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SITE CHARACTERIZATION FOR PROBABILISTIC GROUND SHOCK PREDICTIONS

by

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

Dynamic in-situ compressibility tests	Site characterization
MX horizontal shelters	Soil compressibility
Nevada-Utah siting area	Vertical particle velocity
Probabilistic ground shock predictions	Vertical rattlespace

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

The codes that are currently used to calculate explosive-produced ground shock environments are deterministic tools; i.e., their input parameters are specified as single-valued "representative" quantities. This procedure, which inherently assumes that the calculated ground shock output will be mean-valued "best estimates," is questionable since many of these input parameters (such as the earth material properties and the applied blast loading characteristics)

(Continued)

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20. ABSTRACT (Continued)

are random variables. Thus the resulting state of stress and ground motion are also random variables, and the ground shock calculation problem should be treated probabilistically.

A probabilistic methodology is described for determining the statistical distribution of vertical rattlespace required for MX multiple protective shelters sited within the alluvial valleys of central Nevada and eastern Utah. The approach involves (a) identifying the critical ground motion parameters and the input quantities which dominate their calculation, (b) conducting field and laboratory investigations to define the statistical variation of these quantities within the siting area, and (c) performing ground motion calculations with a probabilistic wave propagation code. Calculations for the high-explosive Dynamic In-Situ Compressibility (DISC) tests conducted in Ralston Valley, Nevada, are used to illustrate the probabilistic methodology.

PREFACE

This paper was prepared to document a presentation given during Session III--Cratering, Ejecta, Ground Shock--of the Defense Nuclear Agency (DNA) Strategic Structures Division Review Conference held at SRI International, Menlo Park, California, on 4-6 May 1982.

The purpose of the presentation was to outline the site characterization methodology developed for DNA in support of the Air Force MX Multiple Protective Shelter program and to illustrate some recently developed probabilistic ground shock prediction and analysis tools. The presentation was prepared by Dr. J. G. Jackson, Jr., and his associates in the Geomechanics Division of the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES).

Mr. Bryant Mather was Chief of SL during the preparation of this paper. The Commander and Director of WES was COL Tilford C. Creel, CE, and the Technical Director was Mr. F. R. Brown.

CONTENTS

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

Non-SI units of measurement used in this paper can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	0.0254	meters
pounds (mass)	0.45359237	kilograms
square miles (U. S. statute)	2.589998	square kilometers

SITE CHARACTERIZATION FOR PROBABILISTIC GROUND SHOCK PREDICTIONS

Viewgraph 1

The codes that we currently use to calculate explosive-produced ground shock environments are deterministic tools; i.e., their input parameters are specified as single-valued quantities. But in reality, much of this input--such as the earth material properties and the applied blast loading characteristics--are random variables, which means that the resulting state of stress and ground motion are also random variables. Thus, the ground shock calculation problem should be treated probabilistically.

There is nothing new about that conclusion--a probabilistic approach to ground shock prediction has long been recognized as the ideal way to go. But it took the ill-fated MX Multiple Protective Shelter (MPS) concept to convince us that it is the only way to go.

Viewgraph 2

Geologic profile and soil property estimates related to our land-based ICBM systems are usually provided on a site-specific basis. Titan involved only 18 sites within each of three relatively compact deployment areas. Site-by-site characterization for Minuteman was much more difficult--involving 150 to 200 sites in each of six areas--but it was still manageable. But when the Air Force proposed playing a "shell game" with 4600 shelters scattered over an 8000- to 9000-square-mile* area of Nevada and Utah, a probabilistic approach was no longer nice--it was absolutely necessary.

Viewgraph 3

The Nevada-Utah siting area for MX/MPS consisted of 47 alluvial valleys of the Basin and Range physiographic province. Soil deposits that result from similar geologic processes and have similar composition (such as density, water content, and gradation) generally have similar engineering properties (such as compressibility and shear strength). So our site characterization approach was to quantify the variability of the key ground shock-relevant geotechnical properties within one of these valleys and then statistically correlate the results with parameters which could readily be measured in the other 46 valleys.

The question then was "What are the key ground shock-relevant geotechnical properties?" The answer, of course, depends on the designer's problem!

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Viewgraph 4

BMO said that the amount of vertical rattlespace--defined as the maximum relative displacement between the shelter and a free-falling missile--was a major cost driver, and wanted a statistical distribution of this requirement for the Nevada-Utah area. Rigid-body motion of the horizontal MX shelter can be approximated by the free-field vertical ground motion at the invert depth, which is dominated by the airslap impulse and the uniaxial strain compressibility of the dry alluvial soil above the first major reflector--usually either the groundwater table or bedrock. But groundwater tables and bedrock can be quite deep in the Nevada-Utah valleys, so determining the compressibility of all of the dry alluvium in them would still have been quite a job. We were fortunate, however, in that a series of sensitivity calculations showed that vertical rattlespace for the MX horizontal shelter problem was unaffected by anything below a depth of 150 feet.

With the above as a background, we developed a program to address the rattlespace issue.

Viewgraph 5

The time driver for the program was the date required for B-4 Specifications to support design of the horizontal shelter. There were three parts to the program--(1) a detailed study of soil compressibility in Ralston Valley, Nevada, (2) two large high-explosive Dynamic In Situ Compressibility (or DISC) tests in Ralston Valley, and (3) acquisition of seismic velocity and other geotechnical data from eight valleys that were statistically distributed across the siting area.

Viewgraph 6

The Ralston Valley Soil Compressibility Study was a statistical study of one valley to generate baseline data applicable to other geologically-similar valleys. With the assistance of Professor Erik Vanmarcke of MIT, a probabilistic sampling and testing program was designed (Reference 1) to define the valley-wide variation of uniaxial strain compressibility to a depth of 150 feet--and if possible, to correlate compressibility with data that were either already available or could readily be obtained (such as the P-wave velocities from seismic refraction surveys).

Viewgraph 7

Fugro National, Inc. (now Ertec Western, Inc.) defined the suitable siting area for Ralston Valley (Reference 2). Within this area we obtained soil samples and seismic velocity data from four widely-spaced borings at each of 17 locations; at two of these locations, additional soil samples and seismic P-wave data were obtained from a large number of closely-spaced borings (References 3-5). And we conducted DISC tests at 2 of the 17 sites (References 6 and 7).

Viewgraph 8

This viewgraph shows the random variation in static uniaxial strain results from 16 tests conducted on samples from one site--the samples were all extracted from the upper 6 meters from 12 borings that were all drilled within a 6-meter radius (Reference 8). There is substantial variation in the loading data, but very little in the unloading data.

Viewgraph 9

Dynamic uniaxial strain tests were conducted with rise-times to 8 MPa ranging between 3 and 4 msec.

This viewgraph shows the depth-biased variation in dynamic uniaxial strain from eight tests conducted on samples from six different sites--these samples were extracted at 6-meter intervals from a depth of 3 meters down to 46 meters (Reference 8).

Results from over 350 uniaxial strain tests were digitized and stored in a computer data bank along with all the seismic velocity, density, and gradation data (Reference 9). Statistical correlation analyses were then performed.

Viewgraph 10

This viewgraph illustrates the statistical correlation we developed between seismic P-wave velocity and dynamic laboratory compressibility. Given only a seismic velocity and a density, the program computes seismic compressibility and then predicts dynamic lab compressibility. The value of dynamic lab compressibility expected between 1.5 and 5.9 meters at the DISC Test I site is shown with a 90 percent confidence interval.

