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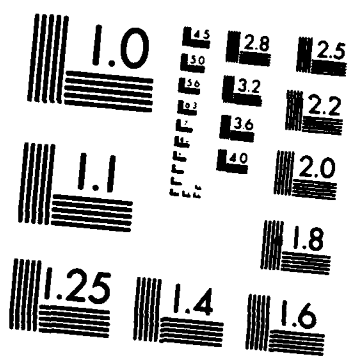

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A Report of Progress in

APPLICATION OF SIGNAL ANALYSIS AND PATTERN RECOGNITION PROCEDURES TO STUDY BLAST INDUCED GROUND MOTION

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Annual Scientific Report
February 1983 - February 1984

Sponsored by
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Air Force System Command
Bolling Air Force Base, DC 20332

March 1984

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFOSR-TR- 84-0581	2. GOVT ACCESSION NO. AD-A143744	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) APPLICATION OF SIGNAL ANALYSIS AND PATTERN RECOGNITION PROCEDURES TO STUDY BLAST INDUCED GROUND MOTION		5. TYPE OF REPORT & PERIOD COVERED Annual Scientific Report February 1983 - February 1984
		6. PERFORMING ORG. REPORT NUMBER TA7-27
7. AUTHOR(s) James M. Carson		8. CONTRACT OR GRANT NUMBER(s) AFOSR-82-0102
9. PERFORMING ORGANIZATION NAME AND ADDRESS New Mexico Engineering Research Institute University of New Mexico, Box 25, University Station, Albuquerque, New Mexico 87131		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2307/C1
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research /NA Air Force Systems Command Bolling Air Force Base, DC 20332		12. REPORT DATE March 1984
		13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

...ed for public release; ...bution unlimited.

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ground Motion
Signal Analysis
Pattern Recognition
Fisher Linear Discriminant
Frequency Domain
Spall
Cepstrum

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The second-year results of an effort to introduce computer automated signal analysis and pattern recognition procedures to the study of blast-induced ground motion is presented. Intermediate results involving the characterization of ground motion acceleration records to identify ground spall versus no spall regions is reported. A computerized procedure extracted information from the time, frequency, and cepstrum description of the signal. These signal features were then incorporated into a Fisher's

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Linear Discriminant (FLD) pattern recognition procedure. Procedures to identify good and bad features are reviewed. This identification seems to be required for the efficient and effective application of the FLD.

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I. INTRODUCTION

This report presents interim results and progress toward accomplishing project objectives. The principal objectives of this effort are

- To introduce pattern recognition techniques as an analysis tool to the civil engineering research area.
- To develop computer automated signal analysis procedures necessary to identify signal characteristics required in pattern recognition procedures.

Last year results of work on a problem involving the identification of unbermed versus bermed explosive events based on the analysis of ground motion accelerometer measurements was reported. The problem focus this year has been the identification of ground spall versus no spall regions using the same set of ground motion accelerometers. The spall phemomena has some interesting characteristics which produce a unique pattern recognition problem. In addition to describing progress on the spall identification problem, progress in the area of computer program development, signal feature extraction, and the identification of "good" features is reviewed.

Information regarding the personnel and technical interactions involved with this project is listed in Appendix A.

II. PROBLEM OVERVIEW

AFWL has conducted a series of explosive tests dubbed PRE-HYBRID GUST (PHG) to better define pore air pressure effects. When soil is subjected to an airblast environment a phenomenon of interest is the expansion of the soil due to higher air pressures in the soil pores than at the surface. Ground motion in influenced by explosive energy transmitted directly through the ground and indirectly through the air (air slap).

The first three PHG events involved 13.6-kg surface tangent spheres of C4 explosive. The next two events were the same except that the C4 explosive was bermed to reduce the airslap. Figure 1 shows the 14 horizontal and vertical accelerometer gage pairs placed at various ranges from the surface explosive and depths below the ground surface. These seventy sets of records were the basis for the ground spall/no spall identification problem. Problems in the data included noise and possible data inversion and are noted in Table 2 in the First Annual Report. Regardless of these data quality judgements, all the data was used in the spall/no spall pattern recognition study.

