ECOM(1,K) = 0.
2470     DO 140 I =2,NPOINT
2480     CEF = SQRT((EMAG(I,K))**2+(EPHS(I,K))**2)
2490     ECOM(I,K) = SIGN(CEF,EMAG(I,K))
2500     ECMX(K) = MAX(ECMX(K),ECOM(I,K))
2510     ECMN(K) = MIN(ECMN(K),ECOM(I,K))
2520 140 CONTINUE
2530     IF(ICNT.EQ.2) GO TO 200
2540C
2550C     IF MORE THAN 1 COMPARISON COMPUTE THE AVERAGES
2560C

```

```

2570     EMAGAV(1) = 0.
2580     EPHSAV(1) = 0.
2590     ECOMAV(1) = 0.
2600     NINVR = 1./ICM1
2610     DO 160 I =2,NPOINT
2620     EMAGAV(I) = 0.
2630     EPHSAV(I) = 0.
2640     ECOMAV(I) = 0.
2650     DO 150 K =1,JCM1
2660     EMAGAV(I) = EMAGAV(I) + EMAG(I,K)
2670     EPHSAV(I) = EPHSAV(I) + EPHS(I,K)
2680     ECOMAV(I) = ECOMAV(I) + ABS(ECOM(I,K))
2690 150 CONTINUE
2700     EMAGAV(I) = EMAGAV(I) * NINVR
2710     EPHSAV(I) = EPHSAV(I) * NINVR
2720     ECOMAV(I) = SIGN(NINVR*ECOMAV(I),EMAGAV(I))
2730 160 CONTINUE
2740C
2750 200 CONTINUE
2760C     OUTPUT PHASE
2770C
2780     PRINT,'WANT TABULATED OUTPUT ?'
2790     READ,ANS
2800     K1 = 1
2810     K2 = (ICM1/8) + 1
2820     K3 = MIN(7,ICM1)
2830     DO 205 I =1,K2
2840     PRINT 665,(K,K=K1,K3)
2850     PRINT 670,(MAXC(K),K=K1,K3)
2860     PRINT 671,(PEF(K),K=K1,K3)
2870     PRINT 672,(EMMX(K),K=K1,K3)
2880     PRINT 673,(EMMN(K),K=K1,K3)
2890     PRINT 674,(EPHX(K),K=K1,K3)
2900     PRINT 675,(EPMN(K),K=K1,K3)
2910     PRINT 676,(ECHX(K),K=K1,K3)
2920     PRINT 677,(ECHN(K),K=K1,K3)
2930     K1 = 8
2940     K3 = ICM1
2950 205 CONTINUE
2960     IF(ANS.NE.1HY) GO TO 300
2970     PRINT 650,TITLE(1)
2980     DO 220 K=1,ICM1
2990     PRINT 660,K,TITLE(K+1)
3000     PRINT 600
3010     PRINT 610,2,EMAG(2,K),EPHS(2,K),ECOM(2,K)
3020     DO 210 I =ISKIP,NPOINT,ISKIP
3030     PRINT 610,I,EMAG(I,K),EPHS(I,K),ECOM(I,K)
3040 210 CONTINUE
3050 220 PRINT,
3060     IF(ICNT.EQ.2) GO TO 260
3070     PRINT 620
3080     PRINT 630,2,EMAGAV(2),EPHSAV(2),ECOMAV(2)
3090     DO 230 I =ISKIP,NPOINT,ISKIP

```

```

3100     PRINT 630,I,EMAGAV(I),EPHSAV(I),ECOMAV(I)
3110 230 CONTINUE
3120     PRINT,
3130 260 CONTINUE
3140     PRINT,'WANT PLOTS ?'
3150     READ,ANS
3160     IF(ANS.NE.1HY) GO TO 999
3170 300 CONTINUE
3180     PRINT,'WANT PLOT OF XX-EMAG ?'
3190     READ,ANS
3200     IF(ANS.NE.1HY) GO TO 340
3210     DO 335 K =1,ICM1
3220     CALL PLOT2(XX,EMAG(1,K),NPOINT)
3230 335 CONTINUE
3240 340 PRINT,'WANT PLOT OF XX-EPHS ?'