But what we want to predict is not seismic compressibility or dynamic lab compressibility, but dynamic in-situ compressibility--to do that, we needed the DISC tests.

Viewgraph 11

The DISC test surface loading was produced by a circular explosive charge designed by AFWL--15,000 lbs of Iremite was placed in a 90-foot-diameter cavity and confined by a 10-foot-high soil berm. Ground motions were measured by a double array of accelerometers placed at preselected intervals to a depth of 15 meters. A state of uniaxial strain was produced in the ground to a depth of about 6 meters; lateral restraint on the gages below 6 meters was reduced by relief waves from the cavity edge.

Viewgraph 12

This photograph shows the circular foam-HEST charge being laid out for center detonation.

Viewgraph 13

This photograph shows the soil berm being constructed to confine the charge.

Viewgraph 14

If you have seen one, you have seen them all!

Viewgraph 15

This is a composite plot showing the rise portions of the particle velocity waveforms that were measured in the upper 6 meters of DISC Test I. Wave speeds for different particle velocity amplitudes were computed for each depth interval and one-dimensional plane wave theory used to deduce stress-strain relations.

Viewgraph 16

The average in-situ stress-strain relation that was deduced from the 0- to 6-meter particle velocity wavefront measurements is plotted in this viewgraph for comparison with the seismic and dynamic lab compressibilities that were previously shown in Viewgraph 10.

Now I plan to illustrate some recently developed probabilistic analysis tools by using the DISC Test I data to make a probabilistic ground shock prediction for DISC Test II. We assumed in-situ compressibility in the upper 6 meters of Ralston Valley to be a random variable--and since the curve deduced from the DISC Test I particle velocities is the only dynamic in-situ compressibility relation for Ralston Valley, we assumed it to be the mean relation.

Viewgraph 17

We then used coefficients of variation computed from the lab uniaxial strain loading data to derive standard deviation bounds for the in-situ uniaxial strain loading relation. As previously shown, there was very little variation in the lab unloading stress-strain data, so we used a constant unloading relation in the probabilistic calculations. Soil density was also input as a constant, since its coefficient of variation was only about 5 percent.

There were only two random variables in the calculations--the in-situ compressibility relation and the airblast loading function. The explosive charge design for DISC Test II was identical to that for DISC

Test I, so we used the DISC Test I data to define airblast variability for the DISC Test II predictions.

Viewgraph 18

This viewgraph shows the nine blast pressure measurements for DISC Test I. But it is the airblast impulse that primarily affects particle velocity at depth, so we statistically analyzed the nine impulse plots obtained by integrating the DISC Test I blast pressure measurements--

Viewgraph 19

and produced this mean impulse function and its standard deviation bounds. Airblast pressure drivers for the probabilistic 1D calculations were then obtained by differentiation.

We have two probabilistic analysis codes--one is based on the method of partial derivatives described by Benjamin & Cornell (Reference 10); the other uses a point-estimate method published by Rosenblueth in 1975 (Reference 11). When there are n uncorrelated random variables, both methods require 2n+1 deterministic calculations; since our problem had two independent variables, five 1D calculations were required. We used both methods and obtained essentially identical results.

Viewgraph 20

This viewgraph shows our prediction of particle velocity at the 3-meter depth for DISC Test II. The solid line is the expected value obtained from the probabilistic analysis. The dashed-line result was obtained from a 1D calculation in which mean values were used for all input variables--and is akin to the "best estimate" we would obtain using "representative" properties for input. While in this case the difference is small, it does illustrate the fact that simply using average or mean input does not necessarily lead to the most probable solution.

But a probabilistic analysis does a lot more than just provide expected values--it also provides information about uncertainties.

Viewgraph 21

This viewgraph shows the coefficient of variation associated with the expected value--or the uncertainty of the output due to the combined uncertainties of the input. It also shows--as a percentage--the relative contribution of each input uncertainty to the overall output uncertainty.

Note that the largest uncertainties are associated with the rise portion of the particle velocity waveform and are due almost entirely to uncertainty in soil compressibility--uncertainty in the airblast impulse has very little effect on rise time. But as time goes on, the airblast impulse contribution steadily increases while the soil compressibility contribution steadily decreases--and it should decrease, because compressibility during unloading was a constant and not a random variable.

Viewgraph 22

This viewgraph shows our DISC Test II prediction compared with the DISC Test II data. The comparison looks pretty good to me, but then beauty is in the eye of the beholder--which leads me to say that we have long needed a less subjective (or prejudiced) way of assessing the degree of agreement or disagreement between computational and experimental results. That is by no means an original conclusion, i.e., at the last one of these conferences (in 1979) Tom Geers of Lockheed Palo Alto said precisely the same thing during an underwater shock session.

Geers suggested an objective method for computing relative differences (or errors) both in magnitude and in phase-and-frequency between two transient response histories (Reference 12). We picked up on it and used it to compare each of the three measured DISC Test II waveforms to the calculated waveform.

Viewgraph 23

This viewgraph shows the magnitude errors and the phase-and-frequency errors computed for each of the three measured waveforms. The errors associated with two of these waveforms are small and essentially identical. They appear to be somewhat larger for the dashed line, but that is really only true during the initial 2- to 3-msec toe (or precursor).

Viewgraph 24

We also compared the mean of the three DISC Test II measurements with the calculated expected value. The magnitude error has a plus-and-minus oscillation during the rise portion and then settles on a value of about minus 10 percent. The phase-and-frequency error is essentially zero.

Viewgraph 25

And finally, for the rattlespace calculations, we were interested in when things started moving at the 3-meter depth, not when the airblast initially loaded the ground surface--so we replotted the expected value of particle velocity in terms of time minus arrival time at 3 meters. We then produced the probabilistic ground shock product of primary interest to all system designers, i.e., confidence intervals about the expected value.