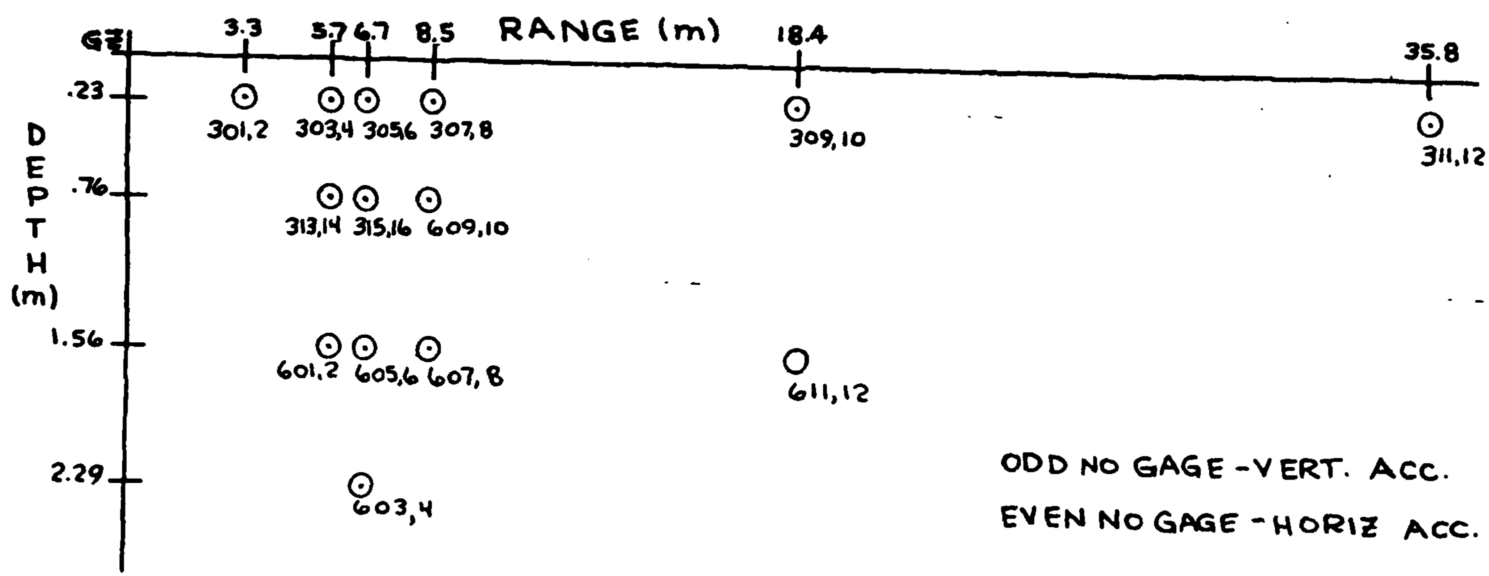

Figure 1. Accelerometer gage locations, PHG I: 1-5.

III. GROUND SPALL/NO SPALL PATTERN RECOGNITION PROBLEM

Stump and Reinke (1) of AFWL established the following criteria for the identification of spall in a waveform.

Primary Criteria

1. -1g (-0.5 to -2.0) vertical acceleration dwell (can also be identified by velocity slope).

2. Implusive rejoin record on all components (horizontal and vertical acceleration records).

3. No acceleration dwells on horizontal.

Secondary Criteria

4. Dwell times.

5. Amplitudes of rejoin.

They also note that classical explanations of spall may not be appropriate for alluvium. The following spall mechanisms were considered

- tensile wave from reflected/refracted arrival (classical mechanism).
- compression phemomena in alluvium (after Perret).
- spall from shear/Rayleigh waves.
- zero stress gradient
- pore air effects

Using the criteria defined by Stump and Reinke, Ake (2) examined the PHG I: 1-3 (no berm) and PHG I: 4-5 (berm) acceleration time and hodograph records and estimated the extent of spall. Figure 2 shows an acceleration record with an obvious indication of spall. Figure 3 shows the result of this visual pattern recognition procedure. A questionable nocation means that some but not all of the spall criteria held for a particular location. No mention was made of what procedure was used if the criteria was met for one test (eg. PHG I-1) and not another (eq. PHG I-2) in a set.

