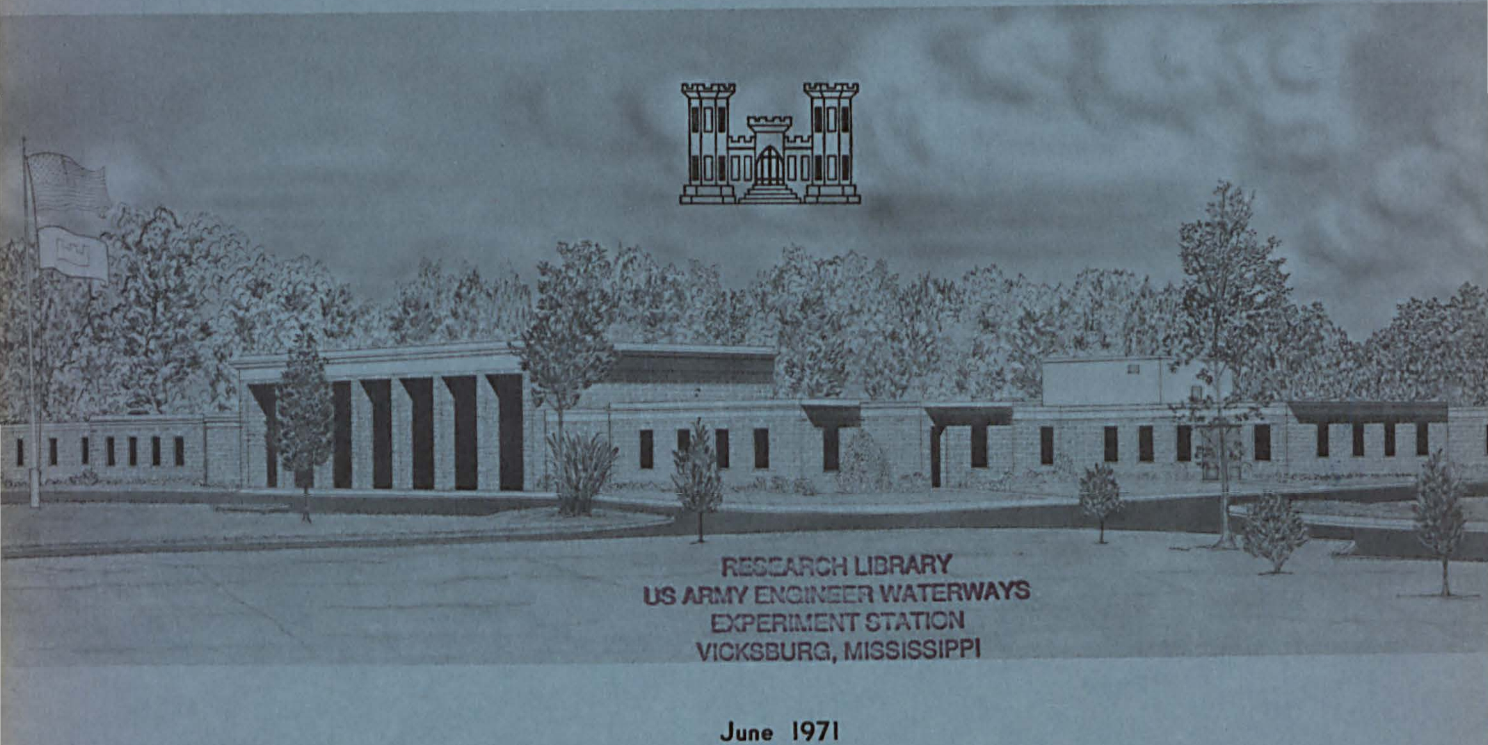
TECHNICAL REPORT N-71-7

DIGITAL FILTERS FOR EXPLOSION EFFECTS ANALYSIS

by

H. D. Carleton



June 1971

Sponsored by Assistant Secretary of the Army (R&D), Department of the Army

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

FOREWORD

This study was conducted during fiscal year 1971 and was sponsored by the Assistant Secretary of the Army (R&D) under Department of the Army Project 4A061101A91D, "In-House Laboratory Initiated Research." It was specifically funded as Task 02, Work Unit 042, administered by Dr. D. R. Freitag, Chief, Office of Technical Programs and Plans, U. S. Army Engineer Waterways Experiment Station (WES).

Project personnel worked under the general supervision of Mr. G. L. Arbuthnot, Jr., Chief, Nuclear Weapons Effects Division (NWED); Mr. L. F. Ingram, Chief, Physical Sciences Branch; and Mr. J. D. Day, Chief, Blast and Shock Section. Principal investigator and author of this report was Mr. H. D. Carleton. Computer program 803-G9R0-158, the basis for this report, was programmed by Mr. J. T. Brogan.

The data used for the examples in this paper are taken from recent field tests sponsored by the Defense Atomic Support Agency. Cooperating in furnishing the data were Mr. T. E. Kennedy and Mr. R. E. Walker of the Protective Structures Branch, NWED, and Mr. D. W. Murrell and Mr. C. E. Joachim of the Physical Sciences Branch.

WES Director during this work was COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

NOTATION

Time Values

i	Impulse response sample number (elapsed time in sampling units)
k	Impulse response duration in sampling units
m	Data duration in sampling units
n	Data sample number (elapsed time in sampling units)
τ	Correlation shift sample number (time shift in sampling units)

Amplitude Values

d_n	Desired output data sample at time n
r_i	Impulse response sample at time i
x_n	Input data sample at time n
y_n	Output data sample at time n
$\phi_{xd}(\tau)$	Crosscorrelation function sample at time shift τ
$\phi_{xx}(\tau)$	Autocorrelation function sample at time shift τ

SUMMARY

A Wiener filter is a mathematical operator designed to convert a given waveform (the filter's input) into another waveform (the filter's output) which is as similar as possible, in the least squares sense, to a third waveform (the desired output). Because filter theory might have application to the problems of explosion effects testing, a computer program has been developed to construct these operators for use in ground shock investigations. This report reviews convolution, crosscorrelation, and autocorrelation, the time domain operations which are basic to the Wiener technique, and shows by examples the operating characteristics of the program. It is concluded, on the basis of work seen during the development of the program, that digital filters may be used to define, accurately and economically, many important explosion effects relationships. Examples are included to demonstrate the fact that ground shock time histories may be estimated in uniform soil and rock using these operators to adjust for relatively large gage range and depth differences in the high pressure airblast region.

DIGITAL FILTERS FOR EXPLOSION EFFECTS ANALYSIS

PART I: TIME DOMAIN OPERATIONS

Introduction

1. A Wiener filter is a mathematical operator designed to convert a given waveform (the filter's input) into another waveform (the filter's output) which is as similar as possible, in the least squares sense, to a third waveform (the desired output)[1,2]. Where the fit of the Wiener filter's output to the desired output is close, the operator may be regarded as a measure of the difference between the filter's input and the desired output. The mission of the Nuclear Weapons Effects Division (NWED) of the U. S. Army Engineer Waterways Experiment Station (WES) includes many areas where such comparisons would be useful. In recognition of this fact a computer program has been developed to determine applications for filter theory using computer equipment presently at WES. This report has been written to review the basis for the program, and to familiarize project officers with its operating characteristics.

2. The operations discussed herein involve comparisons of data in the time domain, i.e., time history manipulations. However, the basic time domain operations will be compared briefly to their equivalents in the frequency domain, since this analogy is likely to be more familiar to engineers.

Time Series Notation

3. If the displacement of a continuous waveform is sampled periodically, the resulting time sequence of equally spaced observations is said to be a "discrete time series." The time represented by any given sample in this series would be $t = nT$, where n is the sample number (counting by units from sample number 0 at $t = 0$) and T is the sampling period

(a constant, commonly in seconds, which is the reciprocal of the sampling frequency*, commonly in hertz). If T is defined as one unit of time, $t = nT$ becomes $t = n$. Thus, a periodically sampled continuous wave is converted into a sequence of numbers:

$$(x_0, x_1, x_2, \ldots, x_m) \tag{1}$$

where m is a parameter (maximum n) which defines the sampled data duration, x_0 is the value of (and continuous wave amplitude at) sample number zero (zero time), x_1 is the value of sample number one, and so forth to x_m, which is the value of the last sample in the series. Sample values outside of the time range of the sampled portion of the wave are defined to be zero. For the time series in (1), then,

$$x_n = 0 \quad \text{for} \quad n < 0 \text{ and } n > m.$$

Convolution

4. A discrete time series may be filtered by means of a moving summation called convolution. This operation may be defined as

$$y_n = \sum_{i=0}^{k} r_i \, x_{n-i} \quad , \qquad n = 0, 1, 2, \ldots, (m + k) \tag{2}$$

where the $m + 1$ values of expression (1) comprise a time history input to a filter, the $m + k + 1$ values to be calculated for y_n will comprise the filter's output time history, and the $k + 1$ values of r_i represent the time history of a linear system's response to a unit impulse**. The time series represented by values of r_i, then, is descriptive of a filter, and is known as that filter's operator. A discrete filter operator may represent the impulsive response of an equivalent electrical network.

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* Sampling frequency selection has been discussed by the author in an earlier paper[3].

** The unit impulse is Kronecker's delta function, which is defined as $\delta_n = 1$ when $n = 0$ and $\delta_n = 0$ when $n \neq 0$.

5. The frequency domain operation which corresponds to convolution involves multiplication (frequency by frequency) of the amplitude spectrum of a filter's input by that of its operator and addition (frequency by frequency) of the phase spectrum of the filter's input to that of its operator, to yield the amplitude and phase spectra of the filter's output.

Crosscorrelation*

6. Two time histories may be compared mathematically by means of their crosscorrelation function

$$\phi_{xd}(\tau) = \sum_{n=0}^{m} x_n d_{n+\tau} , \qquad \tau = -m, \ldots, -1, 0, 1, 2, \ldots, m \qquad (3)$$

where the m + 1 values of expression (1) comprise one time history, and m + 1 values of d_n comprise a compared time history. Values of $\phi_{xd}(\tau)$, when plotted against τ , the correlation time shift in sampling units, produce a graph with strongest maxima at time shifts for which the compared waveforms most nearly coincide**. This plot contains only those frequencies common to both of the original time histories, and is in general not symmetrical about $\tau = 0$.

7. The frequency domain operation which corresponds to crosscorrelation involves multiplication of the amplitude spectra of the compared waveforms and subtraction of one phase spectrum (that of the x_n time history) from the other (that of the d_n time history), to give the amplitude and phase spectra of the crosscorrelation function.

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* Anstey[4] discusses correlations and their uses, and provides an extensive bibliography.

** Values of $\phi_{xd}(\tau)$ are usually normalized for such a plot.

Autocorrelation

8. Where a time history is crosscorrelated with itself the resulting waveform is called an autocorrelation function. This function may be defined by

$$\phi_{xx}(\tau) = \sum_{n=0}^{m} x_n \, x_{n+\tau} \quad , \qquad \tau = -m, \ldots, -1, 0, 1, 2, \ldots, m \qquad (4)$$

where the m + 1 values of expression (1) comprise the only input time history. A plot of this function is always symmetrical about $\tau = 0$, and values of $\phi_{xx}(\tau)$ for $\tau \neq 0$ never exceed its value at $\tau = 0$.

9. The frequency domain operation which corresponds to autocorrelation is the same as that which corresponds to crosscorrelation, with the special condition that the compared spectra are identical. Thus, the input's amplitude spectrum is squared (producing its power spectrum), and its phase spectrum is zeroed as a result of subtraction from itself. All phase information is therefore lost in the process of taking the autocorrelation function of a time history.

PART II: WIENER FILTER CONSTRUCTION

The Wiener Normal Equations

10. A discrete Wiener filter is determined by means of the Wiener normal equations, defined by

$$\sum_{i=0}^{k} r_i \; \phi_{xx}(\tau-i) = \phi_{xd}(\tau) \quad , \qquad \tau = 0, 1, 2, \ldots, k \tag{5}$$

where the $k + 1$ values of r_i (the filter's operator) are to be calculated, and the $k + 1$ necessary values for each of the two correlations have been previously determined from the input (x_n time series) and desired output (d_n time series) through the use of equations (3) and (4).

11. A filter's operator is equivalent to the frequency domain transfer function, which results from the division of the desired output's amplitude spectrum by the input's amplitude spectrum, and subtraction of the input's phase spectrum from the desired output's phase spectrum. The time domain desired output/input crosscorrelation and input autocorrelation together furnish the required amplitude information to the Wiener construction, while the required phase information is contained in the values of the desired output/input crosscorrelation alone.

Computation of a Wiener Operator

12. As an example, let a two sample Wiener filter be constructed to show the relationship between the following discrete time series:

Input (x_n time series)	2, 1, 0
Desired output (d_n time series)	0, -4, -2

Since we specify a two sample operator, $k = 1$. Because the compared time histories consist of three samples each, $m = 2$.

13. The necessary values of the input autocorrelation will be determined from:

$$\phi_{xx}(\tau) = \sum_{n=0}^{2} x_n \, x_{n+\tau} \quad , \qquad \tau = -1, 0, 1$$

Note that the value of k establishes the range of τ necessary for filter construction. Substituting in the above equation:

$$\phi_{xx}(-1) = x_0 \, x_{-1} + x_1 \, x_0 + x_2 \, x_1 = (2 \cdot 0) + (1 \cdot 2) + (0 \cdot 1) = 2$$

$$\phi_{xx}(0) = x_0^{\,2} + x_1^{\,2} + x_2^{\,2} = (2^2) + (1^2) + (0^2) = 5$$

$$\phi_{xx}(1) = x_0 \, x_1 + x_1 \, x_2 + x_2 \, x_3 = (2 \cdot 1) + (1 \cdot 0) + (0 \cdot 0) = 2$$

14. The necessary values of the desired output/input crosscorrelation will be determined from:

$$\phi_{xd}(\tau) = \sum_{n=0}^{2} x_n \, d_{n+\tau} \quad , \qquad \tau = 0, 1.$$

This correlation is calculated only for positive values of τ , and maximum τ is again equal to k. Substituting:

$$\phi_{xd}(0) = x_0 \, d_0 + x_1 \, d_1 + x_2 \, d_2 = (2 \cdot 0) + (1 \cdot -4) + (0 \cdot -2) = -4$$

$$\phi_{xd}(1) = x_0 \, d_1 + x_1 \, d_2 + x_2 \, d_3 = (2 \cdot -4) + (1 \cdot -2) + (0 \cdot 0) = -10$$

15. The two sample Wiener operator is now determined from the Wiener normal equations:

$$\sum_{i=0}^{1} r_i \, \phi_{xx}(\tau - i) = \phi_{xd}(\tau) \quad , \qquad \tau = 0, 1.$$

For the present example this sets up two equations in two unknowns:

$$r_0\,\phi_{xx}(0) + r_1\,\phi_{xx}(-1) = 5r_0 + 2r_1 = \phi_{xd}(0) = -4$$

$$r_0\,\phi_{xx}(1) + r_1\,\phi_{xx}(0) = 2r_0 + 5r_1 = \phi_{xd}(1) = -10$$

Solving by the method of subtraction:

$$\begin{array}{r} 5r_0 + 2r_1 = -4 \\ -5r_0 - 12.5r_1 = +25 \\ \hline -10.5r_1 = +21 \end{array}$$

$$r_1 = -\frac{21}{10.5} = -2$$

Substituting: $5r_0 + (2 \cdot -2) = -4$

$$r_0 = \frac{0}{5} = 0$$

The required two sample operator (r_i time series) is: 0, -2.

16. Referring to equation (2), and using the original input time series (2, 1, 0) and the calculated operator (0, -2), we determine this filter's output:

$$y_0 = r_0\,x_0 + r_1\,x_{-1} = (0 \cdot 2) + (-2 \cdot 0) = 0$$

$$y_1 = r_0\,x_1 + r_1\,x_0 = (0 \cdot 1) + (-2 \cdot 2) = -4$$

$$y_2 = r_0\,x_2 + r_1\,x_1 = (0 \cdot 0) + (-2 \cdot 1) = -2$$

$$y_3 = r_0\,x_3 + r_1\,x_2 = (0 \cdot 0) + (-2 \cdot 0) = 0$$

The output (y_n time series) is 0, -4, -2, 0. This exactly corresponds to the desired output (d_n time series). In this particular very simple case, it has been possible to construct a filter which shows the exact relationship between an input and a desired output. The effect of the required filter is a delay of one sampling unit, a change in polarity, and 2x amplification, i.e., the filter's unit impulse response is a negative impulse of amplitude two at unit delay.