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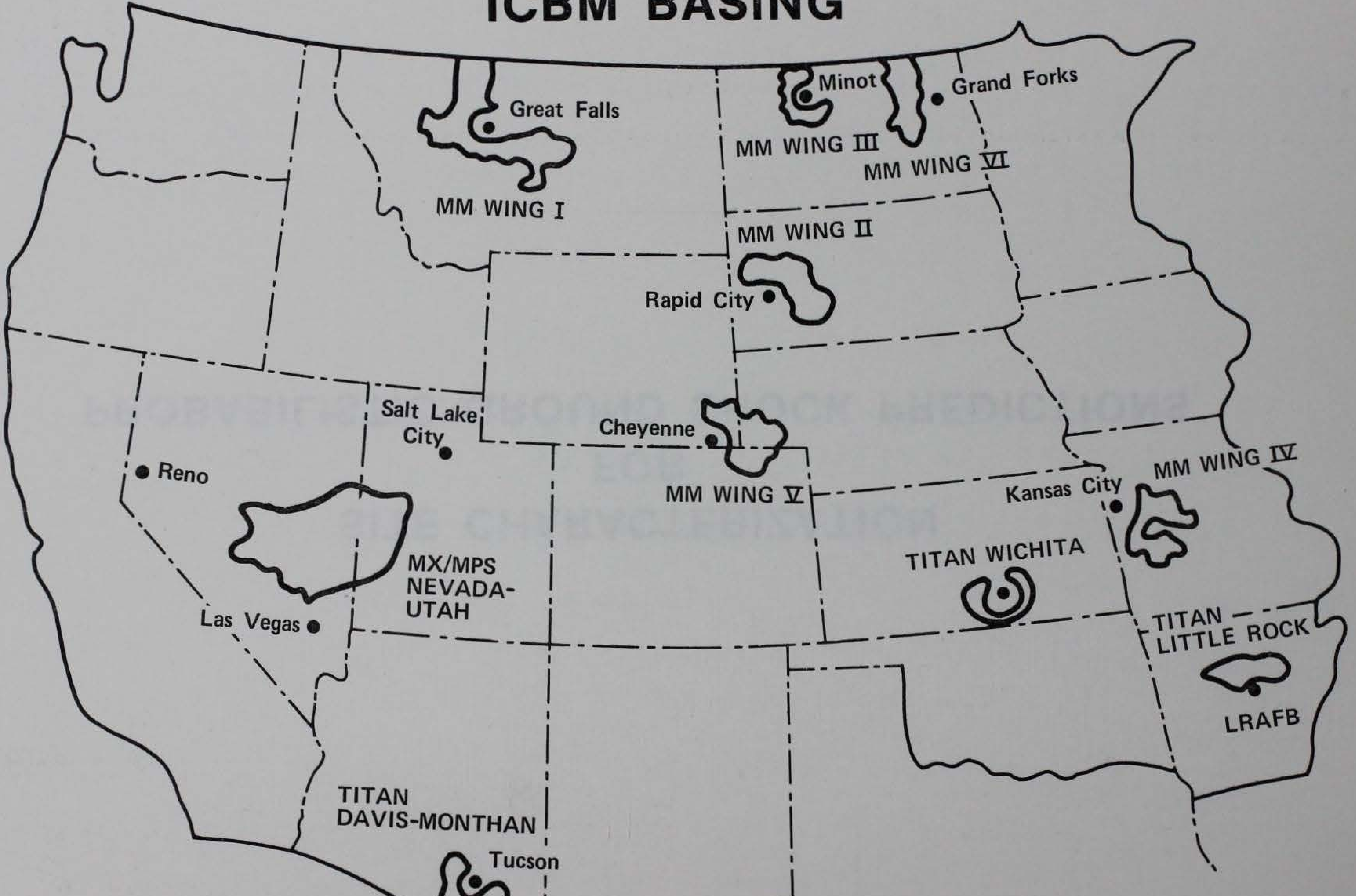
SITE CHARACTERIZATION
FOR
PROBABILISTIC GROUND SHOCK PREDICTIONS