3250     READ,ANS
3260     IF(ANS.NE.1HY) GO TO 350
3270     DO 345 K =1,ICM1
3280     CALL PLOT2(XX,EPHS(1,K),NPOINT)
3290 345 CONTINUE
3300 350 PRINT,'WANT PLOT OF XX-ECOM ?'
3310     READ,ANS
3320     IF(ANS.NE.1HY) GO TO 360
3330     DO 355 K =1,ICM1
3340     CALL PLOT2(XX,ECOM(1,K),NPOINT)
3350 355 CONTINUE
3360 360 IF(ICNT.EQ.2) GO TO 380
3370     PRINT,'WANT PLOT OF XX-EMAGAV ?'
3380     READ,ANS
3390     IF(ANS.EQ.1HY) CALL PLOT2(XX,EMAGAV,NPOINT)
3400     PRINT,'WANT PLOT OF XX-EPHSAV ?'
3410     READ,ANS
3420     IF(ANS.EQ.1HY) CALL PLOT2(XX,EPHSAV,NPOINT)
3430     PRINT,'WANT PLOT OF XX-ECOMAV ?'
3440     READ,ANS
3450     IF(ANS.EQ.1HY) CALL PLOT2(XX,ECOMAV,NPOINT)
3460 380 PRINT,'WANT REPLOT ?'
3470     READ,ANS
3480     IF(ANS.EQ.1HY) GO TO 300
3490     GO TO 999
3500C
3510C     CALCULATE MEAN AND STANDARD DEVIATIONS
3520C
3530 400 CONTINUE
3540     RICNT = 1./ICNT
3550     RNM1 = 1./((ICNT-1)
3560     ES = 0.
3570     EMAX = 0.
3580     EMIN = 0.
3590     EPMAX = 0.
3600     EMMIN = 0.
3610     DO 410 K=1,ICNT
3620     ES = ES + TAR(K)

```

```