17. From equation (5) and the foregoing example, it is readily seen that determination of a hundred point Wiener filter would involve one hundred equations in one hundred unknowns. Such determinations, which involve matrix algebra in computer solutions, result in long computer runs and a considerable storage requirement. Convolution for long operators also becomes a cumbersome process. Recursions (which consider previously computed outputs as well as the usual input values) are available as more efficient alternatives to many convolutions and for the Wiener matrix manipulation. Recursion and the filter problem are discussed by Treitel and Robinson[5]. Shanks[6] discusses recursive alternatives to convolution.

PART III: DATA COMPARISONS

Operator Determination

18. Plate 1 shows a situation similar to that described in par. 16. The input wavelet is accelerometer data from DIAL PACK. The desired output wavelet is from this same channel lagged 10 msec in time, reversed in polarity, and doubled in amplitude. The computer calculated Wiener operator which describes the relationship between this pair contains only one significant nonzero sample amplitude. This amplitude is 2*, it is negative, and it occurs precisely at the 10-msec time position on the operator trace. The unit impulse response of the "system" defined by the input and desired output of plate 1 is essentially a negative impulse of amplitude 2 at a 10-msec delay. If the operator of plate 1 is a good one for the definition of the differences in the indicated data pair, its use as a filter for the plate 1 input should yield as an output a reasonable approximation of the desired output. Plate 2 shows that the actual output from this convolution is a very close copy of the desired output.

19. In plate 3 the input wavelet is free-field accelerometer data from the 90-psi peak pressure region of DIAL PACK. The desired output wavelet (which will be recognized as the input of plate 1) is free-field accelerometer data from the 49 psi peak pressure region of this same event. Both gages were oriented vertically and emplaced at 2-ft depth. It will be noted that although the operator length is very short in relation to the data lengths involved, the actual output shown in plate 4 (the result of convolution of the plate 3 input and the calculated operator) is a good approximation of the plate 3 desired output waveform.

20. The wavelets shown as input and desired output in plate 5 are velocity gage data from MINE ORE. Both wavelets represent vertically

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* Approximately 2 in this case: the last 10 msec of data on the input trace, and the first 10 msec of data on the desired output trace are not precisely at zero amplitude; thus there is a small element in this comparison which can not be defined as a pure delay and calibration change.

oriented gages at 73-ft range and 20-in. depth. The input, however, was recorded on the event's north line, while the desired output was recorded on the east line. Plate 6 shows a relatively short operator calculated from the gage pair data in plate 5, and the actual output resulting from the convolution of this operator and the original input. Obviously a short operator will not do in this case; the actual output is distorted and does not peak properly. Plate 7 shows another operator for the gage pair comparison of plate 5. This one has been made as long as the data wavelets, and its convolution with the original input yields a very good approximation of the desired output.

21. The input and desired output wavelets of plate 8 are radial velocity gage data from 100-ft depth on MINERAL LODE. Both represent stations at 100-ft range. However, the input is from the south gage line, while the desired output is from the west line. In each case indicated zero time is 7 msec later than actual zero time, but the relative time positions of the waveforms are unchanged. The resulting operator's actual output, shown in plate 9, is an excellent reconstruction of the plate 8 desired output; the calculated operator for this wavelet pair in its proper time relationship is a good one.

22. If the input of plate 8 is made the desired output, and the plate 8 desired output becomes the input, we may anticipate two problems, one relative to time positions and another concerned with wavelet frequency content. From equation (2) it is apparent that the duration of a convolution's output is equal to the sum of the durations of its input and its operator. The first portion of a convolution's output, with a duration equivalent to that of the input, correlates to the desired output waveform. The final portion represents system settling time, usually appearing as a "noisy" trace if plotted. The best operator for a given wavelet pair will result from the positioning of the desired output's energy* relative to the anticipated convolution output's duration approximately as the input's energy is positioned relative to its own duration. Plate 10 shows the input/desired output relationship of plate 8 reversed, with a

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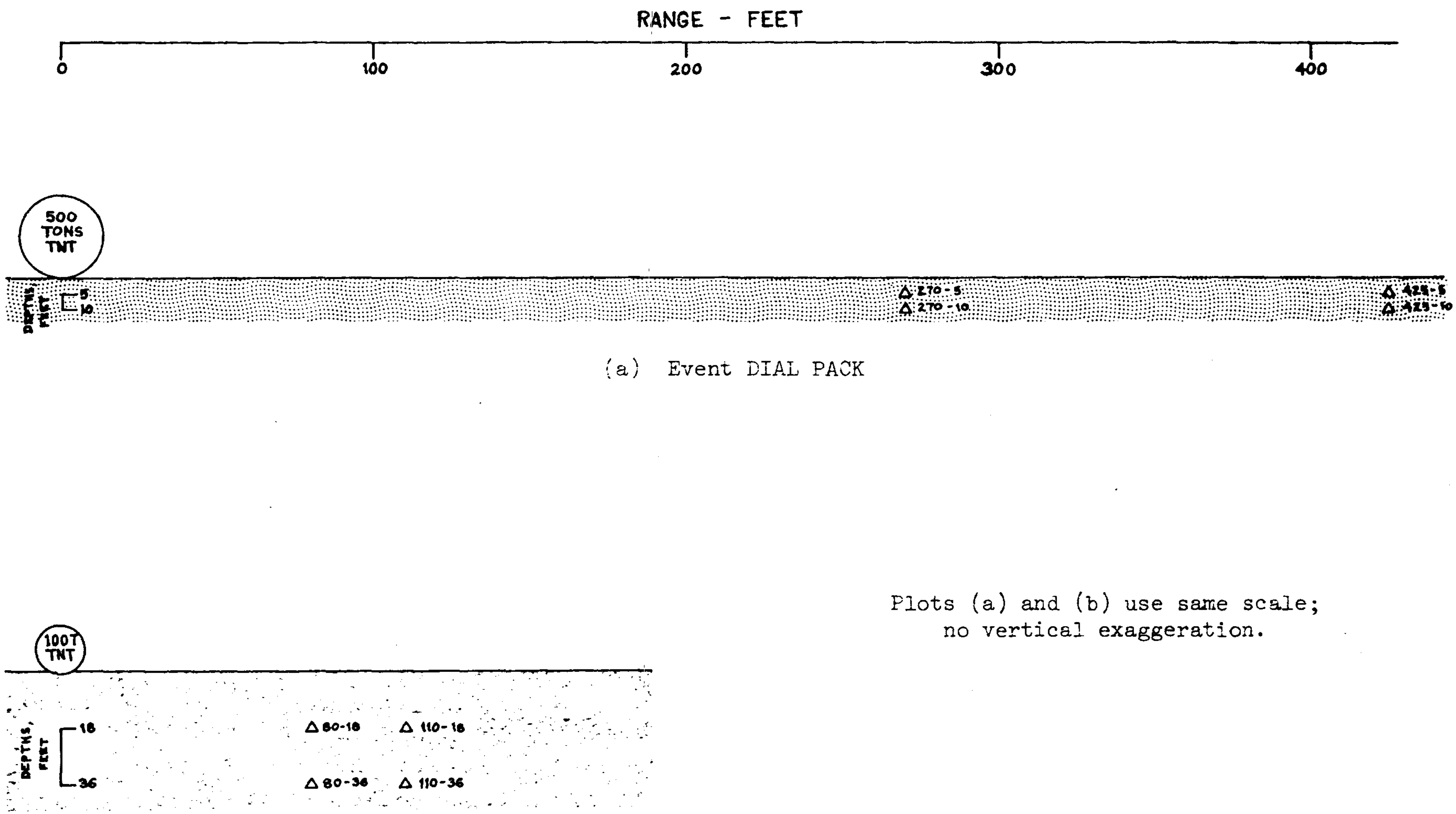
* A wavelet's energy is defined as the sum of the squares of its sample amplitudes. Trietel and Robinson[2, 5] discuss wavelet energy and time positions.

relative lag of 4-1/2 msec assigned to the new desired output. Plate 11 shows that the operator produced from this relationship is not good; its reconstruction of the desired output includes a rise time which is a very poor approximation of that for the gage data. This is an indication that the desired output has not been lagged enough. Plate 12 shows the same gage pair again, only in this case the desired output has been lagged 12 msec relative to the true zero time relationship. The reconstruction in plate 13 is reasonably good but not perfect, in spite of the fact that 12-msec lag is optimum for the wavelet pair being considered. The shorter pulse duration of the desired output wavelet of plate 12 suggests that the frequency band width contained in this signal is wider than that for the broader pulse of the input*. Since a linear system's output can contain only those frequencies present in its input, it is reasonable to expect our reconstruction to be less than perfect in this case.

Operator Use

23. Fig. 1 illustrates in cross section two free-field vertical velocity gage arrays, one from DIAL PACK and one from MINERAL ROCK. Each array consists of gages at two depths at a given range, and identical gages at the same depths at a greater range. Plate 14 shows as input and desired output the nearer gage data from DIAL PACK. The plate 14 operator has been calculated to express the linear relationship between the time history for 5-ft depth and that for 10-ft depth at 270-ft range. Plate 15 shows that the plate 14 desired output can be very accurately reproduced using the plate 14 operator; i.e., the operator is a good one. At this point a question arises: Can an accurate estimate be made of the time history for 10-ft depth at 425-ft range by using the plate 14 operator as a filter for the time history for 5-ft depth at 425-ft range? The estimated output of Plate 16 is the result of the suggested operation. If this estimate is accurate, it should match gage data for the 10-ft depth at 425-ft range.

* The low amplitude high frequency noise which "rides" the input is not considered in this comparison.



(a) Event DIAL PACK

(b) Event MINERAL ROCK

Plots (a) and (b) use same scale;
no vertical exaggeration.

Fig. 1. Velocity gage arrays for example sets 7 through 10

The gage time history for this location is shown on plate 17; the "estimate" of plate 16 has reproduced the peak amplitudes and waveform of this gage very acceptably.

24. In paragraph 23 we constructed a Wiener operator to account for the effects of depth at 270-ft range on DIAL PACK. We then applied this "depth operator" to the shallow time history for 425-ft range, to arrive at an estimate for the output of the deeper gage at 425-ft range. Would a "range operator" achieve the same result? Plate 18 shows as input and desired output the shallow gage data from DIAL PACK. The operator on this plate, then, is an expression of the linear relationship between the waveforms representing 5-ft depth at 270-ft and 425-ft ranges. Plate 19 shows the operator to be a good one. Application of the plate 18 operator to the time history for 10-ft depth at 270-ft range results in the estimated output of plate 20. This estimate is very nearly an overlay of the plate 16 estimate for this same gage location. Its peaks and waveform are as acceptable as those of the previous estimate. (Plate 17 is repeated as plate 21 to allow comparison of this new estimate with the actual gage data.)

25. Plates 22 through 29 repeat for the MINERAL ROCK data indicated by fig. 1b, the procedures followed with the DIAL PACK data of fig. 1a and plates 14 through 21. A "depth operator" has been calculated and applied to produce the estimated output of plate 24, and a "range operator" has been calculated and applied to produce the estimated output of plate 28. Comparison of these estimates with each other and with the location's actual gage data (plates 25 and 29) shows very acceptable peak amplitude and waveform reproduction.

26. The operators of example sets 7 through 10 were calculated without changes in the time positions of the compared waveforms. Since we considered operators to relate stronger data to later, attenuated data, lag positions and frequency content were not critical considerations. Where this situation is reversed (as was shown in example sets 5 and 6), lag adjustments may become necessary and operator efficiency may be reduced.

Operator Noise

27. In paragraph 4 it was noted that a discrete operator represents a linear system's impulse response. So far we have not seen among the examples an operator which appears much like any typical electronics impulse response. Most have been quite ragged in appearance, though they produce accurate outputs in the examples of satisfactory procedure. The data time histories used for example sets 1 through 10 are relatively noise free. Nevertheless, the low amplitude noise present strongly influences the appearances of the operators produced. If spurious data components are removed[3] prior to construction of the operator, a more regular appearance results and visual analysis is simplified. In many cases noise removal will be a necessity.

28. The inputs and desired outputs of example sets 11 through 13 are radial velocity gage data from 100-ft depth on MINERAL LODE. The input for each of these sets is the 75-ft range gage on the south line, while the desired output for each set is the 75-ft range gage on the west line. The operators for all three sets have been calculated without changes in the time positions of the compared waveforms. Plate 30 shows an operator constructed directly from the raw data. The greatest difficulty here is the spurious spike at about 48 msec on the desired output. It causes a very ragged operator to be created, and use of this operator results in the noisy checkout of plate 31*. The input and desired output of plate 32 are identical to those of plate 30 except that the spurious spikes have been removed from the desired output. The operator produced from this pair of time histories is much cleaner than that of plate 30. The operator checkout of plate 33 is satisfactory. However, for plate 34 we take one further step. The input and desired output of this plate are identical to those of plate 32 except that a digital low-pass filter has been applied to each. The operator produced from this pair of time histories is very clean, with little oscillation apparent after 35 msec.

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* Note the scale change caused by automatic adjustment of the plot ordinate to the reproduced spike's change in amplitude.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

29. Digital Wiener filters may be used to define, accurately and economically, many important explosion effects relationships. (See example sets 2, 3, 4, 7 through 10, and 13.)

30. Explosion ground motion time histories may be estimated in uniform soil and rock using linear operators to adjust for relatively large gage range and depth differences in the high pressure airblast region. (See paragraphs 23 through 26.)

Recommendations

31. Available ground shock data should be analyzed to determine the effects of increasing gage range upon the forms taken by Wiener operators derived from succeeding time history pairs. An effort should then be made to characterize differences in site geology and event geometry with time domain operators. The ultimate objective of this study would be a practical routine for ground motion prediction.

32. Wiener filters should be applied to the problem of relating explosion-induced motions in model structures to analogous motions in full sized structures. This application would provide a means for separation of the linear and nonlinear portions of the structural motion problem.

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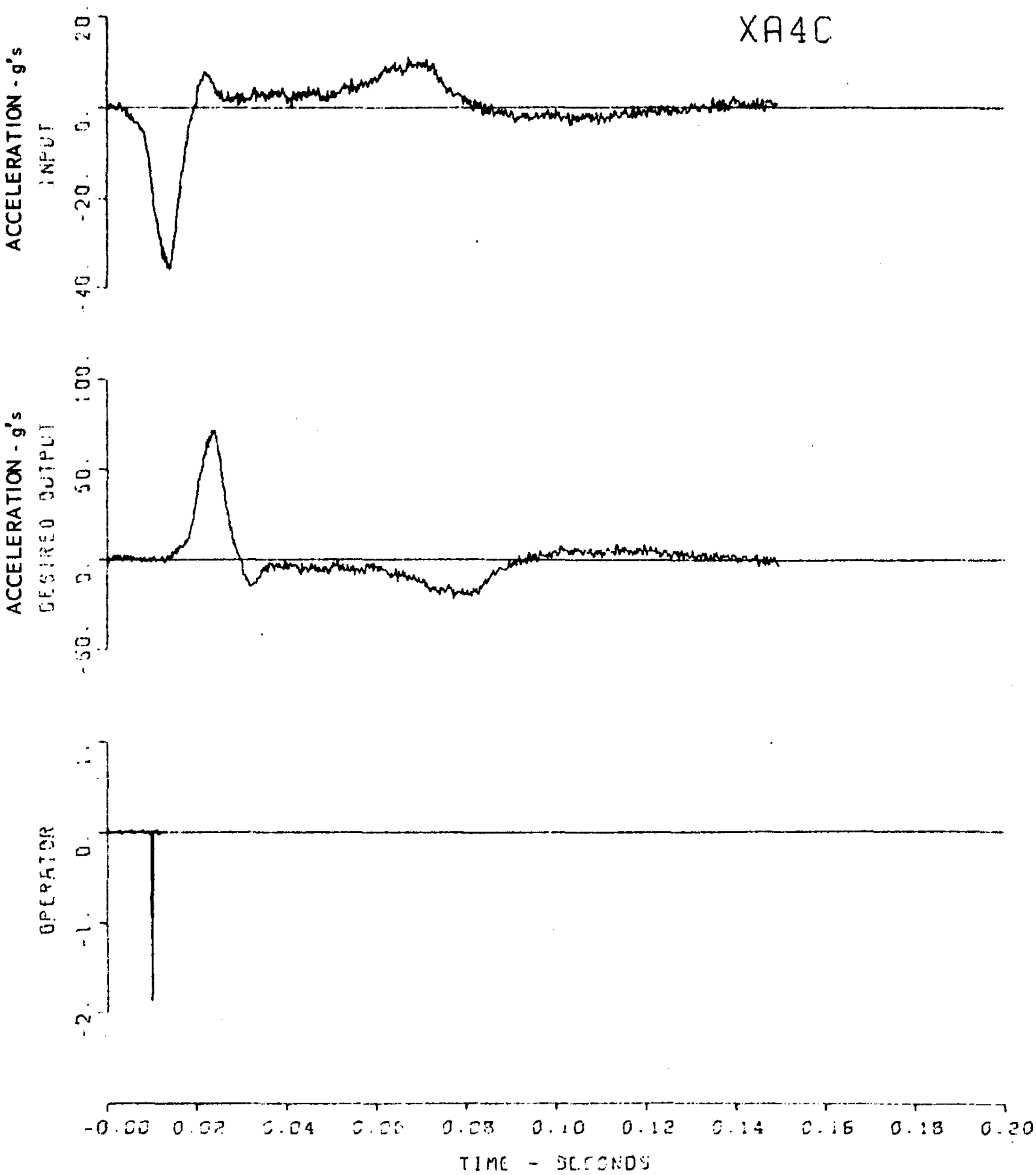
EXAMPLES OF PROGRAM OPERATION