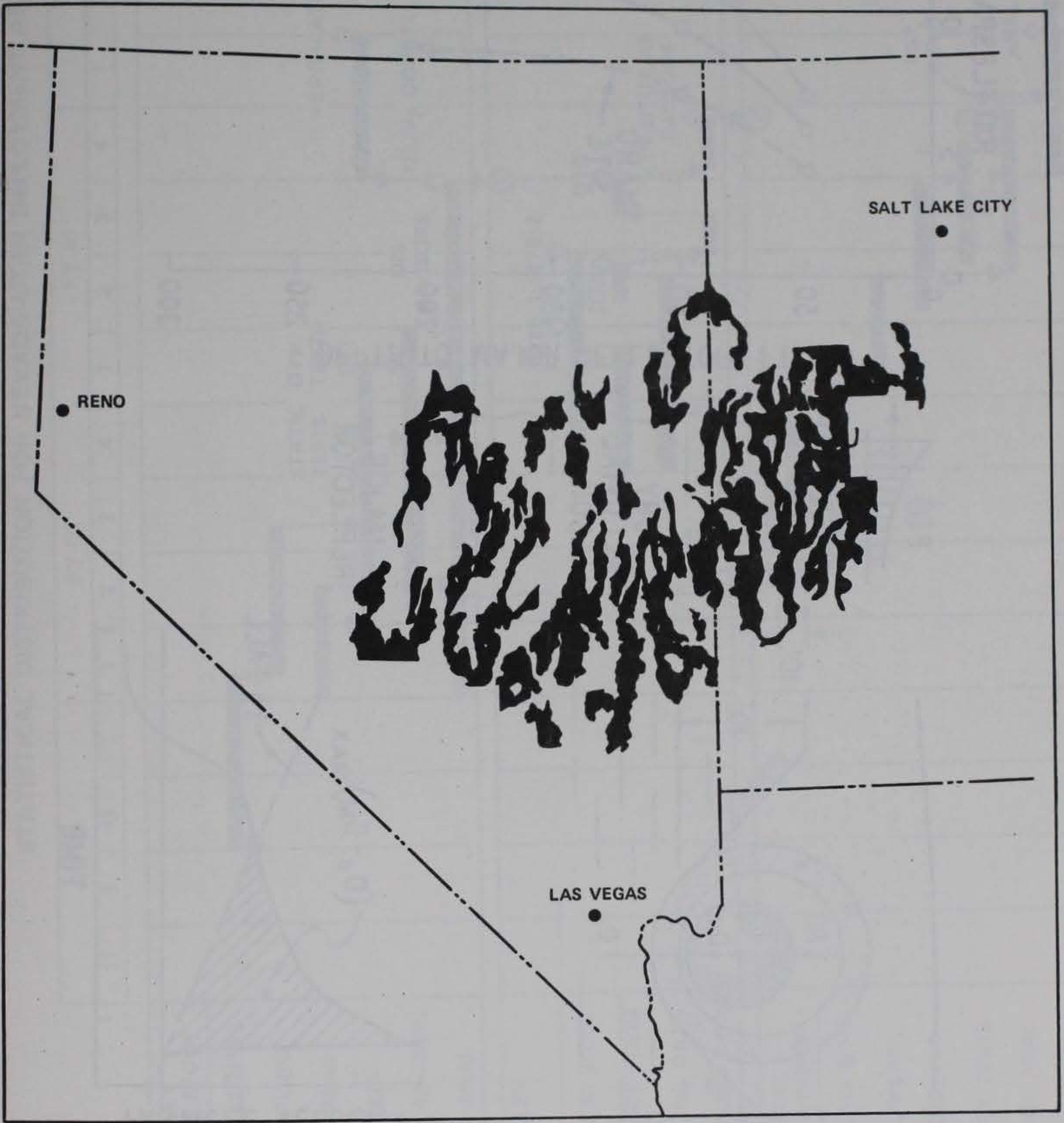
VIEWGRAPH 1

VIEWGRAPH 2

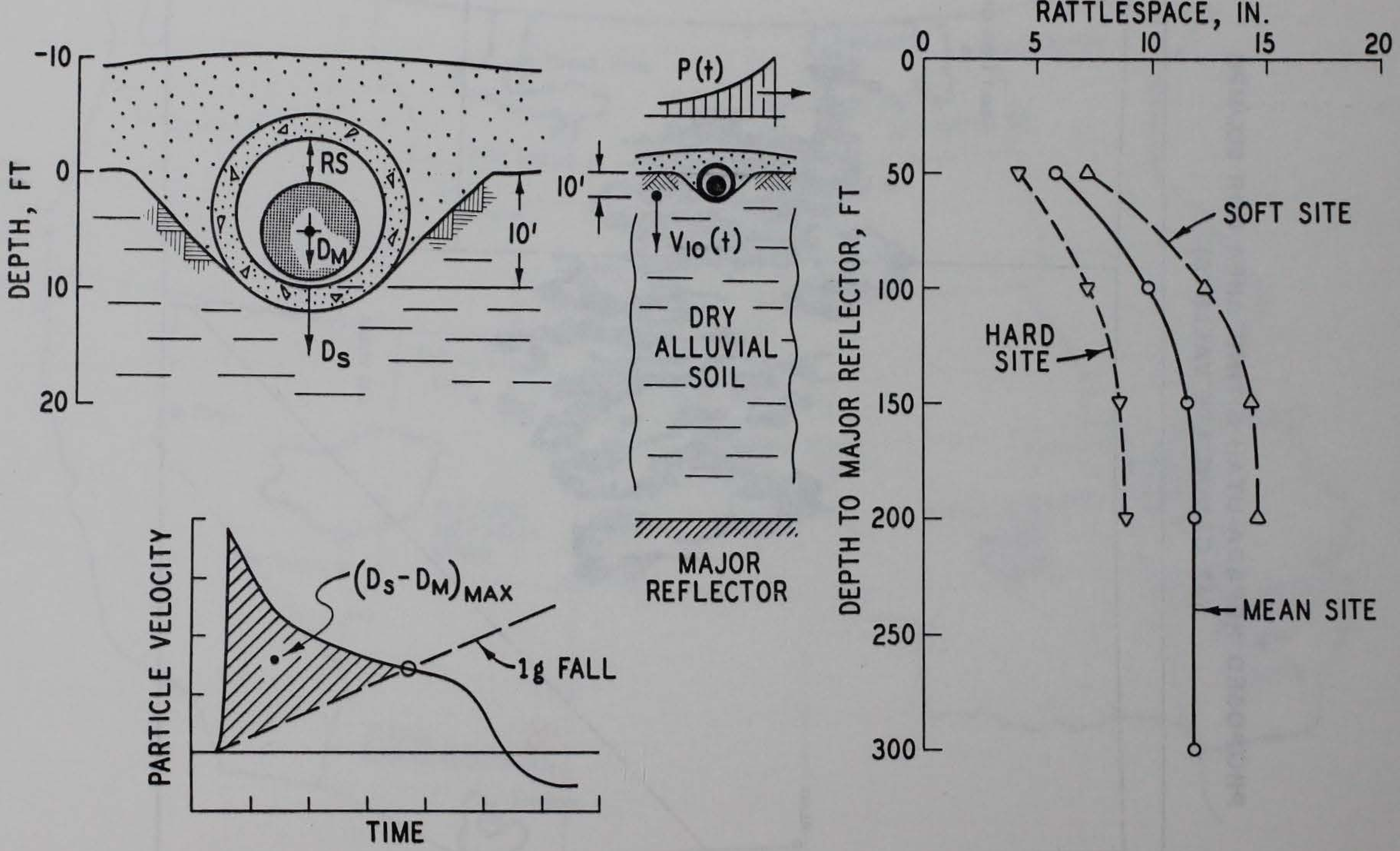
ICBM BASING



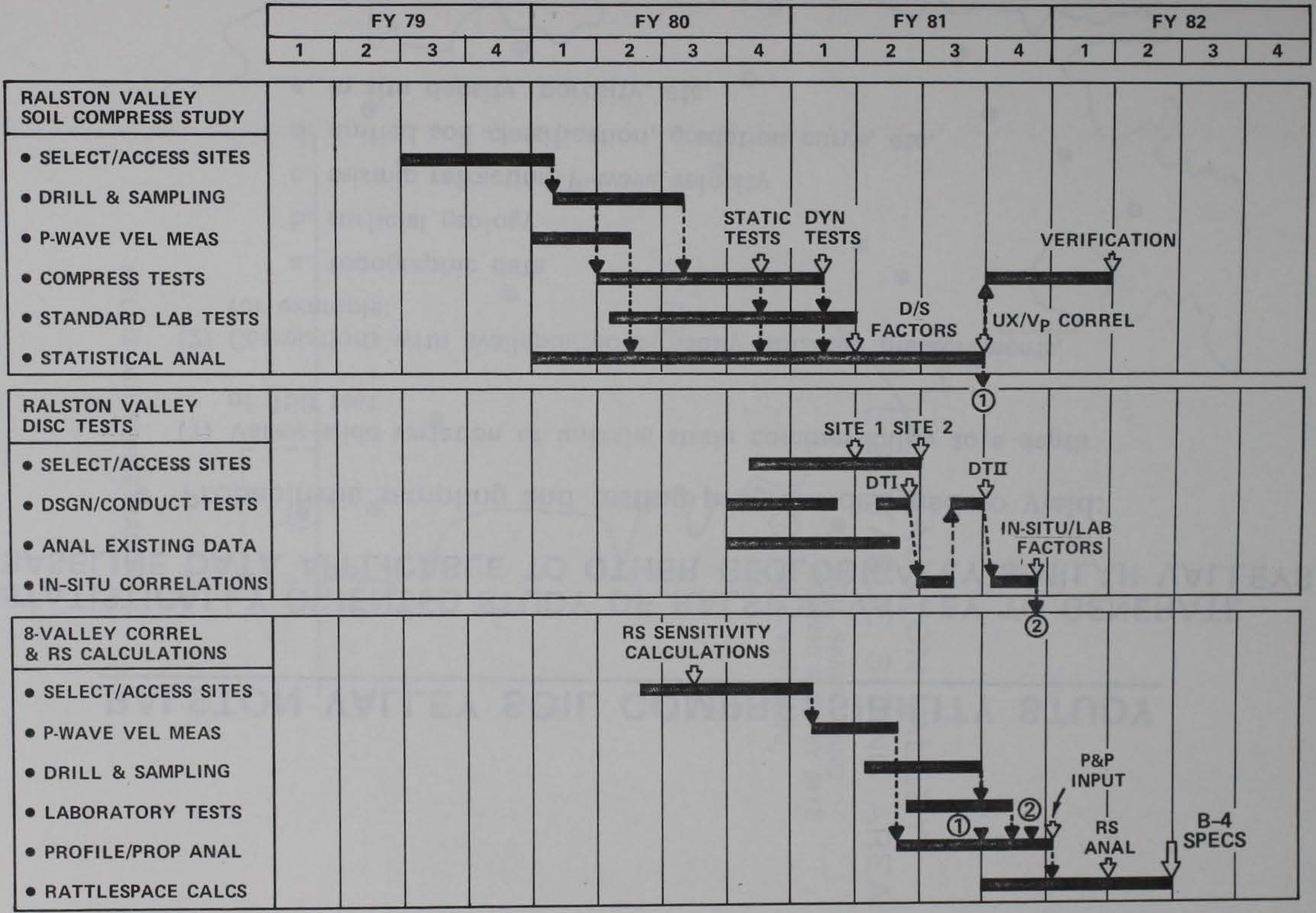
PROPOSED NEVADA-UTAH SITING AREA FOR MX/MPS (47 CANDIDATE VALLEYS)