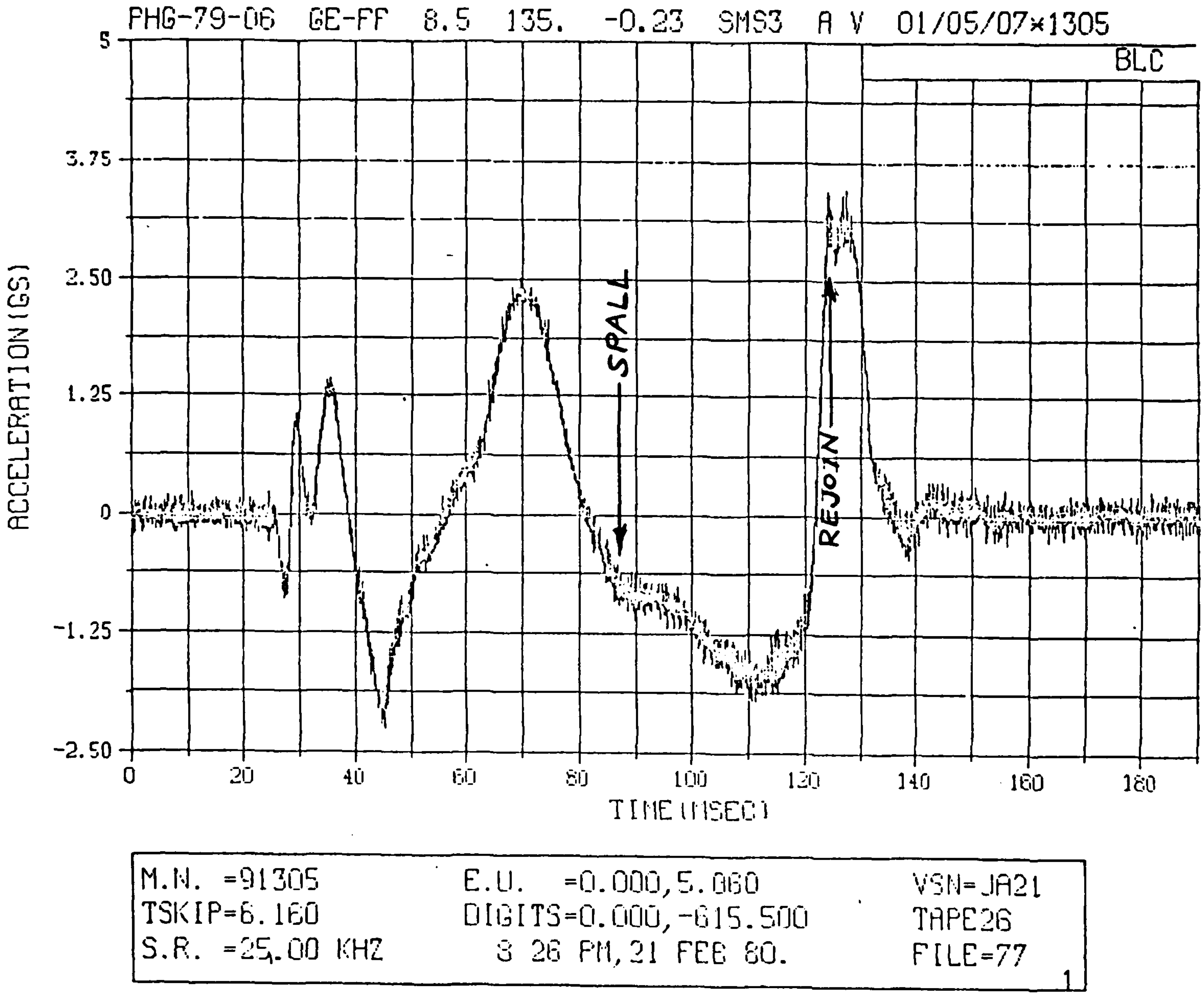

Figure 2. Vertical acceleration record clearly showing spall.

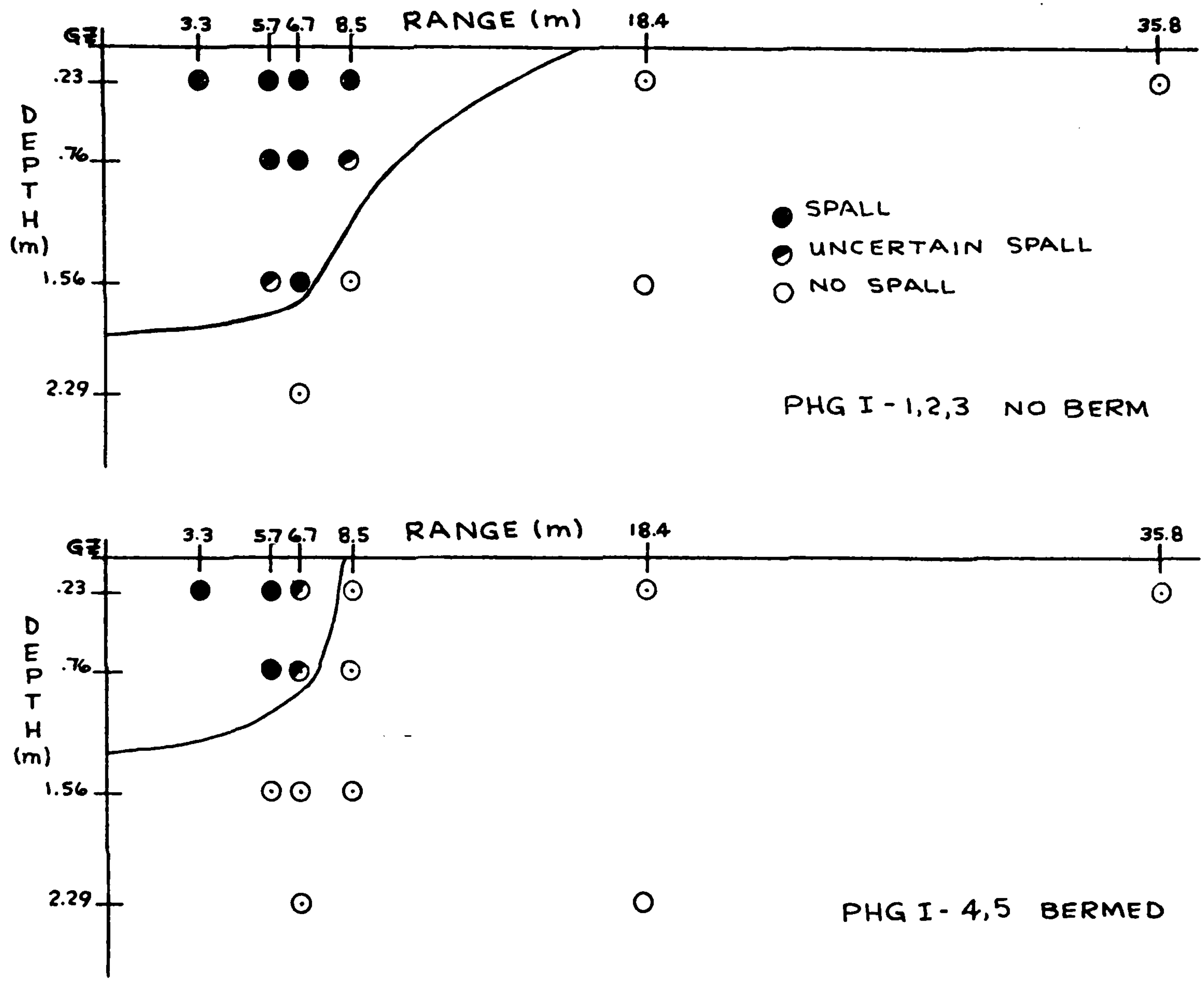

Figure 3. Ake spall/no spall boundary determination.