EXAMPLE SET 1 (DELAY AND CALIBRATION CHANGE)

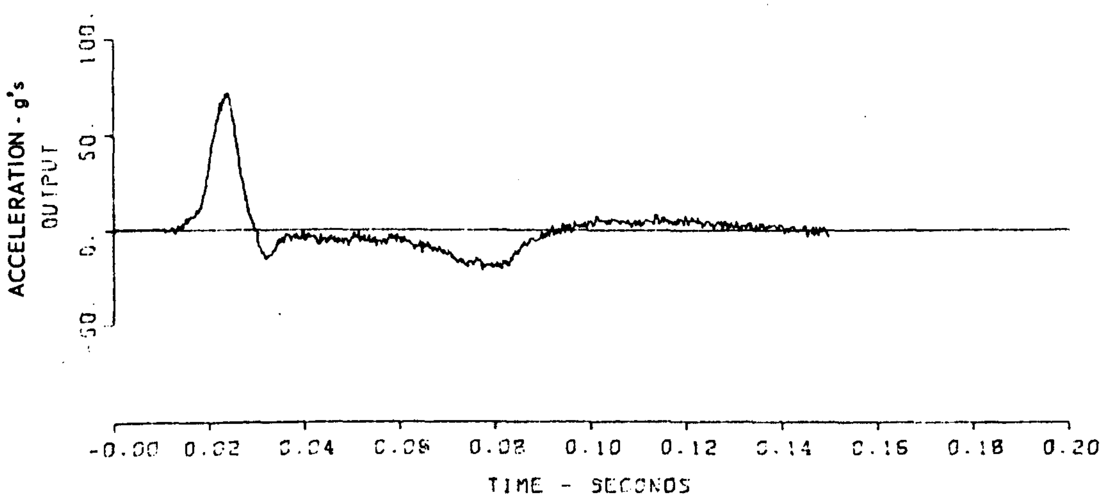
GAGE TYPE:	ACCELEROMETER
SAMPLING FREQUENCY:	8000 SAMPLES PER SECOND
PROBLEM SOLVING TIME:	5 MINUTES



EXAMPLE SET 1

OPERATOR CONSTRUCTION

PLATE 1



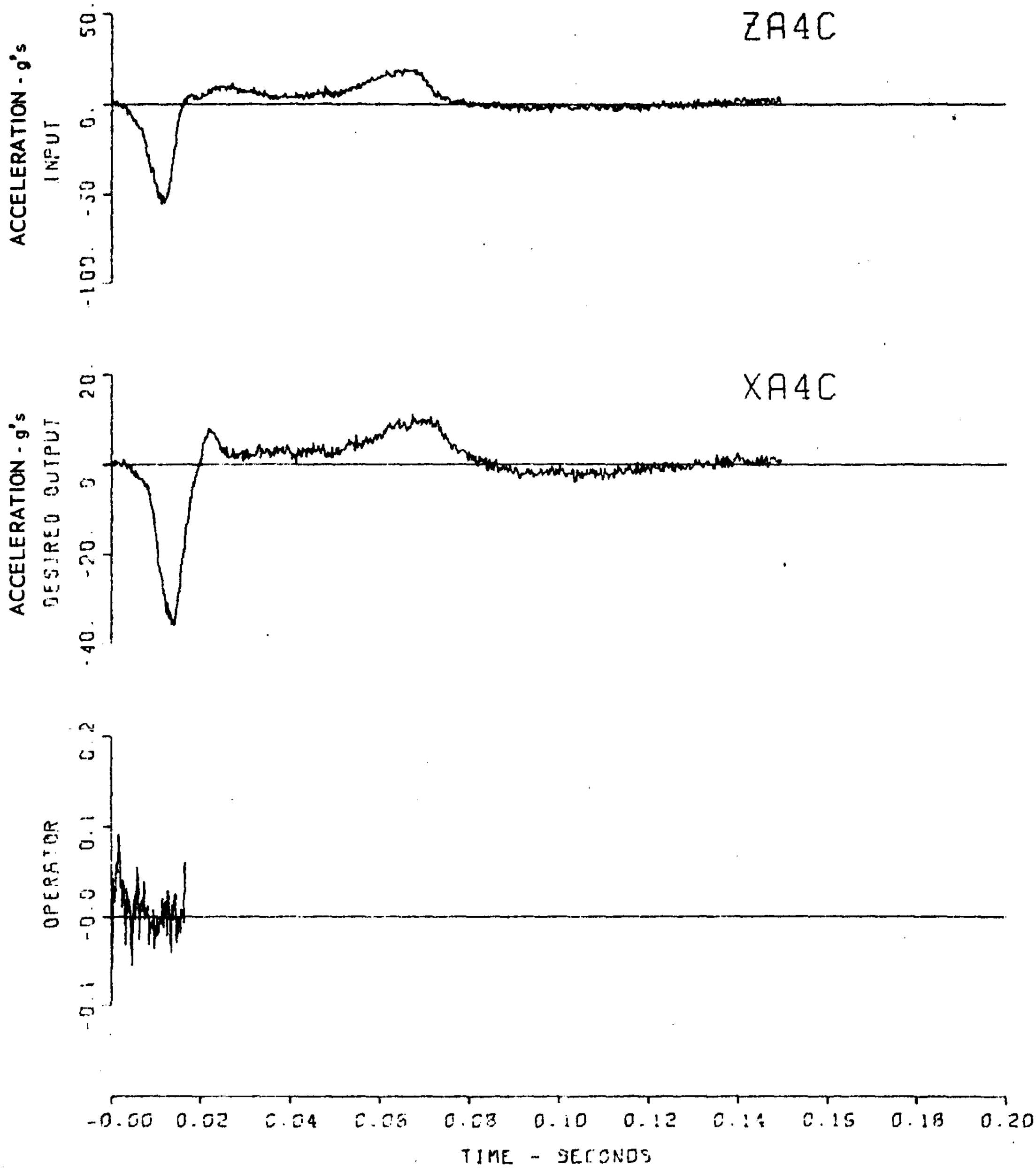
EXAMPLE SET 1

OPERATOR CHECKOUT

PLATE 2

EXAMPLE SET 2 (RANGE DIFFERENCE)

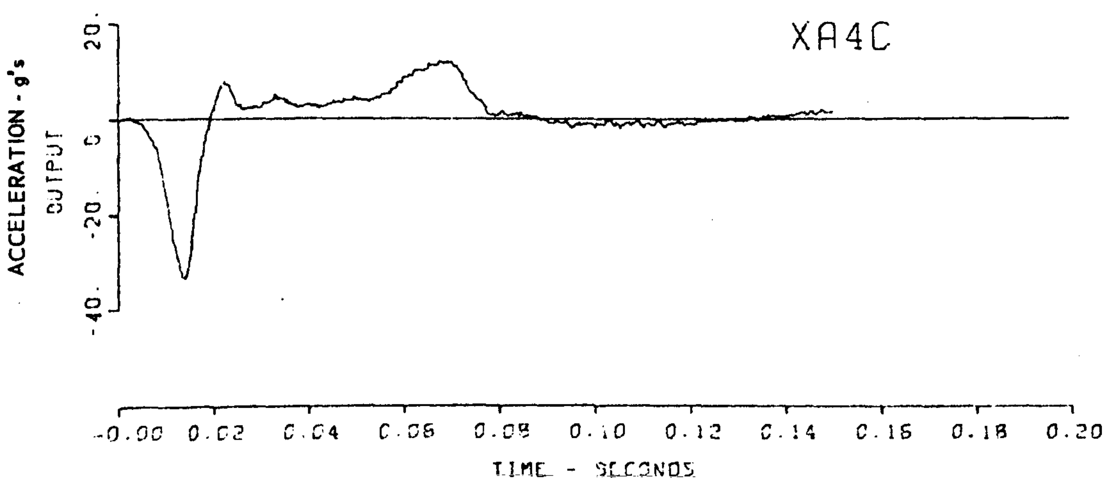
EVENT:	DIAL PACK
GAGE TYPE:	ACCELEROMETER
SAMPLING FREQUENCY:	8000 SAMPLES PER SECOND
PROBLEM SOLVING TIME:	8 MINUTES



EXAMPLE SET 2

OPERATOR CONSTRUCTION

PLATE 3

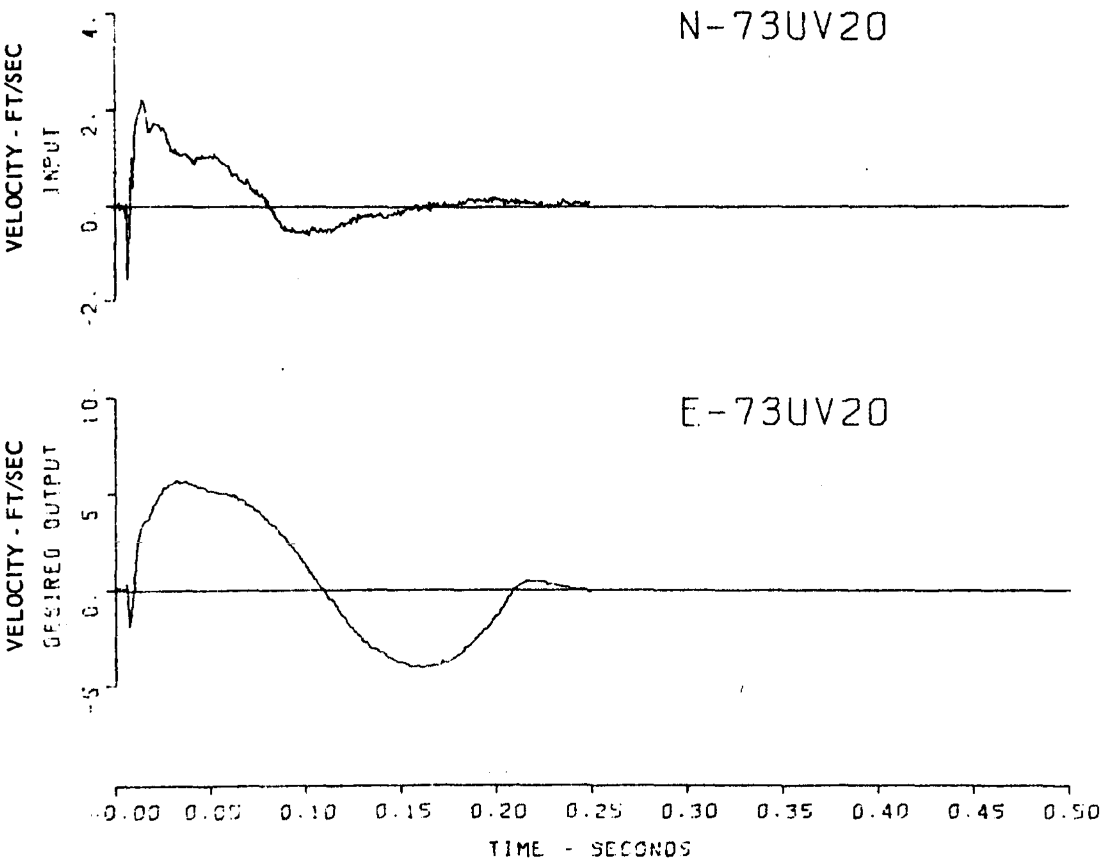


EXAMPLE SET 2

OPERATOR CHECKOUT

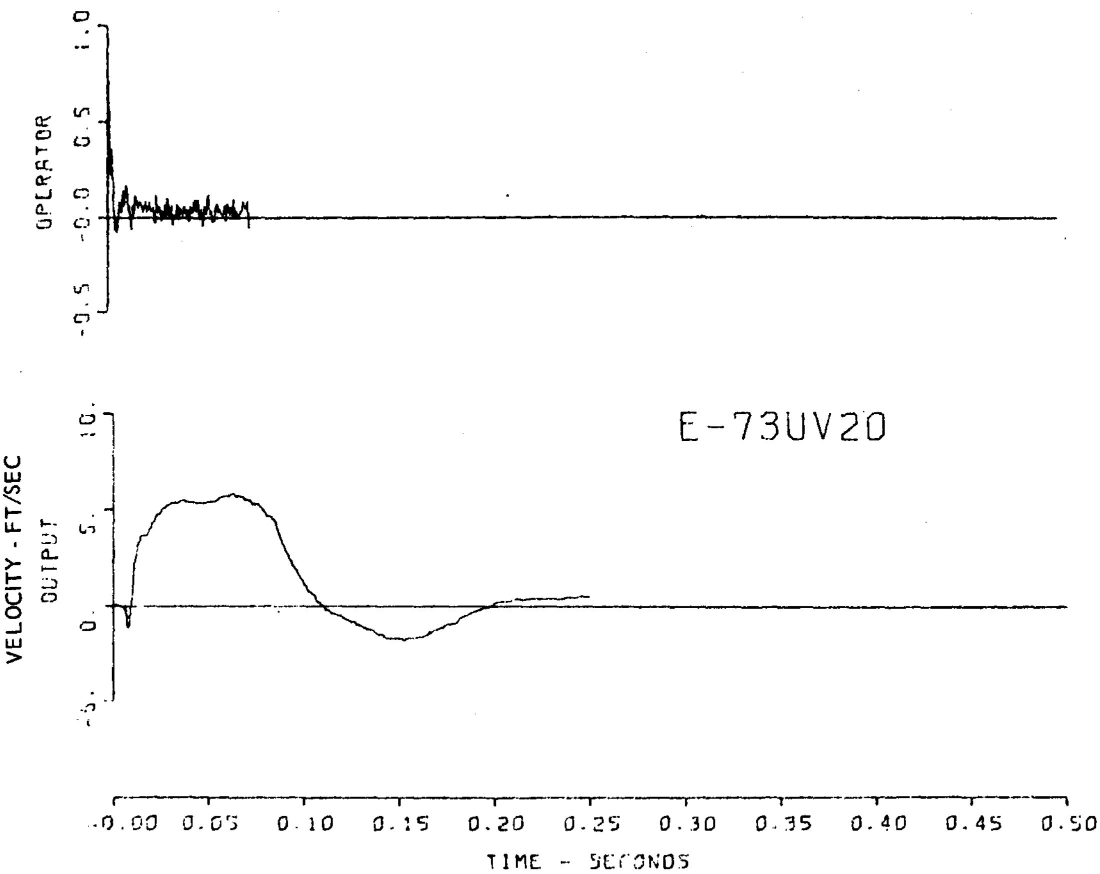
EXAMPLE SET 3 (GAGE SITE DIFFERENCE, SAME RANGES AND DEPTHS)

EVENT:	MINE ORE
GAGE TYPE:	VELOCITY
SAMPLING FREQUENCY:	2000 SAMPLES PER SECOND
PROBLEM SOLVING TIME,	
SHORT OPERATOR:	3 MINUTES
LONG OPERATOR:	7 MINUTES