VIEWGRAPH 4


-10
0
10
20
DEPTH, FT
RS
D_M
D_S
10'
P(t)
10'
V_10 (t)
DRY
ALLUVIAL
SOIL
MAJOR
REFLECTOR
PARTICLE VELOCITY
TIME
(D_S - D_M)_MAX
1g FALL
RATTLESPACE, IN.
0
5
10
15
20
DEPTH TO MAJOR REFLECTOR, FT
0
50
100
150
200
250
300
SOFT SITE
HARD SITE
MEAN SITE

VERTICAL RATTLESPACE FOR MX HORIZONTAL SHELTERS: STATISTICAL DISTRIBUTION FOR NEVADA-UTAH DEPLOYMENT AREA



RALSTON VALLEY SOIL COMPRESSIBILITY STUDY

STATISTICALLY ORIENTED STUDY OF RALSTON VALLEY TO GENERATE BASELINE DATA APPLICABLE TO OTHER GEOLOGICALLY SIMILAR VALLEYS

- **Probabilistic sampling and testing program designed to yield:**

  (1) Valley-wide variation of uniaxial strain compressibility to a depth of 150 feet

  (2) Correlations with available/more-readily-obtained measurements, for example:

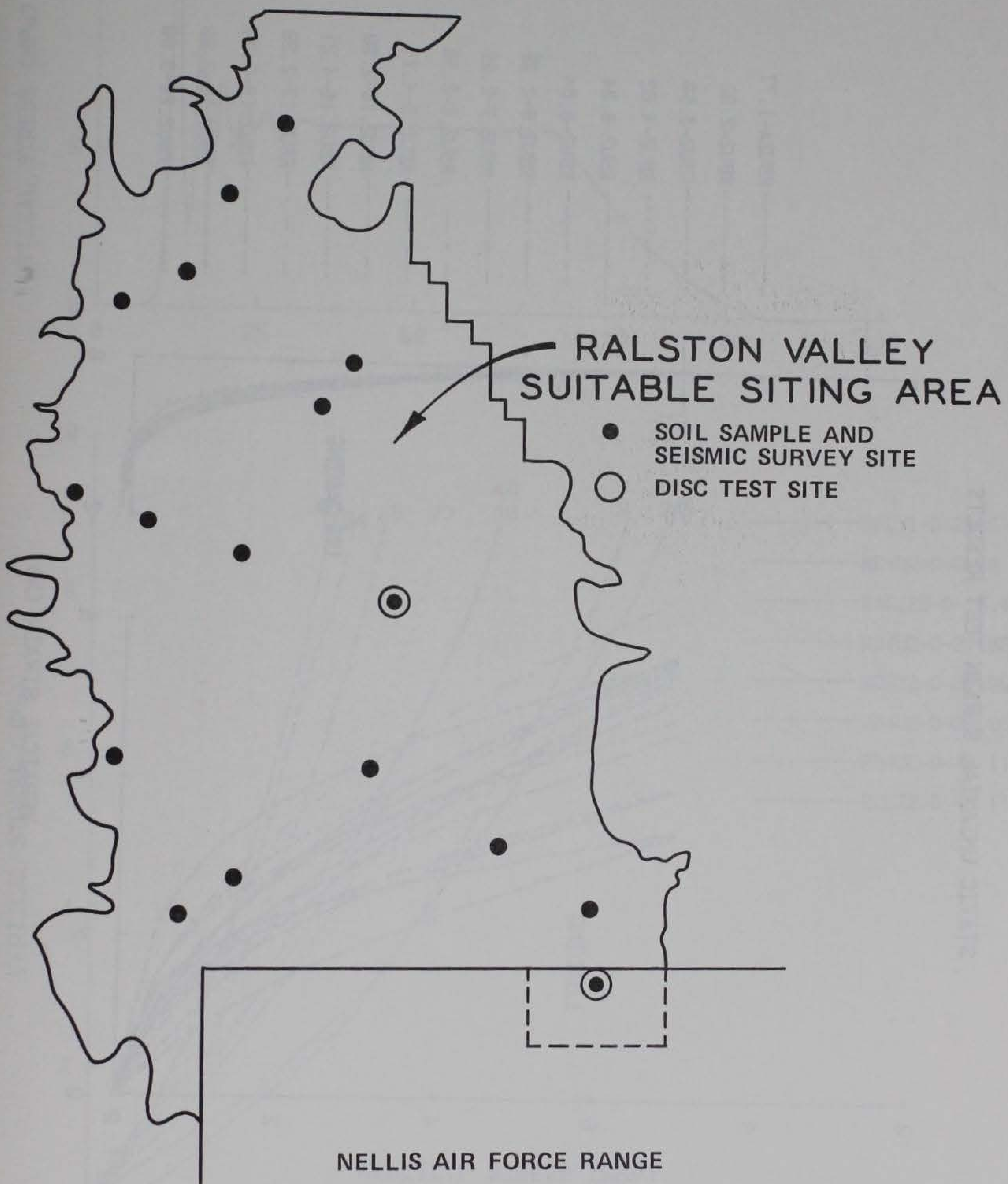
  a. topographic data

  b. surficial geology

  c. seismic refraction P-wave velocity

  d. unified soil classification, gradation curve, etc.

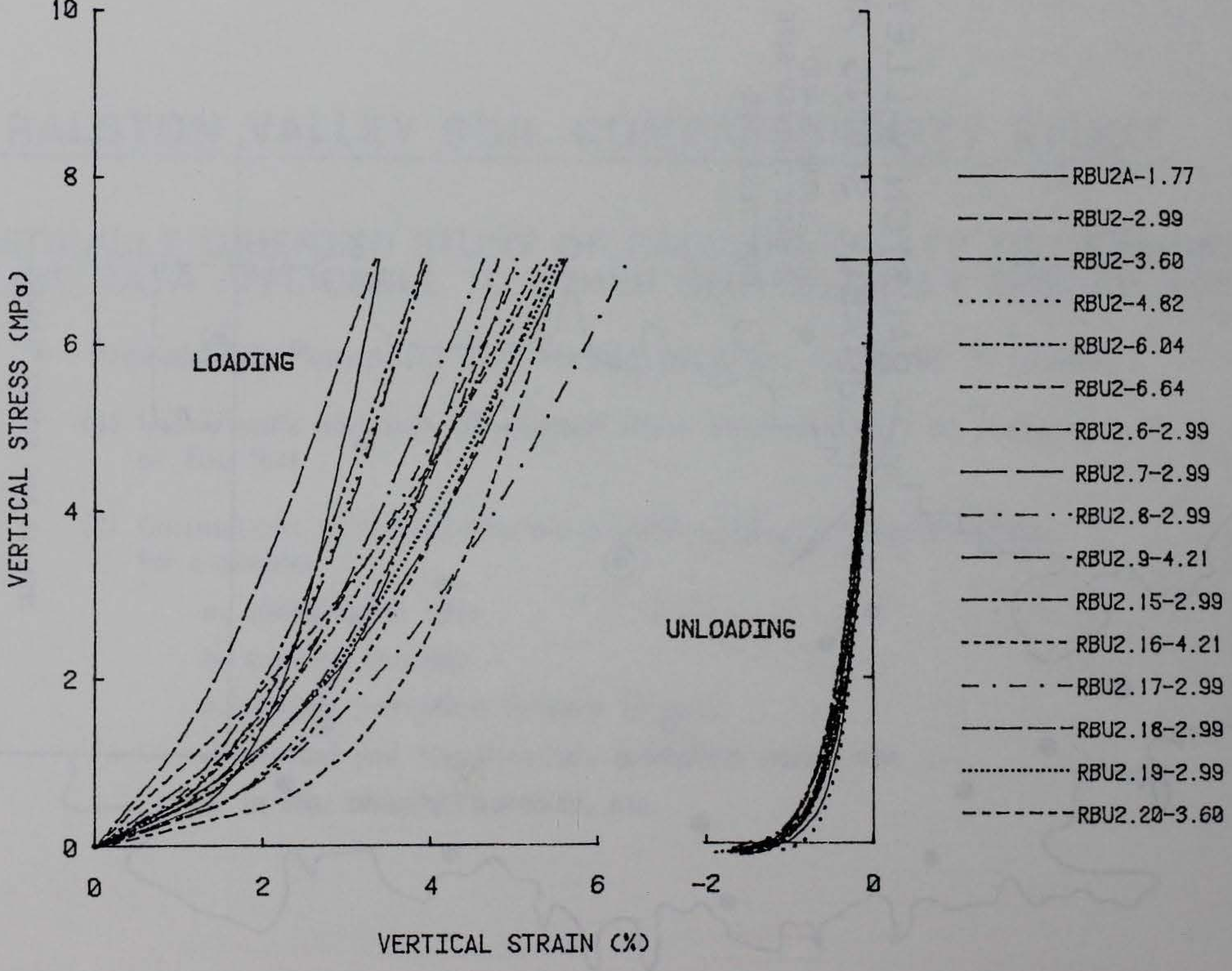
  e. in situ density, porosity, etc.