3630 410 CONTINUE
3640     TE1 = ES*RICNT
3650     SS = 0.
3660     DO 420 K=1,ICNT
3670     SS = SS + (TAR(K)-TE1)**2
3680 420 CONTINUE
3690     ST = SQRT(SS*RNH1)
3700     TP1 = TE1+ST
3710     TM1 = TE1-ST
3720     DO 450 I=1,NPOINT
3730     ES = 0.
3740     DO 430 K=1,ICNT
3750     ES = ES + YY(I,K)
3760 430 CONTINUE
3770     E(I) = ES*RICNT
3780     SS = 0.
3790     DO 440 K=1,ICNT
3800     SS = SS + (YY(I,K)-E(I))**2
3810 440 CONTINUE
3820     ST = SQRT(SS*RNH1)
3830     EP(I) = E(I)+ST
3840     EM(I) = E(I)-ST
3850     EMAX = MAX(E(I),EMAX)
3860     EMIN = MIN(E(I),EMIN)
3870     EPMAX = MAX(EP(I),EPMAX)
3880     EMMIN = MIN(EM(I),EMMIN)
3890     TE(I) = XX(I)+TE1
3900     TP(I) = XX(I)+TP1
3910     TM(I) = XX(I)+TM1
3920 450 CONTINUE
3930     PRINT,'WANT TABULATED OUTPUT ?'
3940     READ,ANS
3950     PRINT 680,EMAX,EMIN,EPMAX,EMMIN,TE1,TP1,TM1
3960     K1 = 1
3970     K2 = (ICNT/8) + 1
3980     K3 = MIN(7,ICNT)
3990     DO 455 I =1,K2
4000     PRINT 665,(K,K=K1,K3)
4010     PRINT 682,(TAR(K),K=K1,K3)
4020     K1 = 8
4030     K3 = ICNT
4040 455 CONTINUE
4050     PRINT,
4060     IF(ANS.NE.1HY) GO TO 470
4070     PRINT 690
4080     DO 460 I =ISKIP,NPOINT,ISKIP
4090     PRINT 630,I,E(I),EP(I),EM(I)
4100 460 CONTINUE
4110     PRINT,
4120     PRINT,
4130     PRINT,'WANT PLOTS ?'
4140     READ,ANS
4150     IF(ANS.NE.1HY) GO TO 500

```

```

4160 470 CONTINUE
4170 PRINT,'WANT PLOT OF TE-E ?'
4180 READ,ANS
4190 IF(ANS.EQ.1HY) CALL PLOT2(TE,E,NPOINT)
4200 PRINT,'WANT PLOT OF TP-EP ?'
4210 READ,ANS
4220 IF(ANS.EQ.1HY) CALL PLOT2(TP,EP,NPOINT)
4230 PRINT,'WANT PLOT OF TH-EM ?'
4240 READ,ANS
4250 IF(ANS.EQ.1HY) CALL PLOT2(TH,EM,NPOINT)
4260 PRINT,'WANT PLOT OF XX-E ?'
4270 READ,ANS
4280 IF(ANS.EQ.1HY) CALL PLOT2(XX,E,NPOINT)
4290 PRINT,'WANT PLOT OF XX-EP ?'
4300 READ,ANS
4310 IF(ANS.EQ.1HY) CALL PLOT2(XX,EP,NPOINT)
4320 PRINT,'WANT PLOT OF XX-EM ?'
4330 READ,ANS
4340 IF(ANS.EQ.1HY) CALL PLOT2(XX,EM,NPOINT)
4350 PRINT,'WANT REPLOT ?'
4360 READ,ANS
4370 IF(ANS.EQ.1HY) GO TO 470
4380 500 CONTINUE
4390 IF(NTPLOT.LT.3) GO TO 999
4400C
4410C CALCULATE DERIVATIVE WITH RESPECT TO TIME
4420C FOR MEAN AND STANDARD DEVIATIONS
4430C
4440 DEMAX = 0.
4450 DEMIN = 0.
4460 DEPMAX = 0.
4470 DEMMIN = 0.
4480 DXI = 1./DX
4490 DE(1) = 0.
4500 DEP(1) = 0.
4510 DEN(1) = 0.
4520 DO 510 I=2,NPOINT
4530 DE(I) = (E(I)-E(I-1))*DXI
4540 DEP(I) = (EP(I)-EP(I-1))*DXI
4550 DEN(I) = (EM(I)-EM(I-1))*DXI
4560 DEMAX = MAX(DE(I),DEMAX)
4570 DEMIN = MIN(DE(I),DEMIN)
4580 DEPMAX = MAX(DEP(I),DEPMAX)
4590 DEMMIN = MIN(DEN(I),DEMMIN)
4600 510 CONTINUE
4610 PRINT,'WANT TABULATED OUTPUT ?'
4620 READ,ANS
4630 PRINT 692,DEMAX,DEMIN,DEPMAX,DEMMIN
4640 PRINT,
4650 IF(ANS.NE.1HY) GO TO 530
4660 PRINT 694
4670 DO 520 I =ISKIP,NPOINT,ISKIP
4680 PRINT 630,I,DE(I),DEP(I),DEN(I)

```