EXAMPLE SET 3

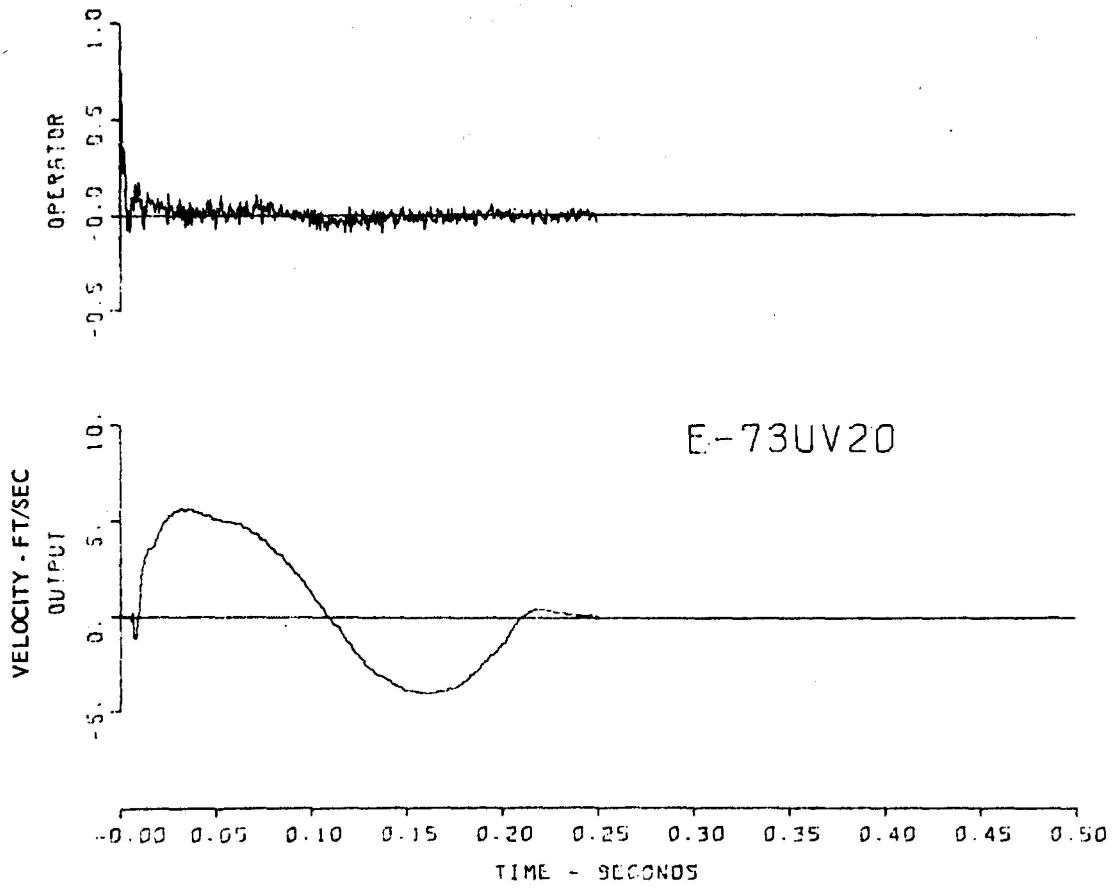
GAGE PAIR COMPARISON



EXAMPLE SET 3

SHORT OPERATOR AND CHECKOUT
(UNSATISFACTORY—INSUFFICIENT
OPERATOR LENGTH)

PLATE 6



EXAMPLE SET 3

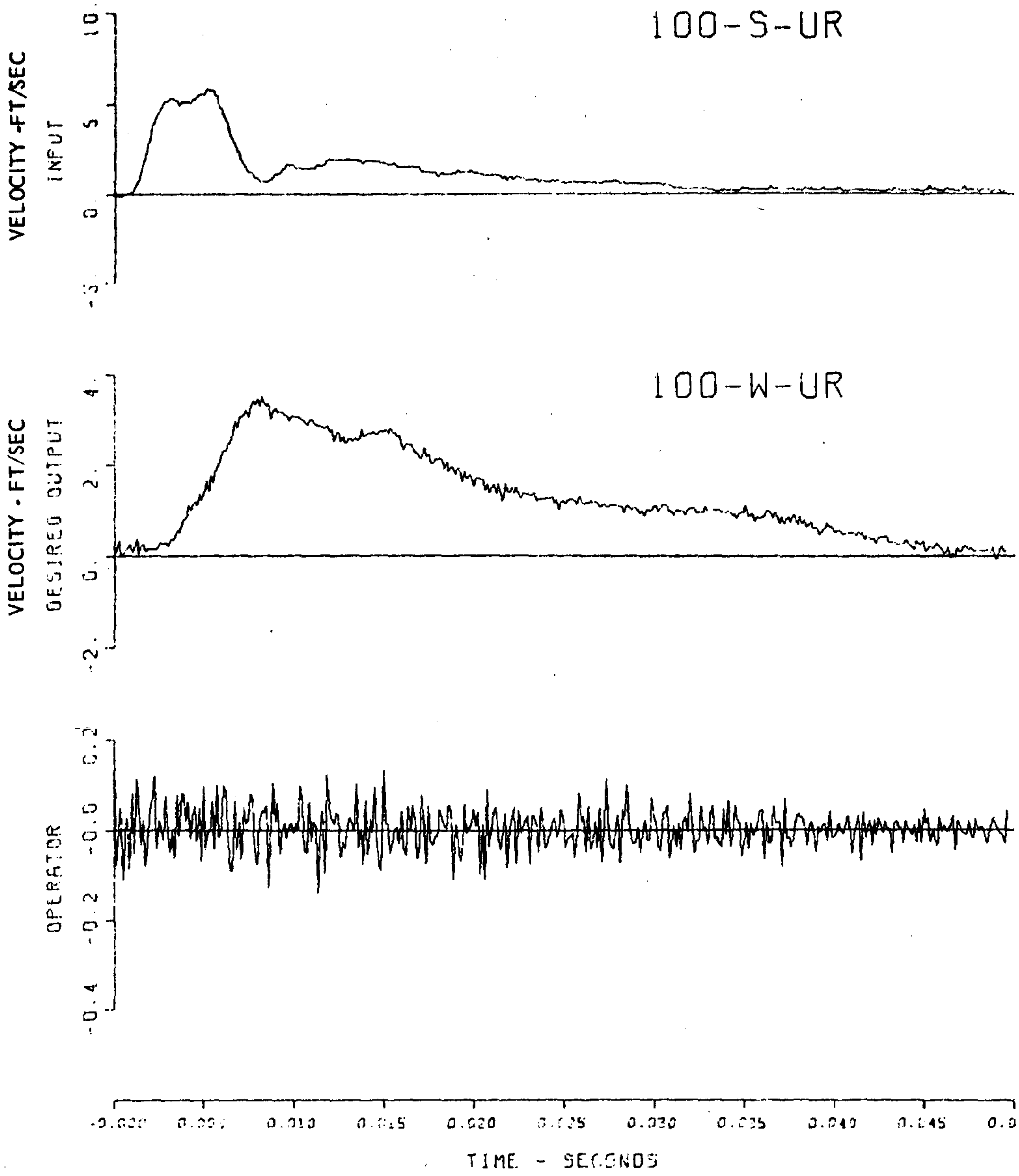
LONG OPERATOR AND CHECKOUT

(SATISFACTORY)

PLATE 7

EXAMPLE SET 4 (GAGE SITE DIFFERENCE, SAME RANGES AND DEPTHS)

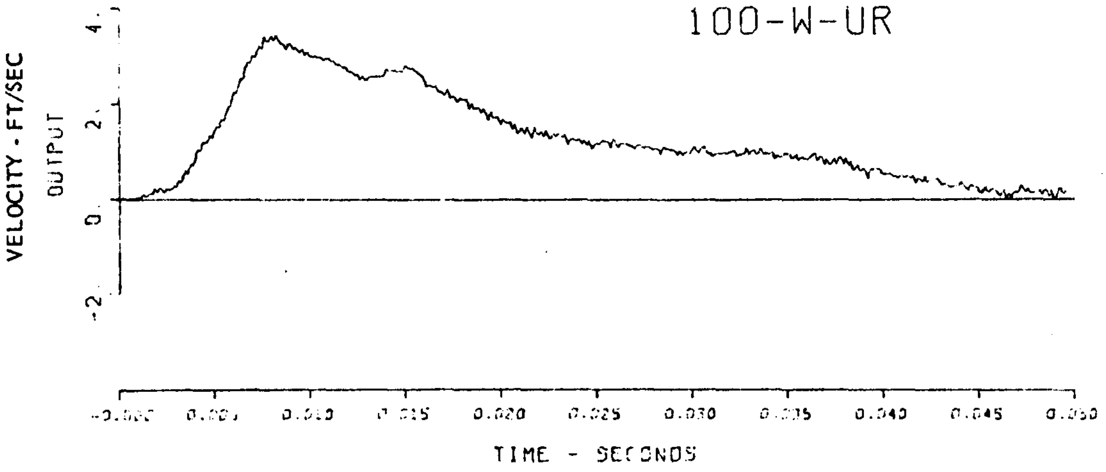
EVENT:	MINERAL LODE
GAGE TYPE:	VELOCITY
SAMPLING FREQUENCY:	8000 SAMPLES PER SECOND
PROBLEM SOLVING TIME:	7 MINUTES



EXAMPLE SET 4

OPERATOR CONSTRUCTION

PLATE 8



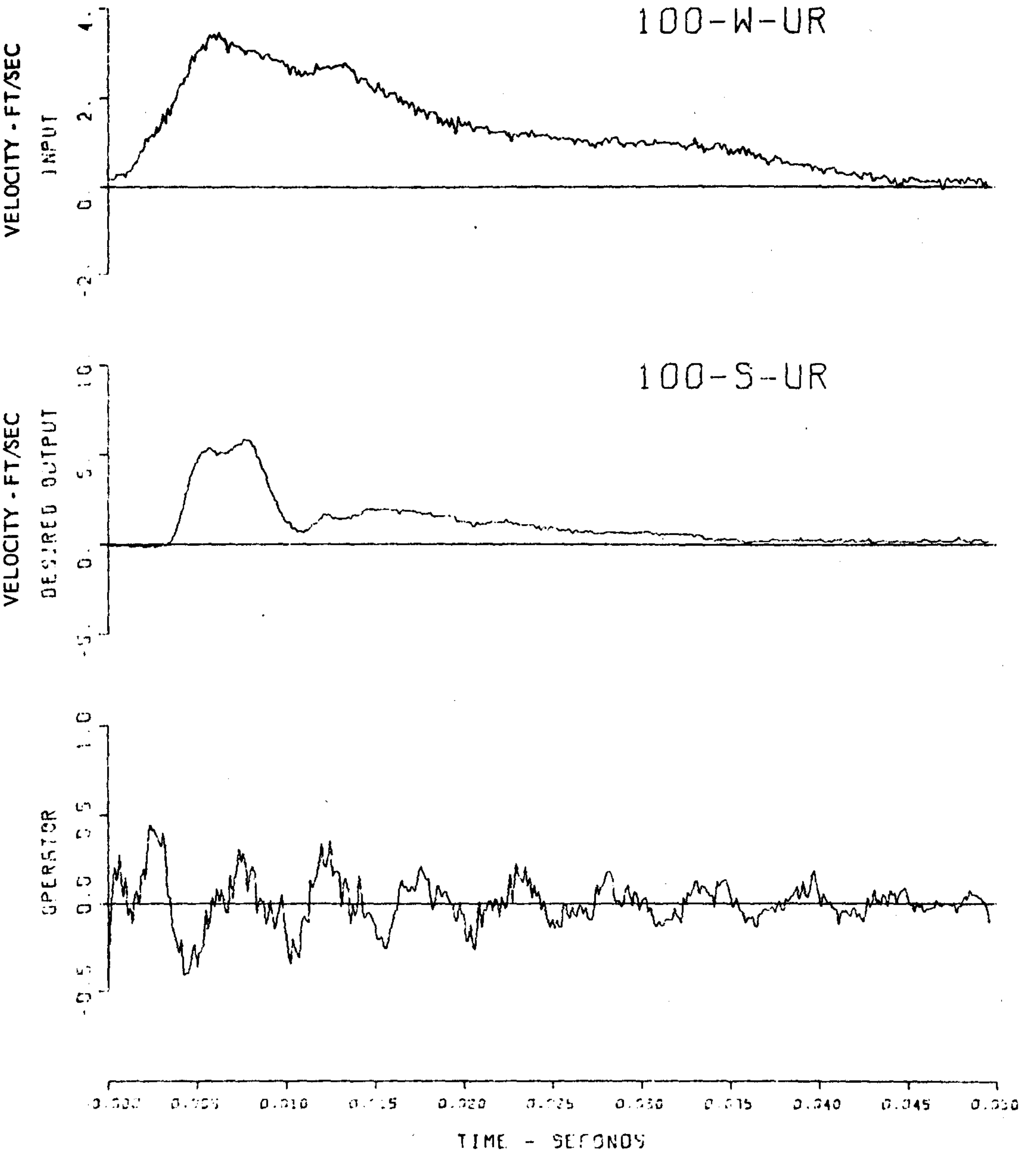
EXAMPLE SET 4

OPERATOR CHECKOUT

PLATE 9

EXAMPLE SET 5 (EXAMPLE SET 4 INPUT/DESIRED OUTPUT RELATIONSHIP REVERSED)

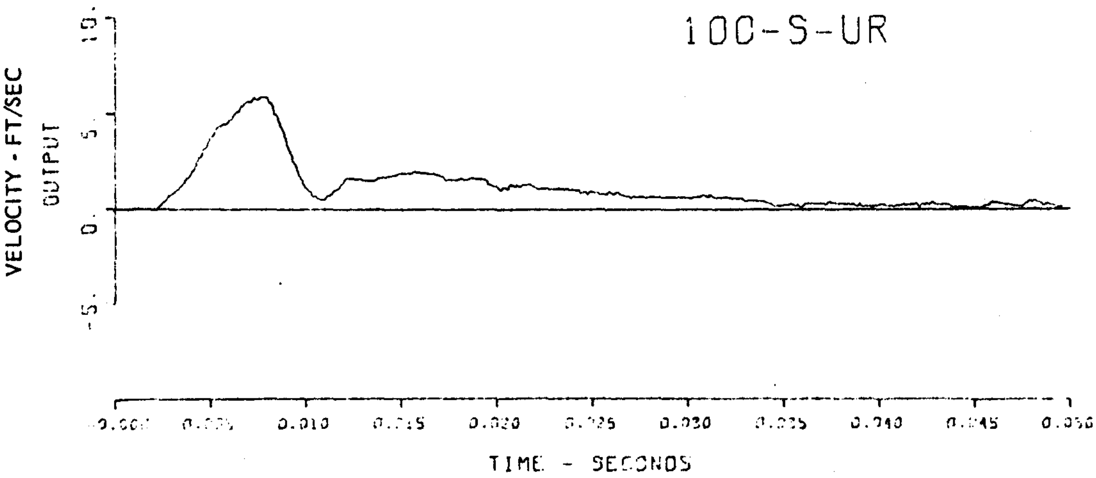
EVENT:	MINERAL LODE
GAGE TYPE:	VELOCITY
SAMPLING FREQUENCY:	8000 SAMPLES PER SECOND
PROBLEM SOLVING TIME:	7 MINUTES



EXAMPLE SET 5

OPERATOR CONSTRUCTION

PLATE 10



EXAMPLE SET 5

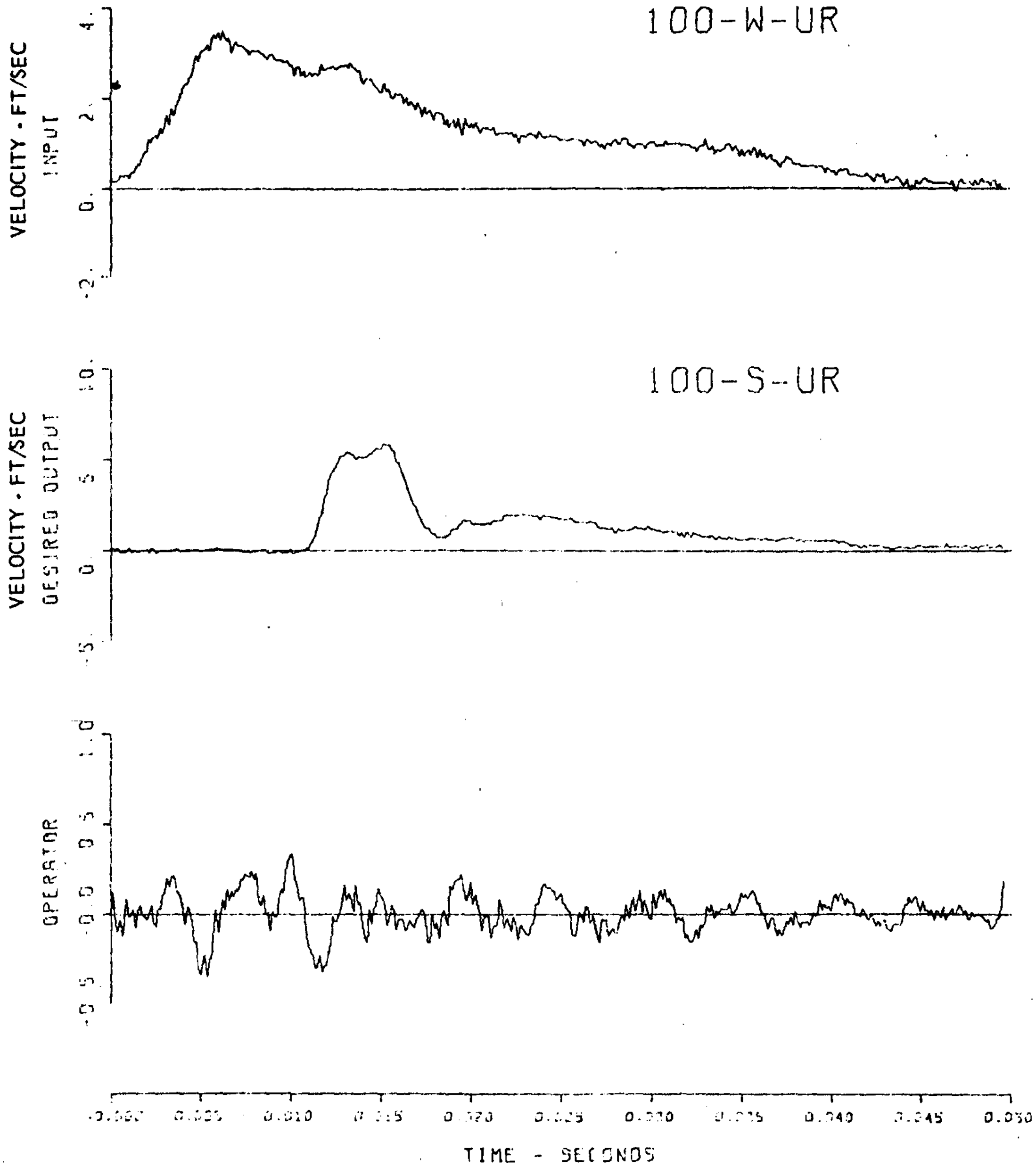
OPERATOR CHECKOUT

(UNSATISFACTORY—INSUFFICIENT

DESIRED OUTPUT LAG)