RALSTON VALLEY
SUITABLE SITING AREA
● SOIL SAMPLE AND SEISMIC SURVEY SITE
○ DISC TEST SITE
NELLIS AIR FORCE RANGE

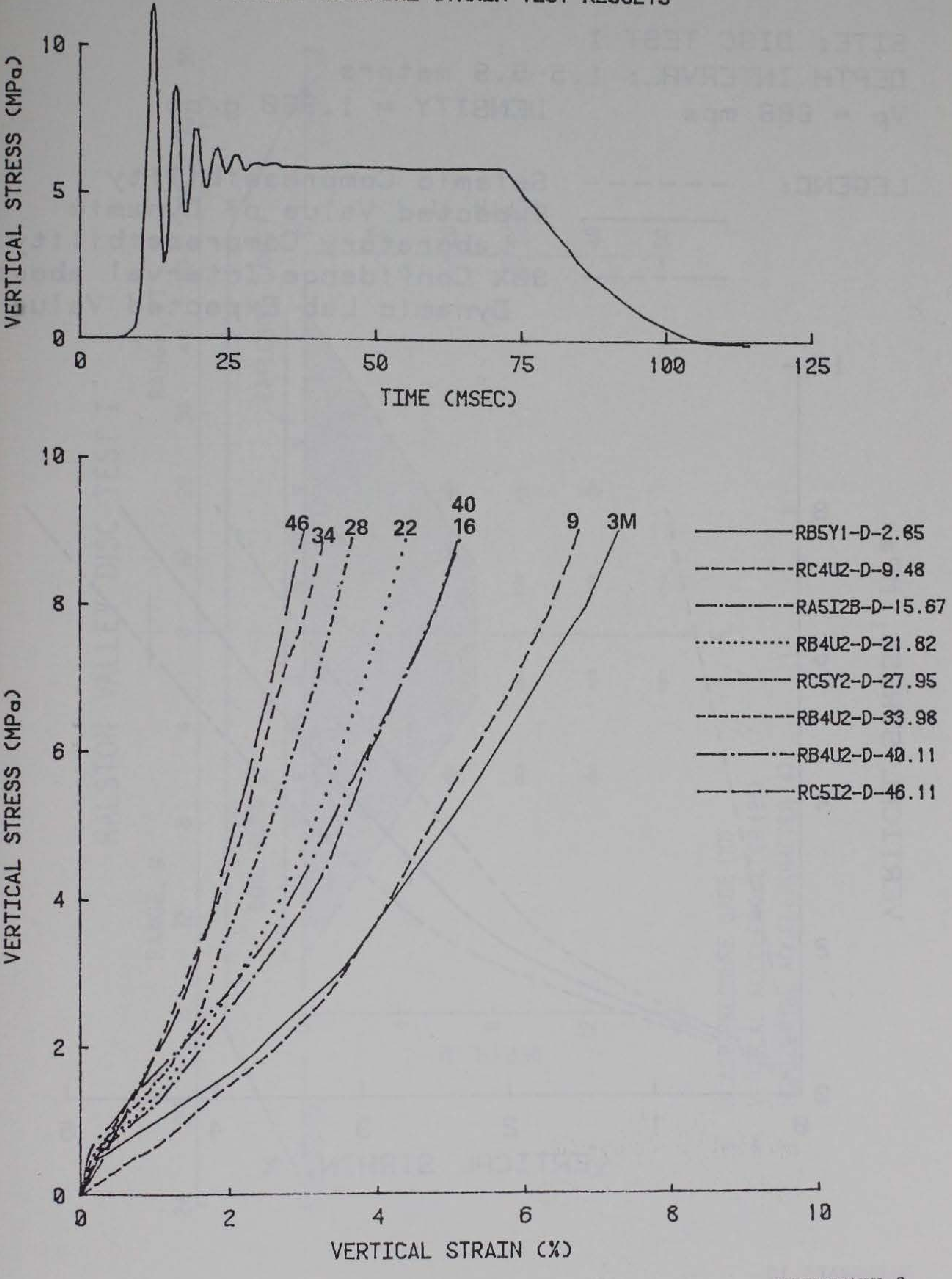
VIEWGRAPH 7

VIEWGRAPH 8

STATIC UNIAXIAL STRAIN TEST RESULTS



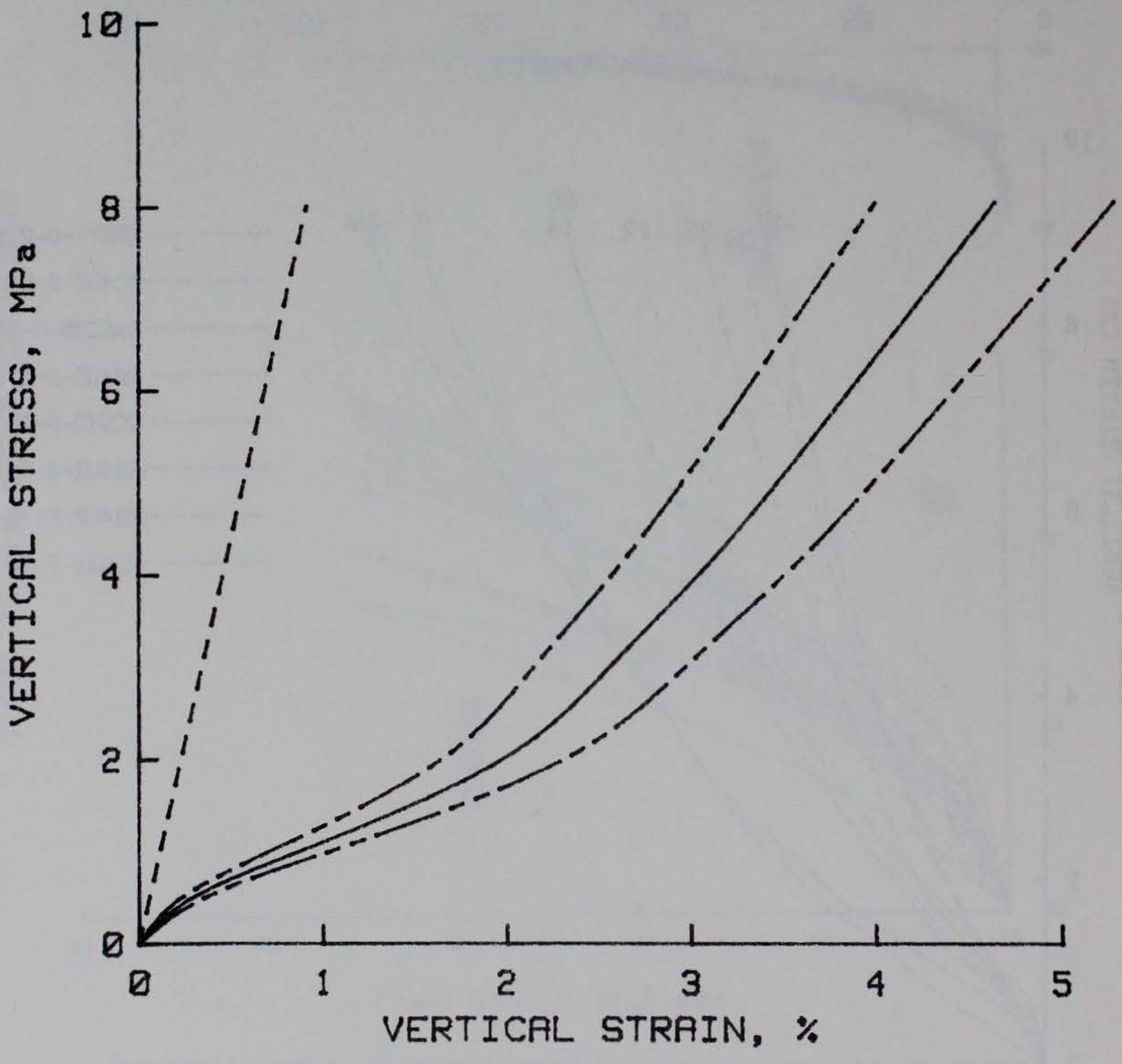
DYNAMIC UNIAXIAL STRAIN TEST RESULTS



VIEWGRAPH 9