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4690 520 CONTINUE
4700 PRINT,
4710 PRINT,
4720 PRINT,'WANT PLOTS ?'
4730 READ,ANS
4740 IF(ANS.NE.1HY) GO TO 999
4750 530 CONTINUE
4760 PRINT,'WANT PLOT OF XX-DE ?'
4770 READ,ANS
4780 IF(ANS.EQ.1HY) CALL PLOT2(XX,DE,NPOINT)
4790 PRINT,'WANT PLOT OF XX-DEP ?'
4800 READ,ANS
4810 IF(ANS.EQ.1HY) CALL PLOT2(XX,DEP,NPOINT)
4820 PRINT,'WANT PLOT OF XX-DEM ?'
4830 READ,ANS
4840 IF(ANS.EQ.1HY) CALL PLOT2(XX,DEM,NPOINT)
4850 PRINT,'WANT REPLOT ?'
4860 READ,ANS
4870 IF(ANS.EQ.1HY) GO TO 530
4880 999 CONTINUE
4890 CALL PTIME(PTU)
4900 PRINT 640,(PTU-PTI)*3600.
4910 STOP
4920 600 FORMAT(4X,'I',5X,'EMAG',6X,'EPHS',6X,'ECOM'//)
4930 610 FORMAT(I6,3F10.3)
4940 620 FORMAT(5X,'I',5X,'EMAGAV',6X,'EPHSAV',6X,'ECOMAV'//)
4950 630 FORMAT(I6,3F10.3)
4960 640 FORMAT(' PTU-SEC = ',F10.2)
4970 650 FORMAT(//'BASE',5X,A60)
4980 660 FORMAT('CASE ',I3,1X,A60//)
4990 665 FORMAT(/' CASE',7I10)
5000 670 FORMAT(' MAXC = ',7F10.3)
5010 671 FORMAT(' PEF = ',7F10.3)
5020 672 FORMAT(' EMMX = ',7F10.3)
5030 673 FORMAT(' EMMN = ',7F10.3)
5040 674 FORMAT(' EPMX = ',7F10.3)
5050 675 FORMAT(' EPMN = ',7F10.3)
5060 676 FORMAT(' ECMX = ',7F10.3)
5070 677 FORMAT(' ECMN = ',7F10.3)
5080 680 FORMAT(/7X,'EMX',7X,'EMN',7X,'EPMX',6X,'EMMN'/2X,4F10.3//
5090 7X,'TE1',7X,'TP1',7X,'TM1'/2X,3F10.3)
5100 682 FORMAT(' TAR = ',7F10.3)
5110 690 FORMAT(5X,'I',6X,'E',9X,'EP',8X,'EN')
5120 692 FORMAT(/7X,'DEMX',6X,'DEMN',6X,'DEPMX',5X,'DEMMN'/2X,4F10.3)
5130 694 FORMAT(5X,'I',6X,'DE',8X,'DEP',7X,'DEM')
5140 END
5150 SUBROUTINE READIN
5160 PARAMETER NC = 10,N1 = NC-1,NP = 200
5170 DIMENSION TDUM(20),C1(4),C2(4),C3(4)
5180 CHARACTER TITLE*60,TITL*20(3,NC)
5190 CHARACTER FILE*12,FMTF*9/9H(T12,1H;)/,ANS*1
5200 EQUIVALENCE (TITLE,TITL)
5210 COMMON /INPUT/ XFINAL,DX,NTPLOT,ISKIP,NIBASE,NICOMP,

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5220      &          ICNT,NPOINT,DT(NC),TAR(NC),NPTS(NC).
5230      COMMON /ARRA1/ X(NP,NC),Y(NP,NC),XX(NP),YY(NP,NC),
5240      &          MAXC(N1),PEF(N1),EMMX(N1),EMMN(N1),EPMX(N1),
5250      &          EPMN(N1),ECMX(N1),ECMN(N1),TITLE(NC)
5260      DATA NOE,NAFT/0400000000000,0403700000000/
5270      PRINT,'READ XFINAL,DX,NTPLOT,SEARV,ISKIP,NIBASE,NICOMP'
5280      READ,XFINAL,DX,NTPLOT,SEARV,ISKIP,NIBASE,NICOMP
5290      ICNT = 0
5300      NPTM = NP
5310      NPOINT = XFINAL/DX + 1
5320      IF(NPOINT.LE.NP) GO TO 5
5330      XFINAL = (NP-1) * DX
5340      PRINT 300,NPOINT,NP,XFINAL
5350      NPOINT = NP
5360      5 CONTINUE
5370      PRINT,'NPOINT =',NPOINT
5380      10 ICNT = ICNT + 1
5390      PRINT,'READ NSORCE,NFILE'
5400      READ,NSORCE,NFILE
5410      IF(NSORCE.EQ.0) GO TO 200
5420      IF(NFILE.LT.1) GO TO 700
5430      IF(NSORCE-1) 200,20,100
5440      20 REWIND 1
5450      IF(NFILE.EQ.1) GO TO 40
5460      DO 30 I =1,2*(NFILE-1)
5470      30 READ(1,END=10)