EXAMPLE SET 6 (EXAMPLE SET 5 WITH DESIRED OUTPUT AT BEST LAG)

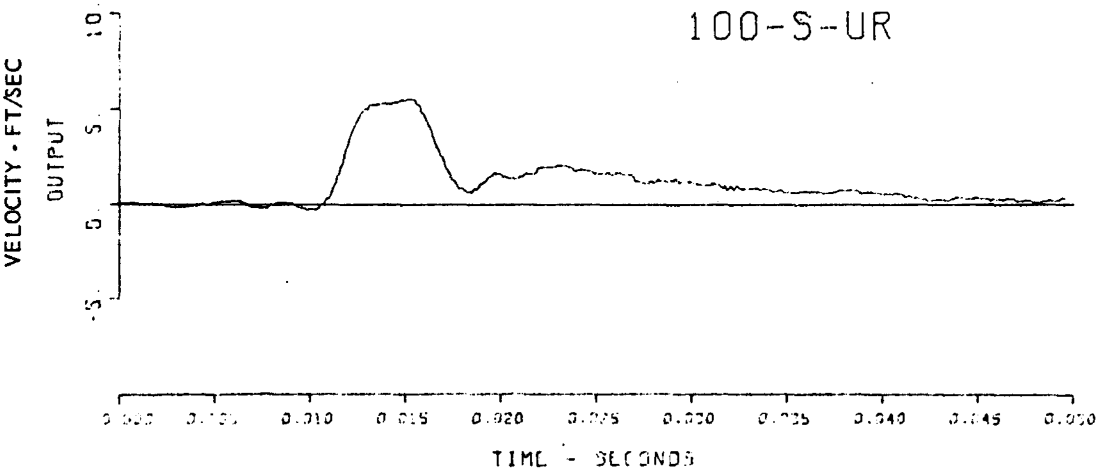
EVENT:	**MINERAL LODE**
GAGE TYPE:	**VELOCITY**
SAMPLING FREQUENCY:	**8000 SAMPLES PER SECOND**
PROBLEM SOLVING TIME:	**7 MINUTES**



EXAMPLE SET 6

OPERATOR CONSTRUCTION

PLATE 12



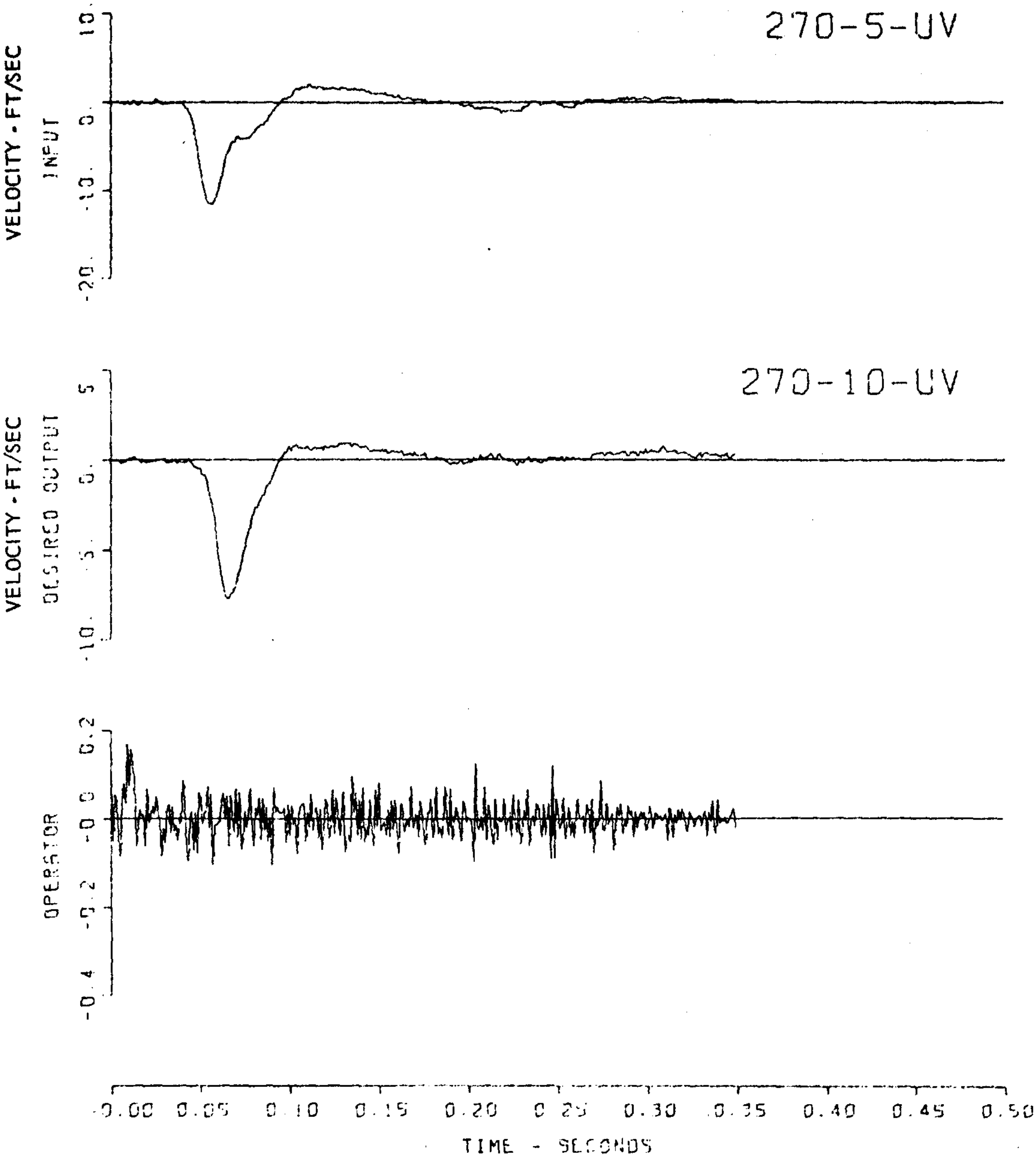
EXAMPLE SET 6

OPERATOR CHECKOUT
(IMPERFECT—POOR FREQUENCY
RELATIONSHIPS)

PLATE 13

EXAMPLE SET 7 (DEPTH EFFECT CONVERSION)

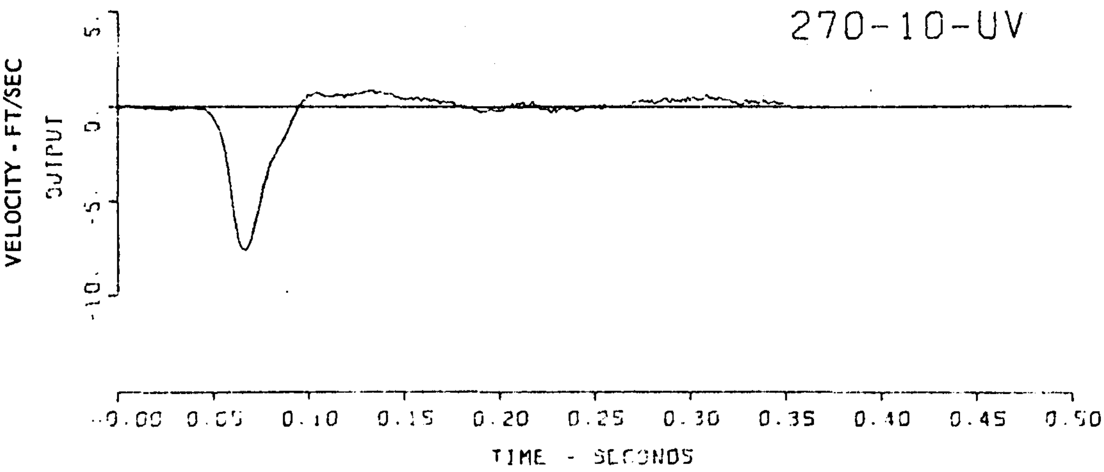
EVENT:	DIAL PACK
GAGE TYPE:	VELOCITY
SAMPLING FREQUENCY:	1000 SAMPLES PER SECOND
PROBLEM SOLVING TIME:	4 MINUTES



EXAMPLE SET 7

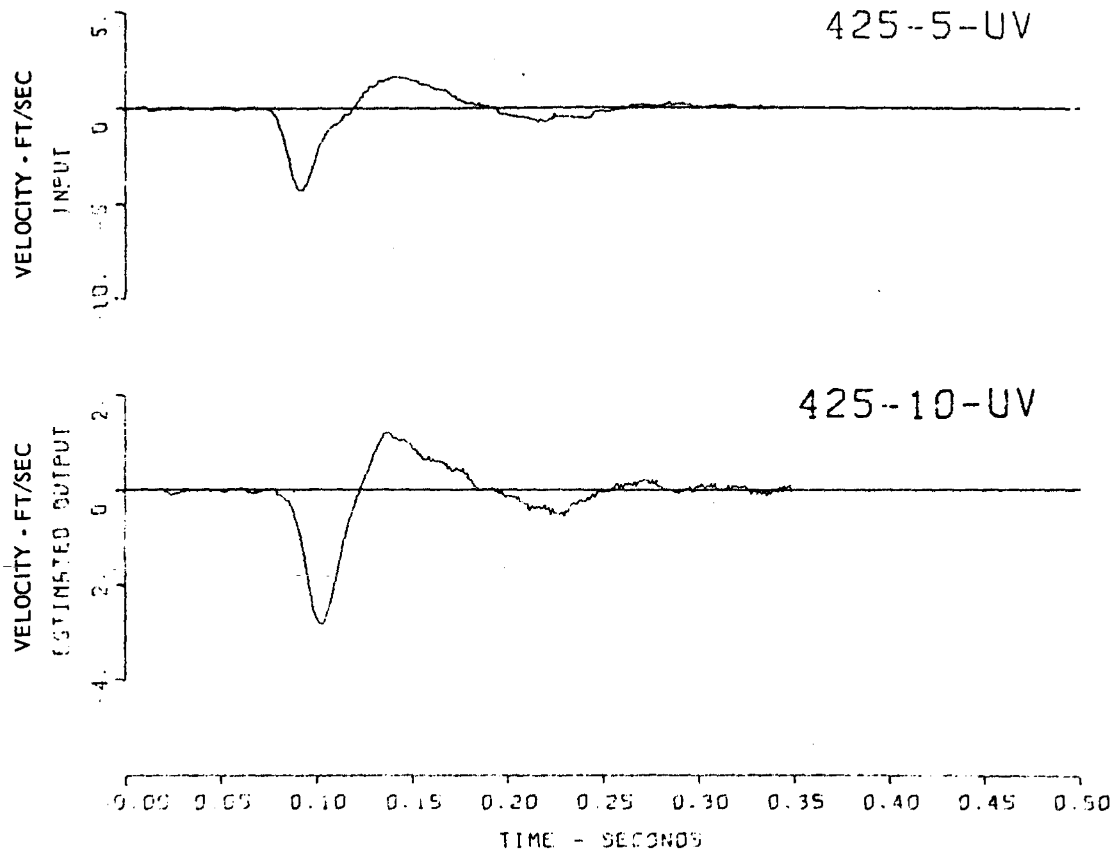
OPERATOR CONSTRUCTION

PLATE 14



EXAMPLE SET 7

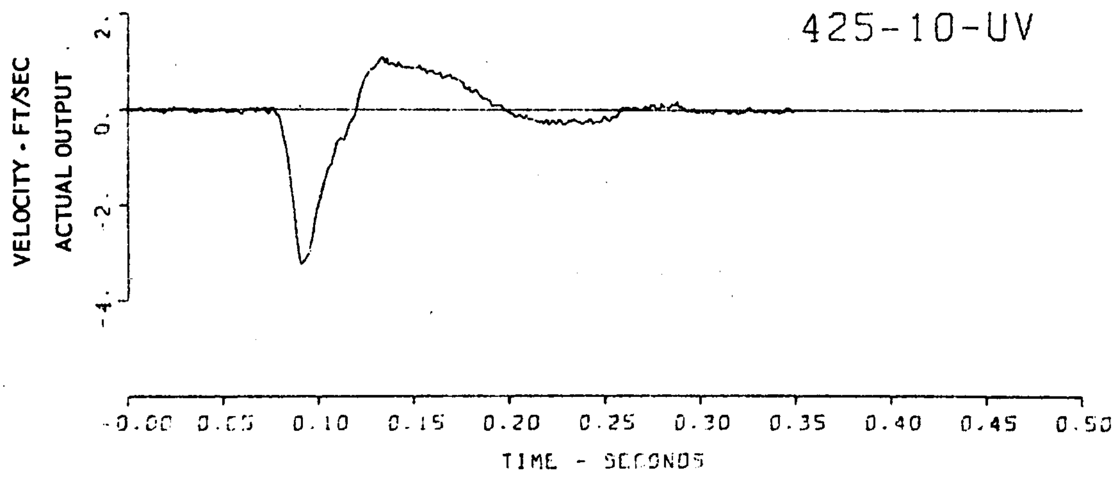
OPERATOR CHECKOUT



EXAMPLE SET 7

OPERATOR APPLICATION

PLATE 16



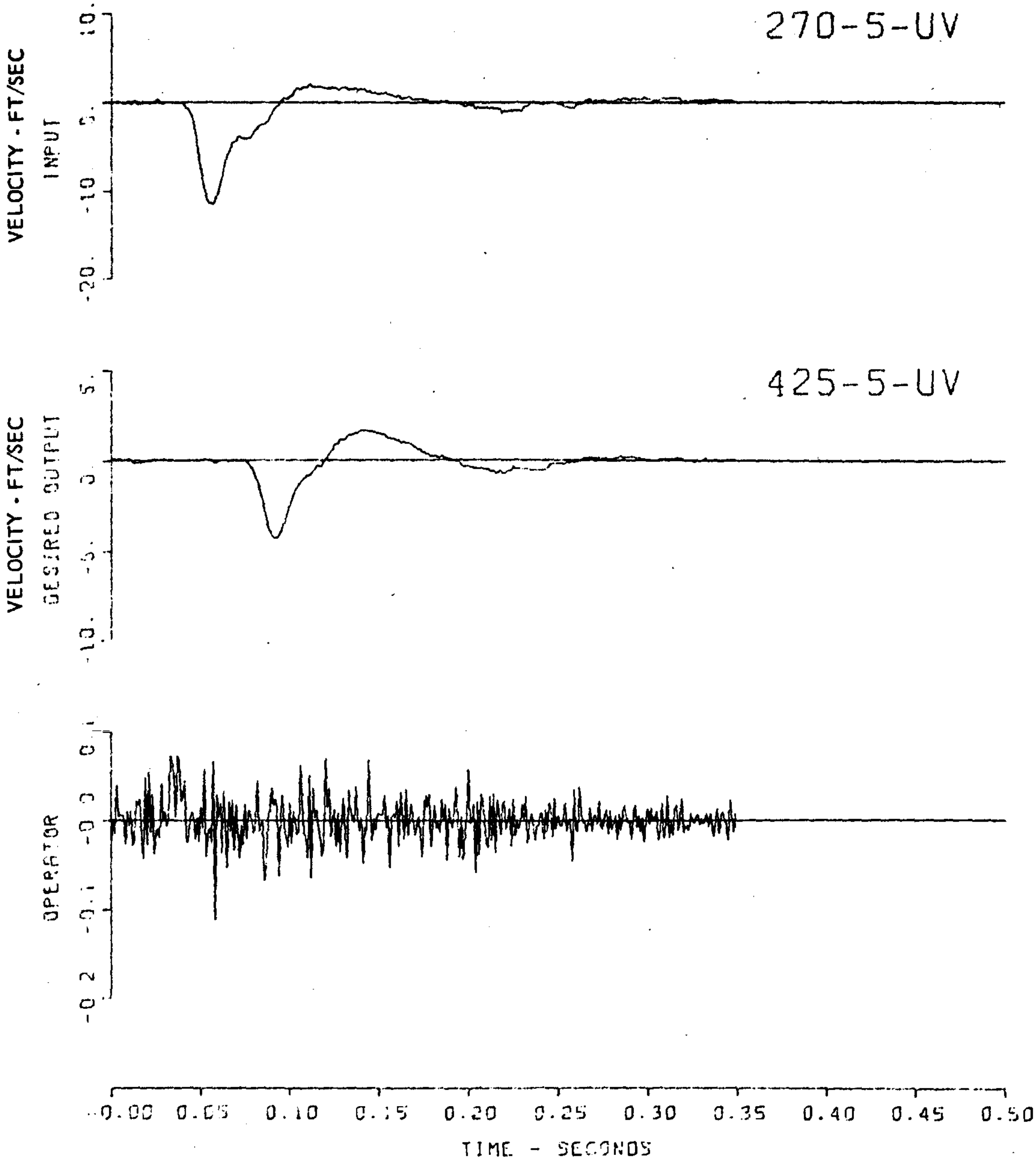
EXAMPLE SET 7

COMPARISON GAGE DATA

PLATE 17

EXAMPLE SET 8 (RANGE EFFECT CONVERSION)