The spall/no spall pattern recognition problem is complicated by at least three factors.

1. There is no absolute "known" set of data for learning purposes since a post test soil trench analysis can not identify a spall plane. Thus the Ake analysis was used to help define learning and test sets. A grey zone around the Ake spall extent lines was defined as the test set and the more distant and presumely accurately identified gage locations was defined as the learning set. The results of this procedure are reviewed later under test results.

2. Other class distinctions exist within the data. For example, the explosive sources were bermed and unbermed and the sizes of the two berms used varied by 20%.

3. The "spall" phemomena may have multiple mechanisms and all mechanisms may not be present in all the data. The bermed experiments, for example, were designed to avoid air blast; thus the pore air spall mechanism would not be present. It should be noted that some acceleration records contain multiple dwell and rejoin regions.

TEST RESULTS

Two "grey" zones were defined as the unknown or test data sets. The smaller grey zone was correctly predicted 64% of the time and the larger grey zone was correctly predicted 62.9% of the time. The percent correct are with respect to the Ake visual estimate which can itself be in error. Figures 4 and 5 present the spall boundaries as defined by these pattern recognition procedures. The fact that these boundaries are smooth, as expected from physical considerations, is encouraging. The percentage correct is not encouraging since chance could produce similar percentage results.

A pattern recognition experiment was conducted in which all data was used in both the learning and test capacity. To some extent this procedure amounts to extended curve fitting. However, it does check that the data is self consistent and that the set of signal features used have some capacity to indentify the two classes. Also, examination of those classified incorrectly can help identify anomolous data (eg. gage locations 301 & 302, PHG-I-5) or locations in the grey zone that were possibly incorrectly identified by Ake.

This procedure classified 88.6% correct with respect to Ake's classifications. More importantly the classification was physically consistent as seen in Figure 6.