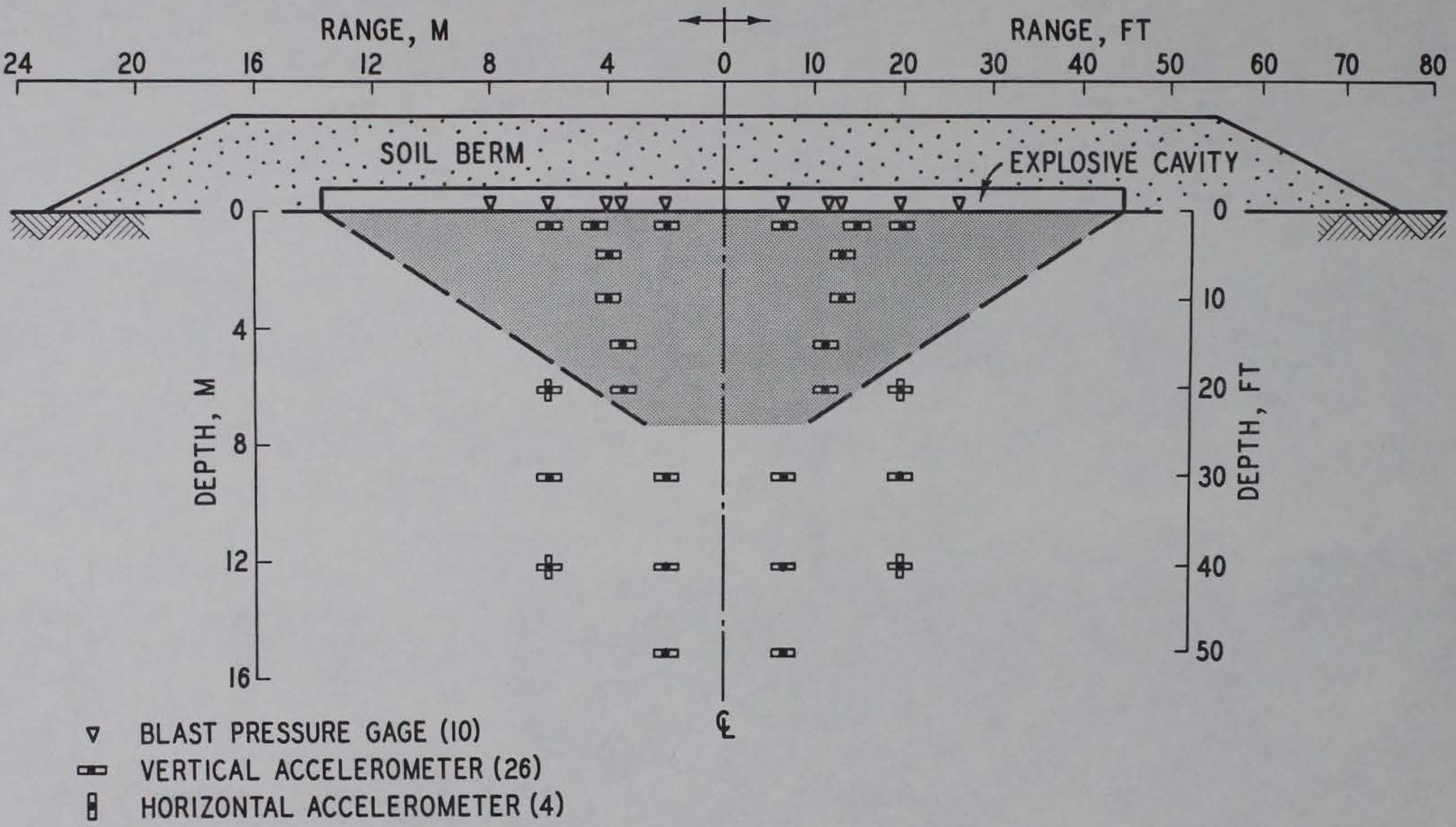
SITE: DISC TEST I
DEPTH INTERVAL: 1.5-5.9 meters
Vp = 686 mps   DENSITY = 1.860 g/cc

LEGEND:
- - - - - - - Seismic Compressibility
——————— Expected Value of Dynamic Laboratory Compressibility
——- - -—— 90% Confidence Interval about Dynamic Lab Expected Value