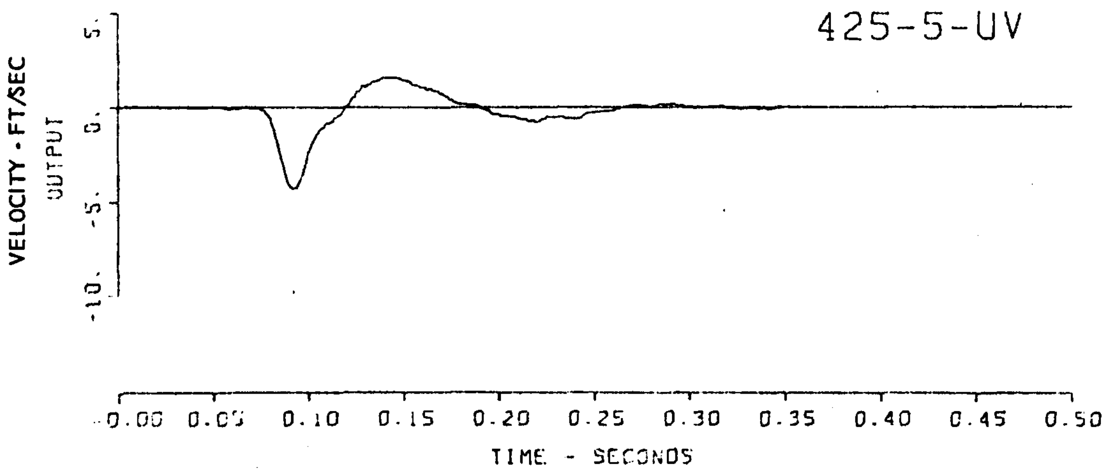
EVENT:	DIAL PACK
GAGE TYPE:	VELOCITY
SAMPLING FREQUENCY:	1000 SAMPLES PER SECOND
PROBLEM SOLVING TIME:	4 MINUTES



EXAMPLE SET 8

OPERATOR CONSTRUCTION

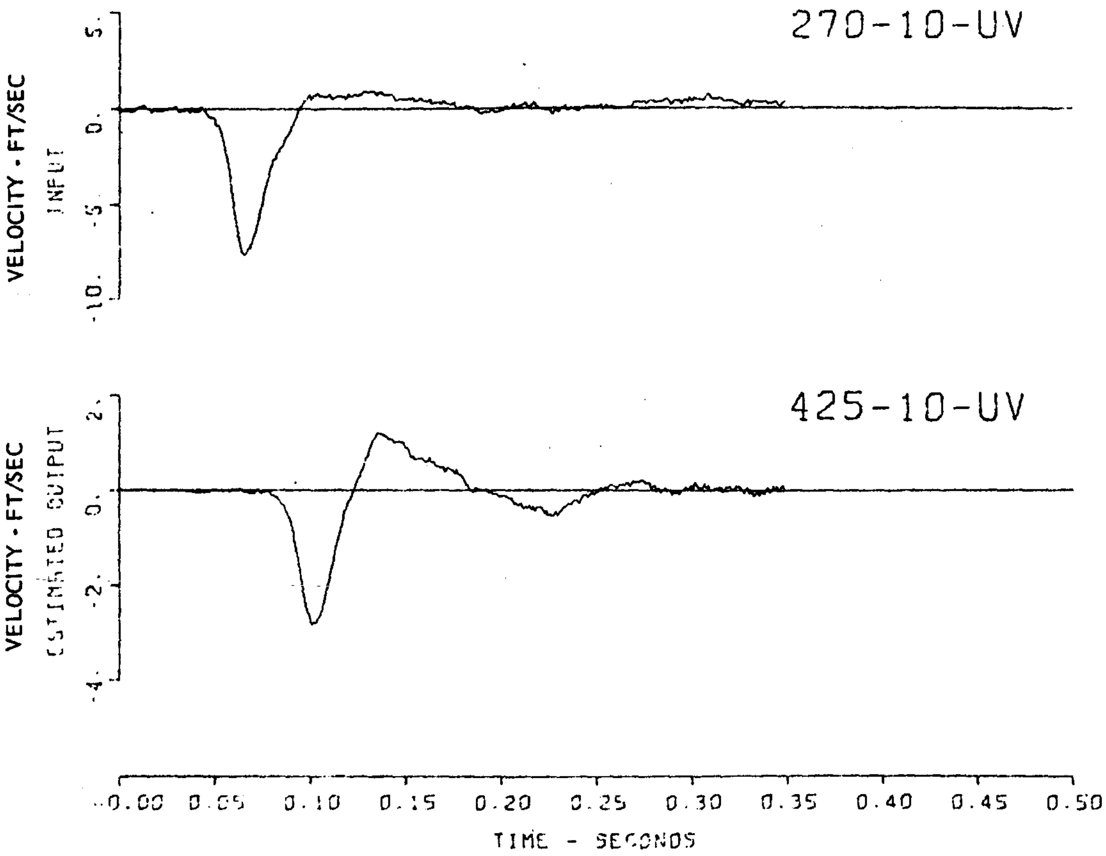
PLATE 18



EXAMPLE SET 8

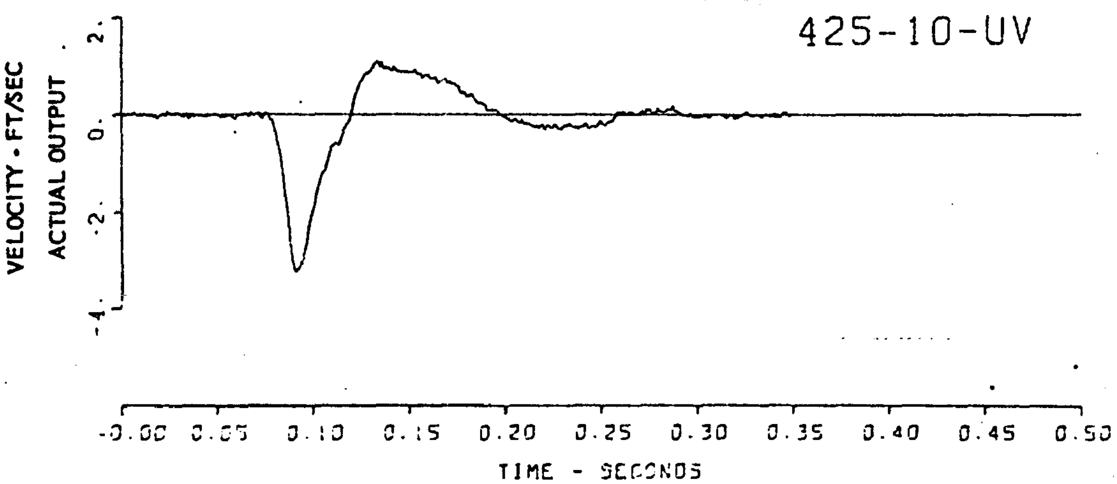
OPERATOR CHECKOUT

PLATE 19



EXAMPLE SET 8

OPERATOR APPLICATION

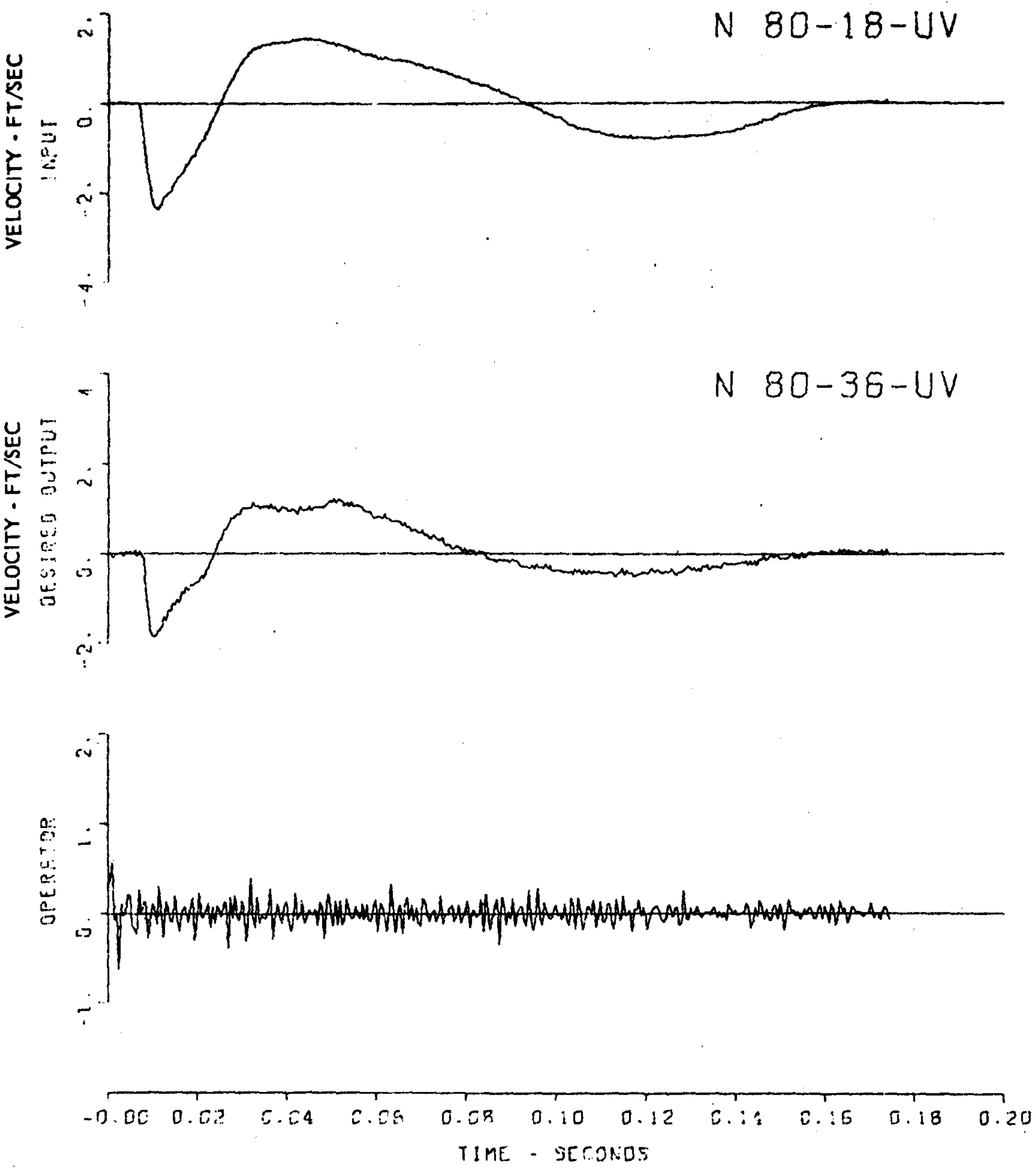


EXAMPLE SET 8

COMPARISON GAGE DATA

EXAMPLE SET 9 (DEPTH EFFECT CONVERSION)

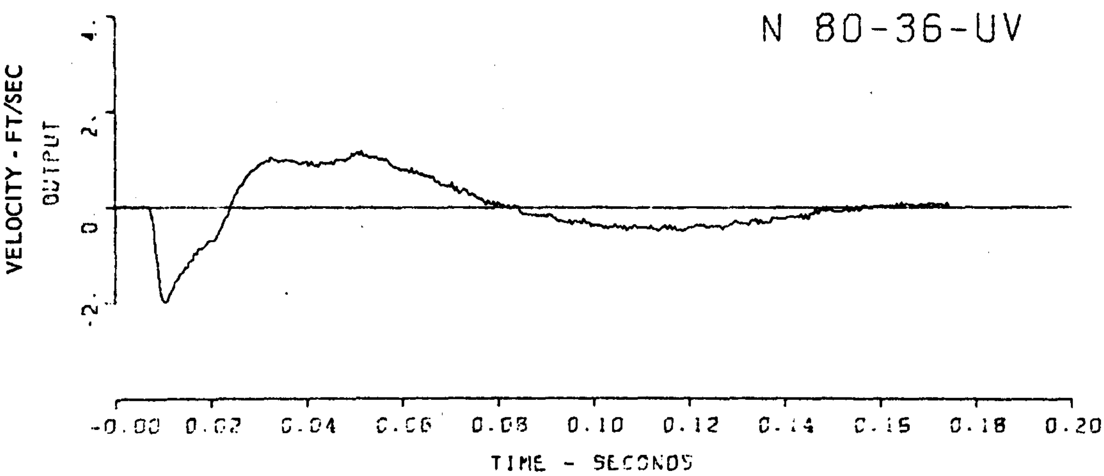
EVENT:	MINERAL ROCK
GAGE TYPE:	VELOCITY
SAMPLING FREQUENCY:	2000 SAMPLES PER SECOND
PROBLEM SOLVING TIME:	4 MINUTES