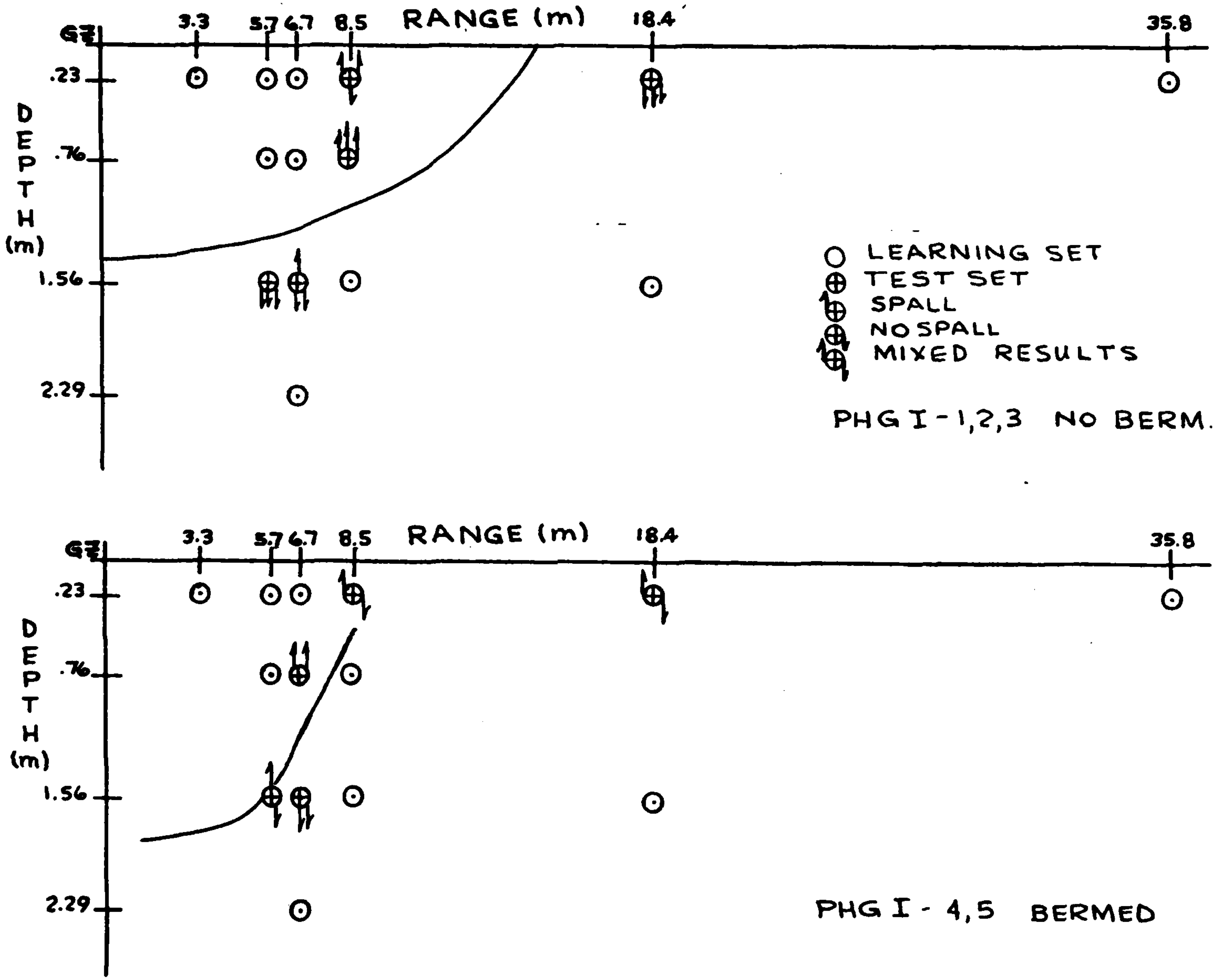

Figure 4. Spall/no spall boundary with small grey test area.

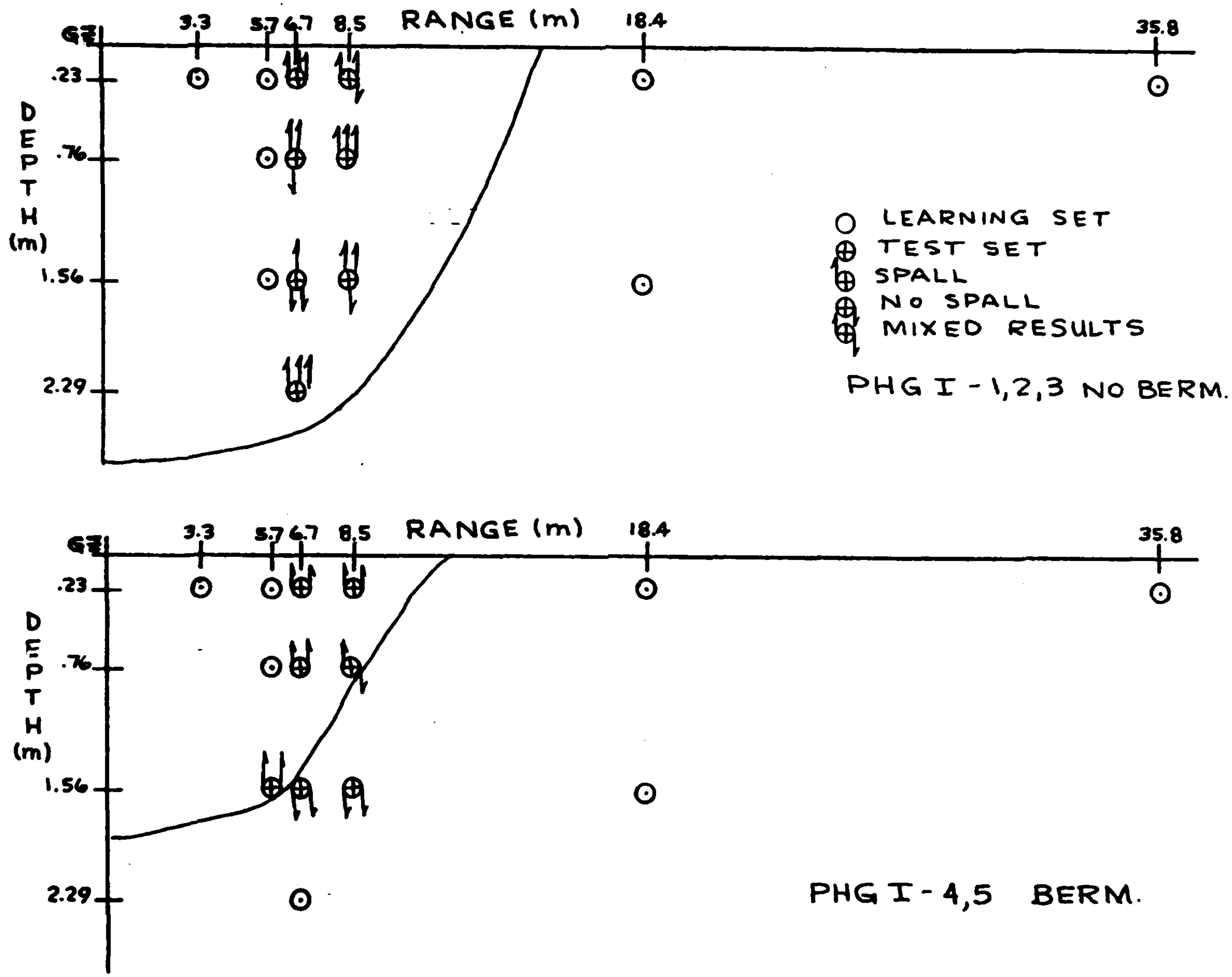

Figure 5. Spall/no spall boundary with large grey test area.