5480      40 READ(1) NPTS(ICNT),DT(ICNT),C1,C2,C3
5490      NPT = MIN(NPTS(ICNT),NPOINT)
5500      IF(SEARV.LE.0.) GO TO 70
5510      NPS = MIN(NPTS(ICNT),NP)
5520      READ(1) (XX(I),I=1,NPS)
5530      DO 50 I=1,NPS
5540      IF(XX(I)-SEARV) 50,60,60
5550      50 CONTINUE
5560      60 CONTINUE
5570      NSTRT = I-1
5580      TAR(ICNT) = DT(ICNT)*NSTRT
5590      NPT = MIN(NPTS(ICNT)-NSTRT,NPT)
5600      BACKSPACE 1
5610      READ(1) (SKIP,K=1,NSTRT-1),(Y(I,ICNT),I=1,NPT)
5620      GO TO 80
5630      70 CONTINUE
5640      READ(1) (Y(I,ICNT),I=1,NPT)
5650      TAR(ICNT) = 0.
5660      80 CONTINUE
5670      NPTS(ICNT) = NPT
5680      NPTM = MIN(NPT,NPTM)
5690      CALL BCDASC(C1,TITL(1,ICNT),20)
5700      CALL BCDASC(C2,TITL(2,ICNT),20)
5710      CALL BCDASC(C3,TITL(3,ICNT),20)
5720      GO TO 10
5730      100 REWIND 2
5740      IF(NFILE.EQ.1) GO TO 140

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5750      DO 130 I =1,2*(NFILE-1)
5760 130 READ(2,END=10)
5770 140 READ(2) NPTS(ICNT),DT(ICNT),TDUM
5780      NPT = MIN(NPTS(ICNT),NPOINT)
5790      IF(SEARV.LE.0.) GO TO 170
5800      NPS = MIN(NPTS(ICNT),NP)
5810      READ(2) (XX(I),I=1,NPS)
5820      DO 150 I=1,NPS
5830      IF(XX(I)-SEARV) 150,160,160
5840 150 CONTINUE
5850 160 CONTINUE
5860      NSTRT = I-1
5870      TAR(ICNT) = DT(ICNT)*NSTRT
5880      NPT = MIN(NPTS(ICNT)-NSTRT,NPT)
5890      BACKSPACE 2
5900      READ(2) (SKIP,K=1,NSTRT-1),(Y(I,ICNT),I=1,NPT)
5910      GO TO 180
5920 170 CONTINUE
5930      READ(2) (Y(I,ICNT),I=1,NPT)
5940      TAR(ICNT) = 0.
5950 180 CONTINUE
5960      NPTS(ICNT) = NPT
5970      NPTM = MIN(NPT,NPTM)
5980      CALL BCDASC(TDUM,TITLE(ICNT),60)
5990      GO TO 10
6000 200 ICNT = ICNT-1
6010      DO 500 K =1,ICNT
6020      DT(K) = DT(K)*1000.
6030      TAR(K) = TAR(K)*1000.
6040      DO 500 I =1,NPTS(K)+1
6050      X(I,K) = DT(K) * (I-1)
6060 500 CONTINUE
6070C
6080      IF(NPTM.GE.NPOINT) GO TO 600
6090      NPOINT = NPTM
6100      XFINAL = (NPOINT-1)*DX
6110      PRINT 310,NPOINT,XFINAL
6120 600 CONTINUE
6130      RETURN
6140 700 CONTINUE
6150      PRINT,'INPUT FILE ?'
6160      READ,FILE
6170      IF(FILE.EQ.1H ) GO TO 200
6180      CALL DETACH(NSORCE,,)
6190      ENCODE(FILE,FMTF)
6200      CALL ATTACH(NSORCE,FILE,1,0,ISTAT,)
6210      IF(ISTAT.EQ.NOE.OR.ISTAT.EQ.NAFT) GO TO 98
6220      PRINT,'ISTAT = ',ISTAT,' FILE ',FILE
6230      PRINT 96,ISTAT
6240 96 FORMAT(2X,012)
6250      GO TO 700
6260 98 CONTINUE
6270      PRINT,'READ NFILE'

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```
6280      READ,NFILE
6290      IF(NSORCE-1) 200,20,100
6300 300 FORMAT('XFINAL TOO LARGE NPOINT = ',I10,' NP = ',I10/
6310      &      'NEW XFINAL = ',F10.2)
6320 310 FORMAT('NPOINT RESET TO ',I10,' XFINAL = ',F10.2)
6330      END
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