EXAMPLE SET 9

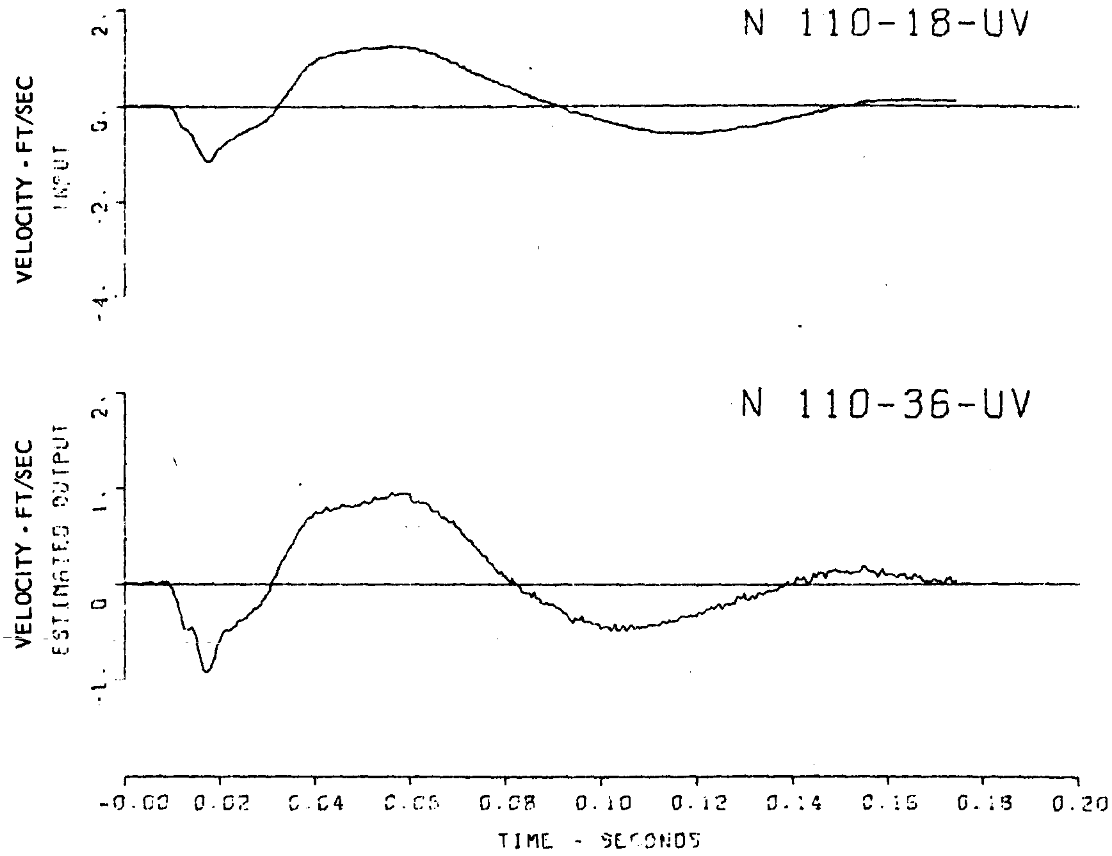
OPERATOR CONSTRUCTION

PLATE 22



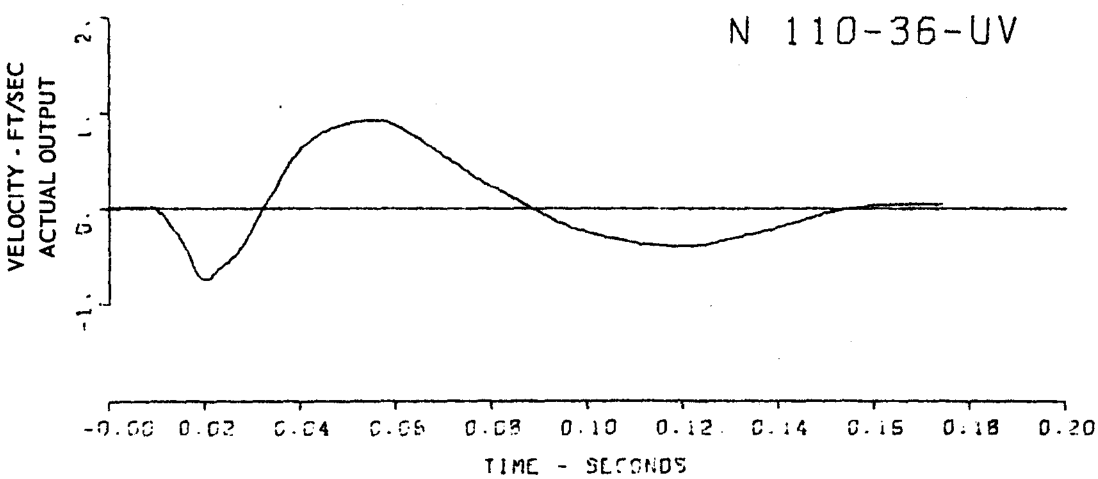
EXAMPLE SET 9

OPERATOR CHECKOUT



EXAMPLE SET 9

OPERATOR APPLICATION

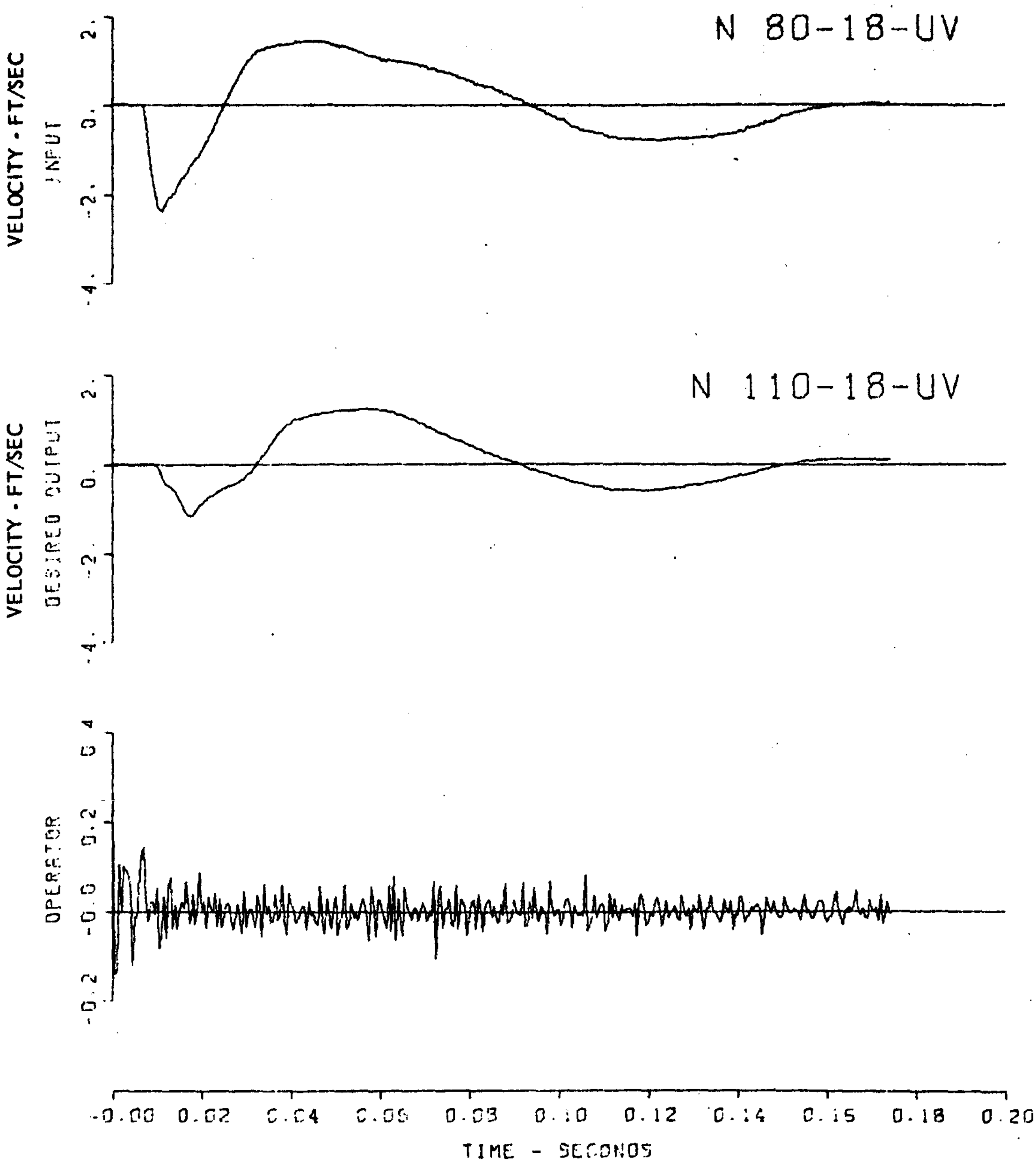


EXAMPLE SET 9

COMPARISON GAGE DATA

EXAMPLE SET 10 (RANGE EFFECT CONVERSION)

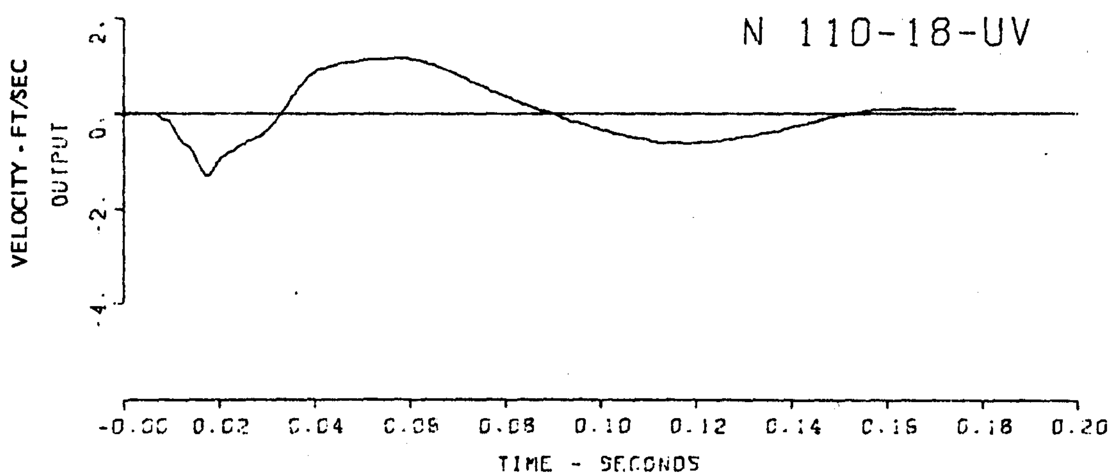
EVENT:	**MINERAL ROCK**
GAGE TYPE:	**VELOCITY**
SAMPLING FREQUENCY:	**2000 SAMPLES PER SECOND**
PROBLEM SOLVING TIME:	**4 MINUTES**