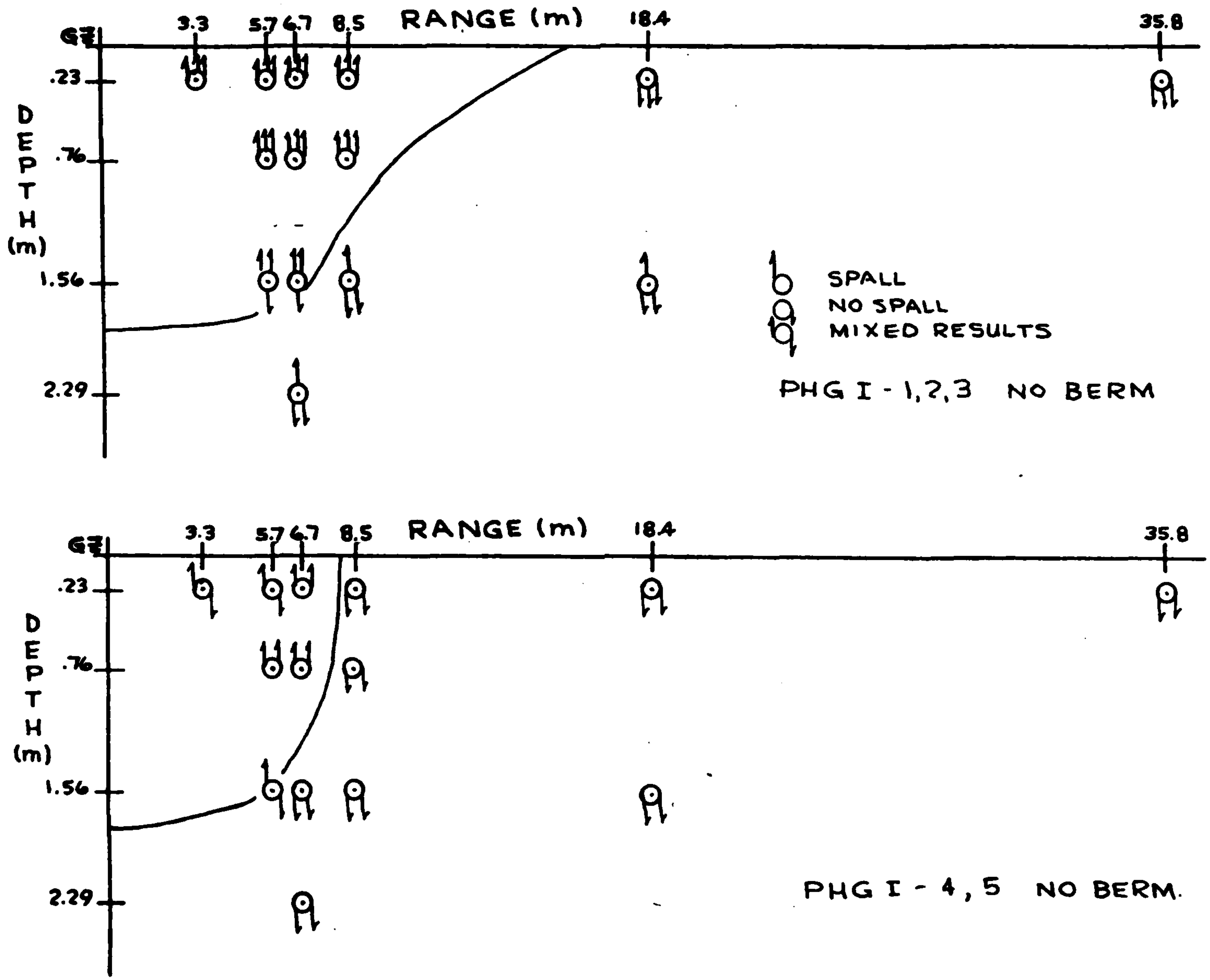

Figure 6. Spall/no spall boundary using all data in test set.

IV COMPUTER PROCEDURES AND FEATURE EXTRACTION

The concept of the signal processing and feature extraction remains the same as reported in the first annual report. However, the organization of the instrument and feature files has been changed to improve the processing capability and efficiency. Pattern recognition studies using various data and feature combinations are now significantly easier to run.

The total number of features that can be computer extracted from the time or transformed time signal is now thirty. For the studies performed to date the features from the horizontal and vertical accelerometers at a particular location were pooled. Thus sixty features are available for a particular study and any combination of these can be independently selected for a particular study.

Table 1 lists the features available. Note that features from the Cepstrum Transform, a transform useful in extracting the time between superimposed "echo" signals, have been added this year. The studies reported in this report used the 23 features from the time, frequency and cepstrum representations of the data marked by an asterisk in Table 1.

NO.	HORIZ/VERT	EXTRACTION SUBROUTINE	ID NO.	FEATURE DESCRIPTION
1	V	1	010	acceleration, time of arrival
2	V	2	020	acceleration, 1st. positive peak
3*	V	3	030	acceleration, 1st. negative peak
4	V	4	040	acceleration, maximum peak
5*	V	5	050	acceleration, time of maximum peak
6*	V	6	060	velocity, 1st positive peak
7*	V	7	070	velocity, 1st negative peak
8	H	1	510	acceleration, time of arrival
9*	H	2	520	acceleration, 1st positive peak
10*	H	3	530	acceleration, 1st negative peak
11	H	4	540	acceleration, maximum peak
12*	H	5	550	acceleration, time of maximum peak
13	H	6	560	velocity, 1st positive peak
14	H	7	570	velocity, 1st negative peak
15*	V	12	120	frequency, peak
16	V	14	140	frequency, power 0-100 HZ
17	V	14	141	frequency, power 100-200 HZ
18*	V	14	142	frequency, power 200-300 HZ
19*	V	14	143	frequency, power 300-400 HZ
20*	V	14	144	frequency, power 400-500 HZ
21*	V	14	145	frequency, power 500-600 HZ
22*	H	14	620	frequency, peak
23*	H	14	640	frequency, power 0-100 HZ
24	H	14	641	frequency, power 100-200 HZ
25*	H	14	642	frequency, power 200-300 HZ
26	H	14	643	frequency, power 300-400 HZ
27	H	14	644	frequency, power 400-500 HZ
28	H	14	645	frequency, power 500-600 HZ
29	V	18	180	cepstrum, time of 1st peak
30	V	18	181	cepstrum, time of 2nd peak

Table 1. List of features.

List of features (continued)

NO.	HORIZ/VERT	EXTRACTION SUBROUTINE	ID NO.	FEATURE DESCRIPTION
31	V	18	182	cepstrum, time of 3rd peak
32	V	18	183	cepstrum, time of 1st largest peak
33	V	18	184	cepstrum, time of 2nd largest peak
34	V	18	185	cepstrum, time of 3rd largest peak
35	V	19	190	cepstrum, 180-181
36	V	19	191	cepstrum, 181-182
37	V	19	192	cepstrum, 182-180
38*	V	19	193	cepstrum, 183-184
39	V	19	194	cepstrum, 184-185
40*	V	19	195	cepstrum, 185-183
41	V	18	680	cepstrum, time of 1st peak
42	H	18	681	cepstrum, time of 2nd peak
43	H	18	681	cepstrum, time of 3rd peak
44*	H	18	683	cepstrum, time of 1st largest peak
45	H	18	684	cepstrum, time of 2nd largest peak
46	H	18	685	cepstrum, time of 3rd largest peak
47	H	19	690	cepstrum, 680-681
48	H	19	691	cepstrum, 681-682
49	H	19	692	cepstrum, 682-680
50*	H	19	693	cepstrum, 683-684
51	H	19	694	cepstrum, 684-685
52*	H	19	695	cepstrum, 685-683
53*	V	8	080	velocity, peak
54	V	9	090	velocity, time of peak
55*	V	10	100	displacement, peak
56	V	11	110	displacement, time of peak
57	H	8	580	velocity, peak
58	H	9	590	velocity, time of peak
59*	H	10	600	displacement, peak
60	H	11	610	displacement, time of peak

V. FEATURE EVALUATION

A fundamental problem of the Fisher Linear Disciminant (FLD) pattern recognition procedure involves the matrix inversion operation. When the number of features exceeds the number of learning records a singular matrix may result. Since the number of learning data records was limited the number of features used in a particular study also had to be limited. Elimination of poor performing or the identification of good features was also a recognized requirement from an efficiency viewpoint. A short study also indicated that the elimination of a poor feature can improve the performance of remaining features. This result was not expected and to date is not understood. This fact has not appeared in surveyed literature and will receive further attention.

The following procedures are being used to evaluate features

1. Feature probability density functions (Figure 7) which show the feature value distribution for the two classes of interest.

2. Feature statistical variables including mean, variance and weighted variance.

3. Feature weighting factors from the FLD. These weighting factors project the feature to the Fisher Line and bear some relation to the statistical parameters mentioned in 2.

4. FLD results using one feature at a time.

These procedures can also be used to evaluate nonlinear combinations of features, however this has not yet been done.