EXAMPLE SET 10

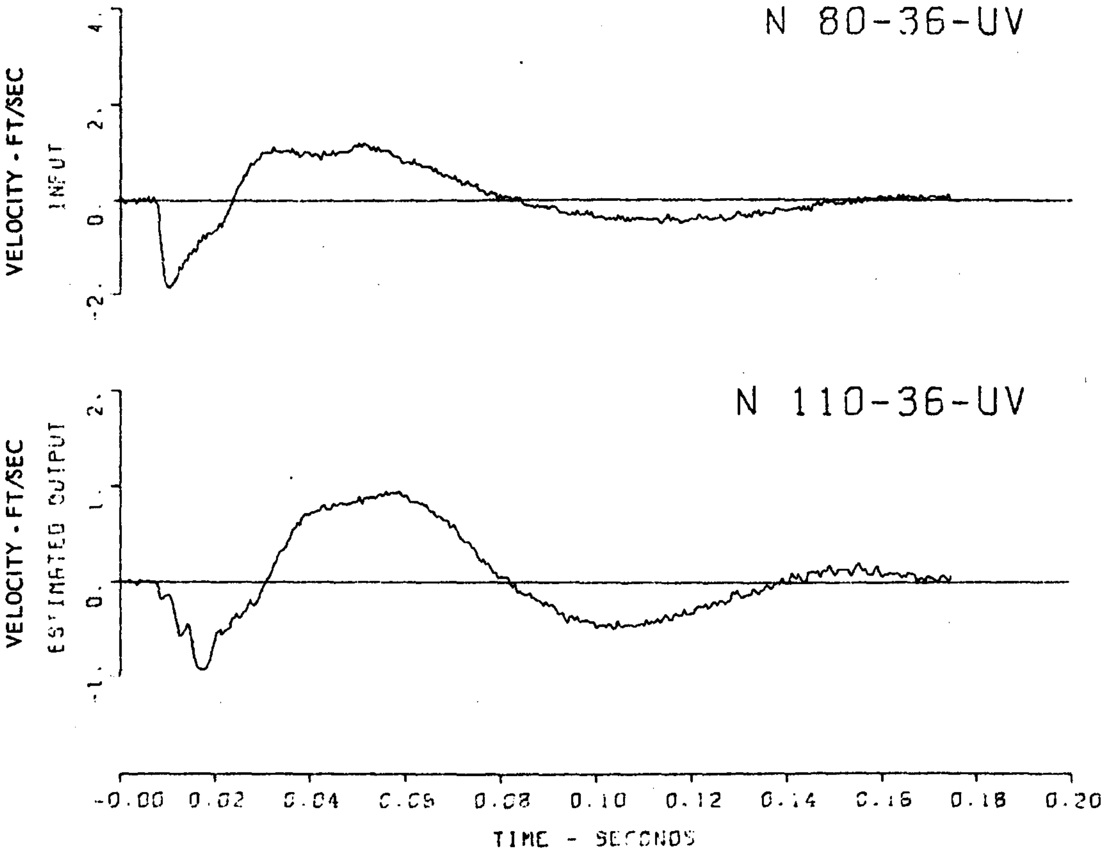
OPERATOR CONSTRUCTION

PLATE 26



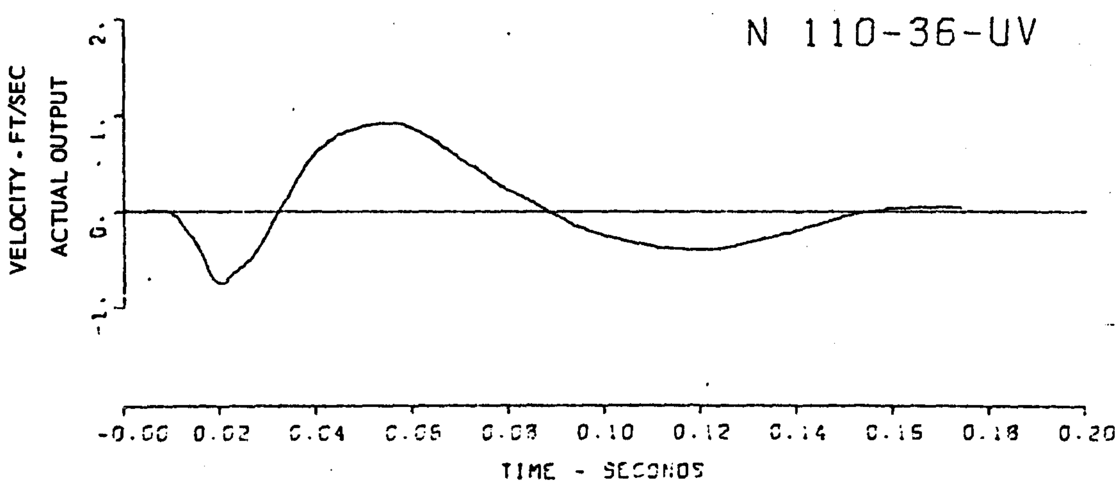
EXAMPLE SET 10

OPERATOR CHECKOUT



EXAMPLE SET 10

OPERATOR APPLICATION

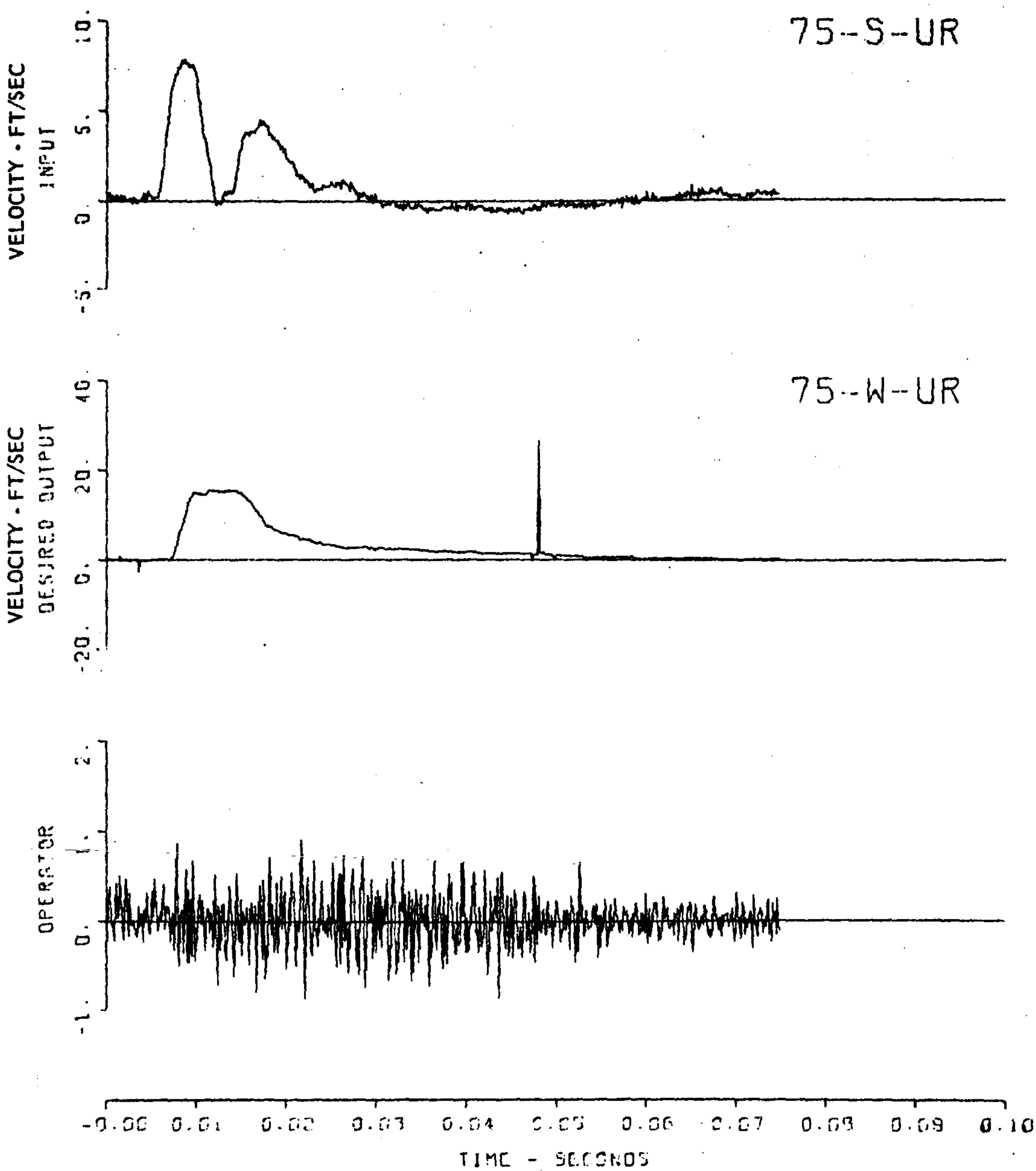


EXAMPLE SET 10

COMPARISON GAGE DATA

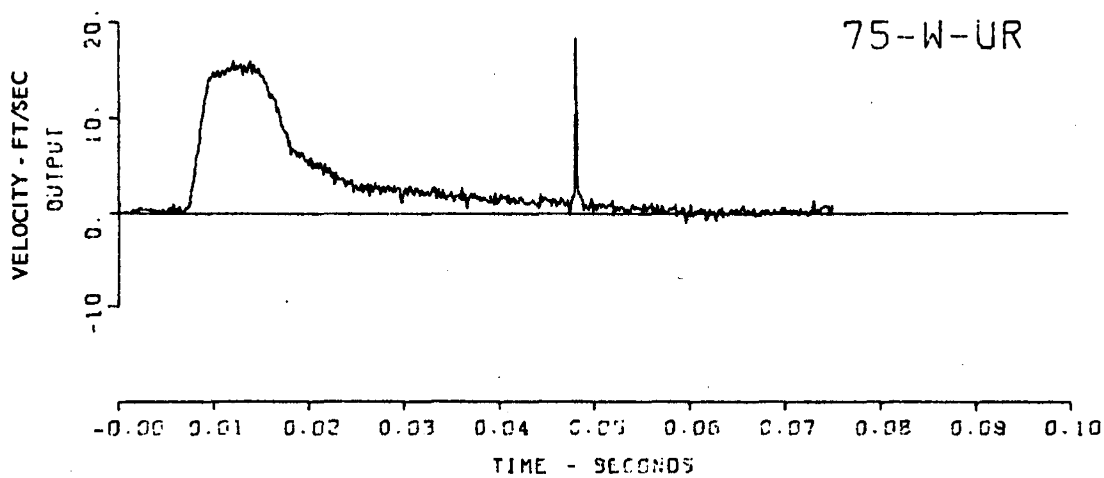
EXAMPLE SET 11 (GAGE SITE DIFFERENCE, SAME RANGES AND DEPTHS)

EVENT:	MINERAL LODE
GAGE TYPE:	VELOCITY
SAMPLING FREQUENCY:	8000 SAMPLES PER SECOND
PROBLEM SOLVING TIME:	9 MINUTES



EXAMPLE SET 11

OPERATOR CONSTRUCTION
(FROM RAW DATA)

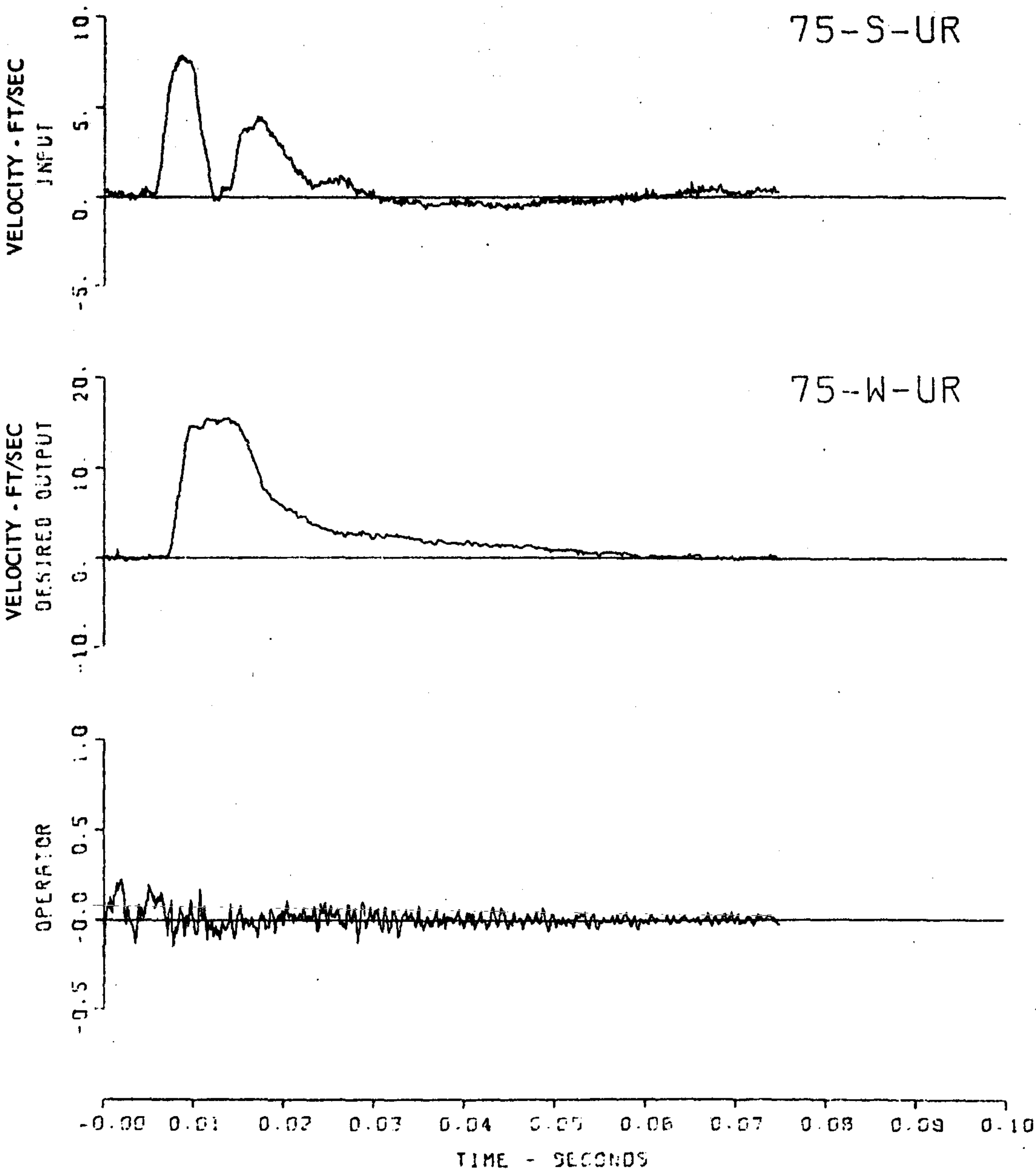


EXAMPLE SET 11

OPERATOR CHECKOUT

EXAMPLE SET 12 (EXAMPLE SET 11 WITH RANDOM SPIKES REMOVED FROM DATA)

EVENT:	MINERAL LODE
GAGE TYPE:	VELOCITY
SAMPLING FREQUENCY:	8000 SAMPLES PER SECOND
PROBLEM SOLVING TIME:	9 MINUTES

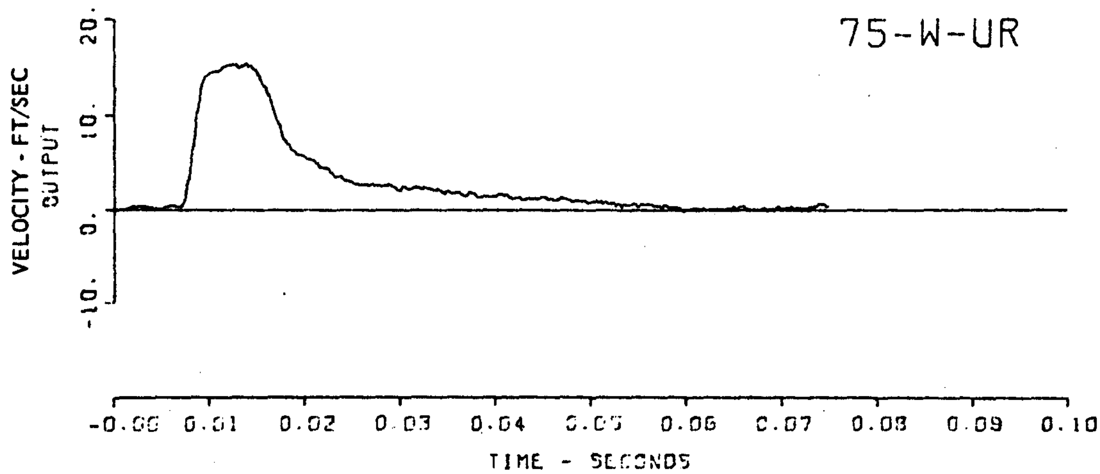


EXAMPLE SET 12

OPERATOR CONSTRUCTION

(AFTER SPIKE REMOVAL)

PLATE 32

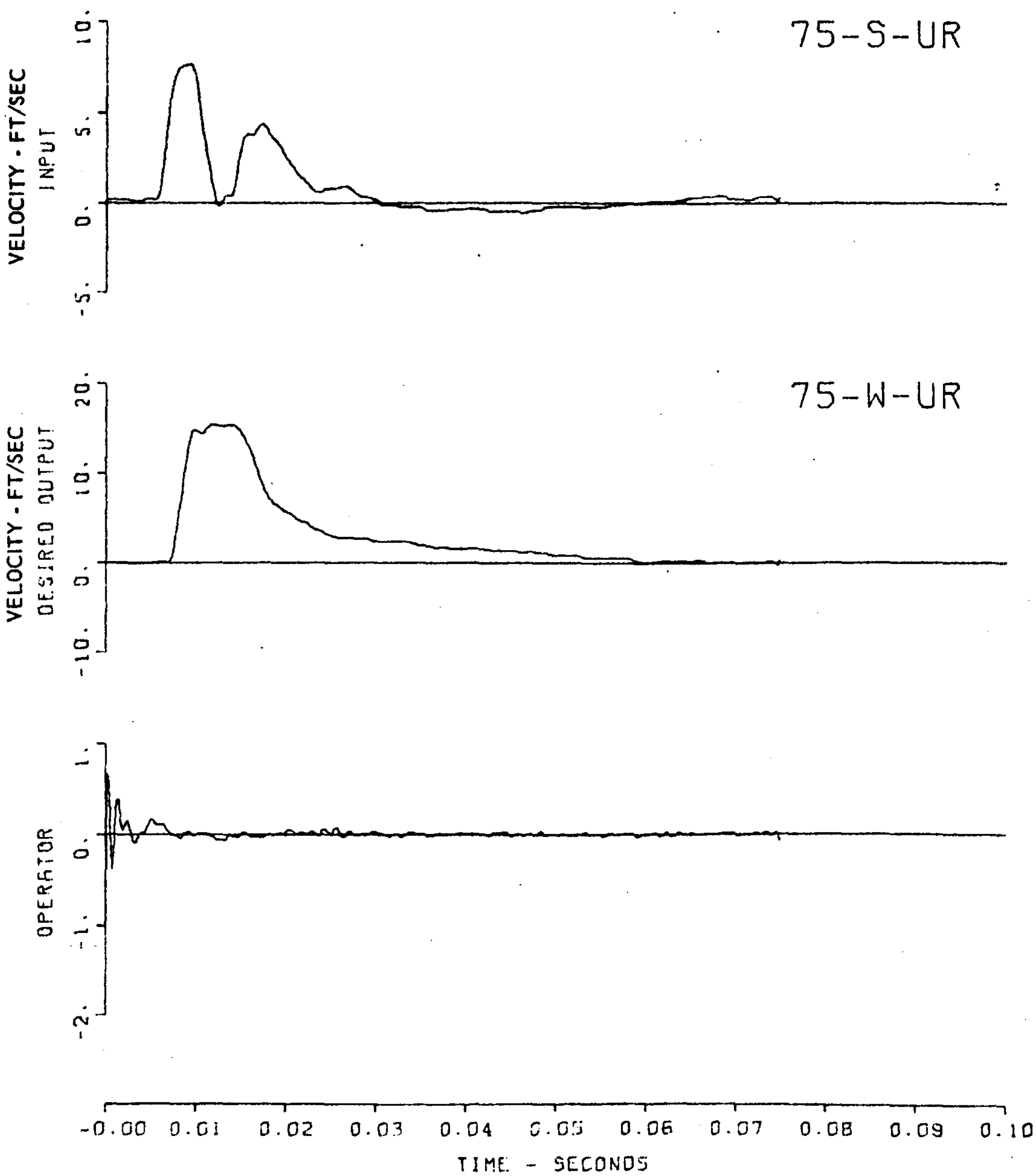


EXAMPLE SET 12

OPERATOR CHECKOUT

EXAMPLE SET 13 (EXAMPLE SET 12 WITH DATA LOW-PASS FILTERED)

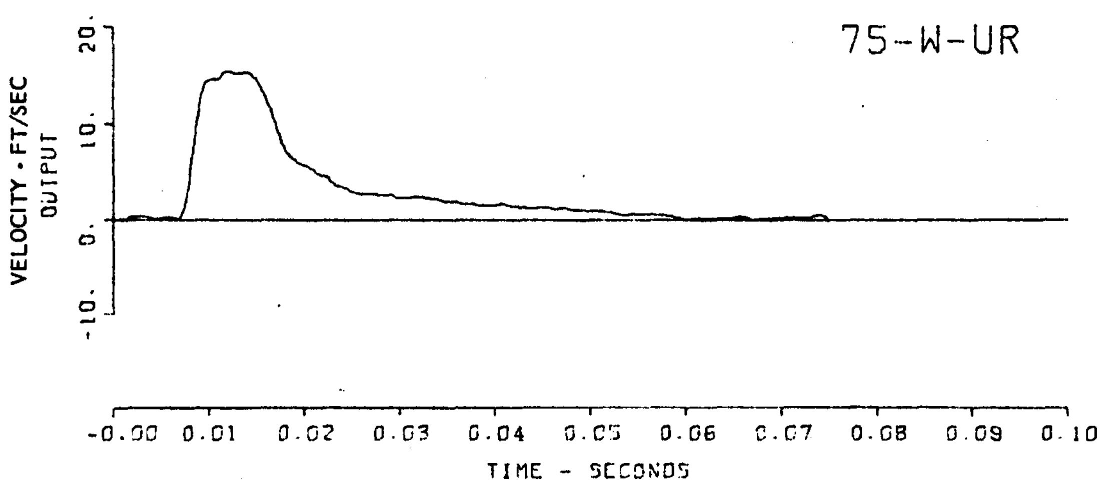
EVENT:	MINERAL LODE
GAGE TYPE:	VELOCITY
SAMPLING FREQUENCY:	8000 SAMPLES PER SECOND
PROBLEM SOLVING TIME:	9 MINUTES



EXAMPLE SET 13

OPERATOR CONSTRUCTION

(AFTER SPIKE REMOVAL AND LOW-PASS FILTERS)



EXAMPLE SET 13

OPERATOR CHECKOUT

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13. ABSTRACT

A Wiener filter is a mathematical operator designed to convert a given waveform (the filter's input) into another waveform (the filter's output) which is as similar as possible, in the least squares sense, to a third waveform (the desired output). Because filter theory might have application to the problems of explosion effects testing, a computer program has been developed to construct these operators for use in ground shock investigations. This report reviews convolution, crosscorrelation, and autocorrelation, the time domain operations which are basic to the Wiener technique, and shows by examples the operating characteristics of the program. It is concluded, on the basis of work seen during the development of the program, that digital filters may be used to define, accurately and economically, many important explosion effects relationships. Examples are included to demonstrate the fact that ground shock time histories may be estimated in uniform soil and rock using these operators to adjust for relatively large gage range and depth differences in the high pressure airblast region.

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