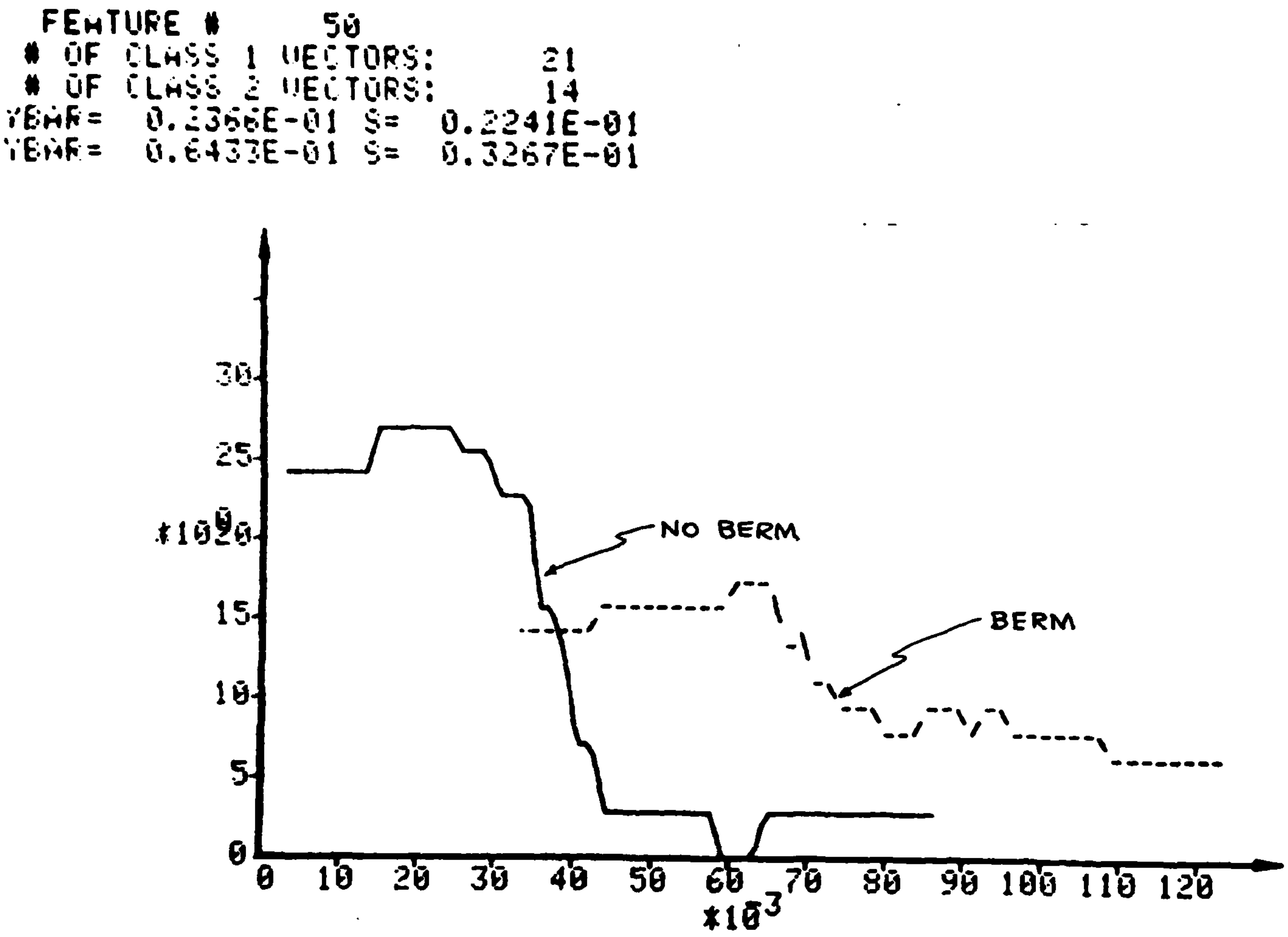

Figure 7. Probability density function (PDF) for acceleration, time of maximum peak feature, bermed/no berm problem.

VI CONCLUSIONS AND RECOMMENDATIONS

Problems involving berm/no berm and spall/no spall have been addressed. The berm/no berm problem was successfully solved the first year. The spall/no spall problem was attacked with more limited success the second year. Refinements in the computer procedures allow a variety of problems to be more efficiently attached.

The follow-on work will be aimed at addressing the nuclear/non nuclear classification problem. In addition, the berm/no berm and spall/no spall data bases will be used to continue some of the efforts described in this report. Specifically, the following work areas will be pursued or continued

1. Continue to investigate means to identify good and bad features.

2. Investigate the interaction of features, and the usefulness of nonlinear features.

3. Examine the unexplained detrimental effect of a bad feature on the other features used in the FLD and the operation of the FLD in this situation.

References

1. Stump, B.W. and Reinke, R.E., Spall-Like Waveforms Observed in High-Explosive Testing in Alluvium, AFWL-TR-82-15, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, 1982.

2. Ake, J., Spall, NMERI unpublished report.

Appendix A

Personnel and Technical Interactions

This appendix presents specific information required in the Annual Scientific Report as specified in Administration of U.S. Air Force Grants and Cooperative Agreements for Basic Research. Item numbers used here match content numbers on page 16 of the administration guide.

4. Journal publications - None.

5. Professional personnel associated with research:

   Dr. James Carson - Principal Investigator, February 1982 to present.

   Mr. Eloy Gonzales - Analyst/Programmer, June 1982 to present. Mr. Gonzales left NMERI in March 1984 to accept other employment. A replacement has not yet been identified.

6. Interactions:

   a. Continuing discussions have been held with Dr. T. Ross and Dr. R. Reinke, AFWL, regarding spallation, pattern recognition, fuzzy sets, and the transfer of the techniques developed under this grant to AFWL use.

   b. Dr. Carson attended a Continuing Education Institute short course, "Optimal Deconvolution - An Estimation Based Approach", by Dr. Jerry Mendel, August 1-5, 1983. Since then Dr. Mendel and Dr. Carson have been in communication regarding applications to AFWL efforts. While it is unlikely that Mendel's deconvolution techniques will be applied to the AFOSR sponsored research, they can be combined in follow-on efforts. It appears that Mendels techniques can be a powerful data preprocessor for pattern recognition procedures as well as being independently useful.

7. New discoveries - Some of the FLD characteristics are potentially new. Following some further research in this area a technical publication may be warranted.

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