VIEWGRAPH 10

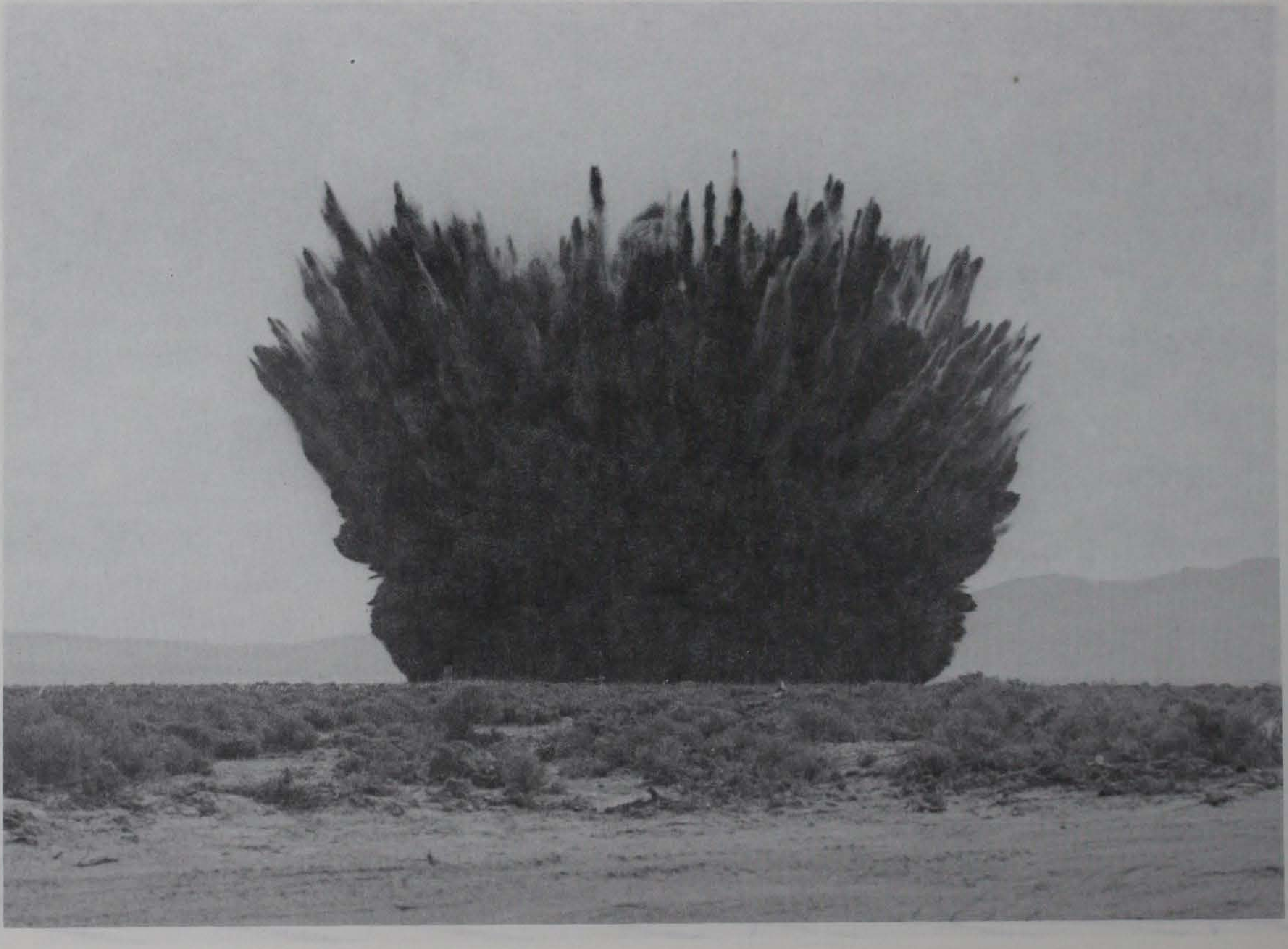
RALSTON VALLEY DISC TEST I

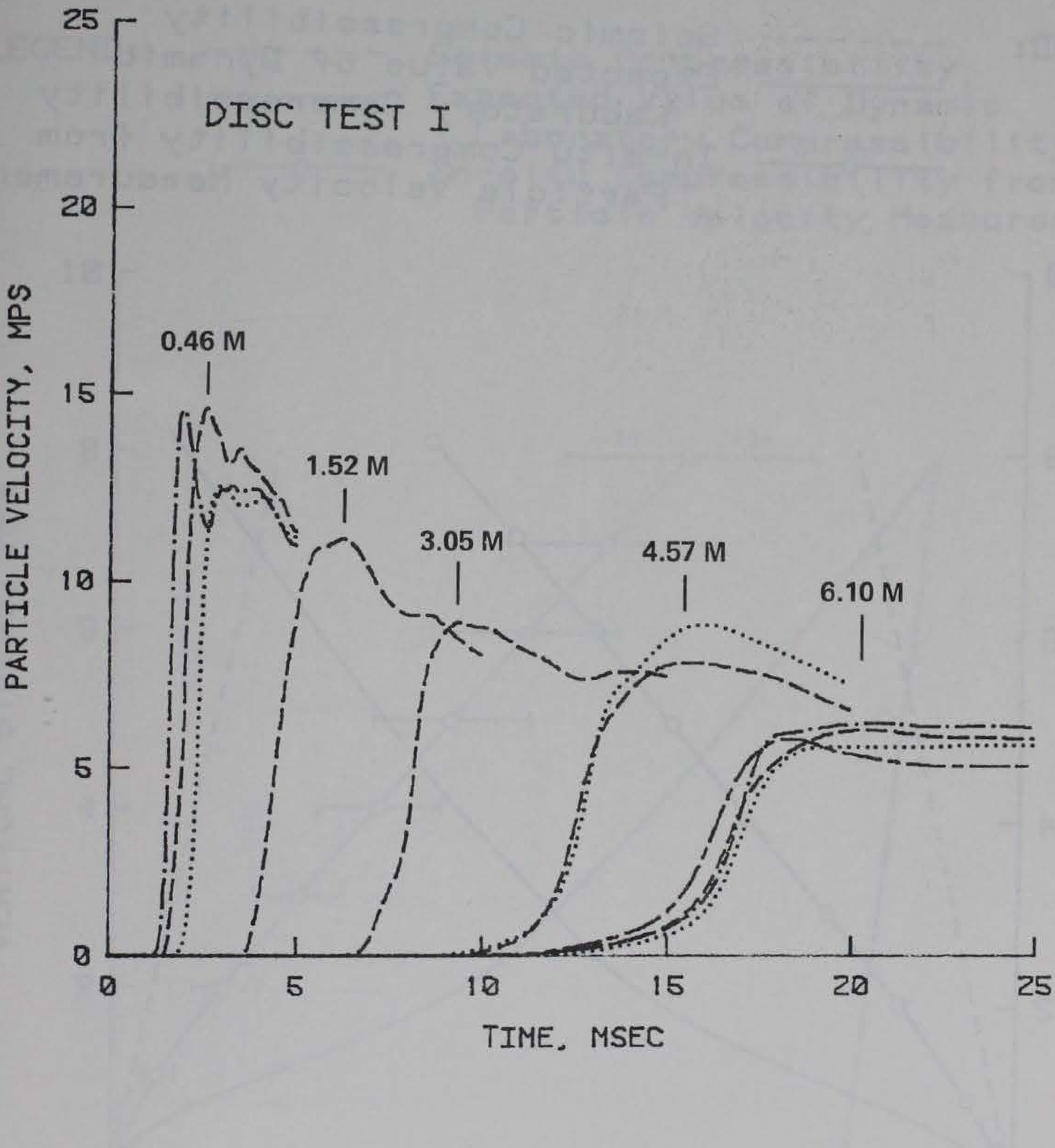


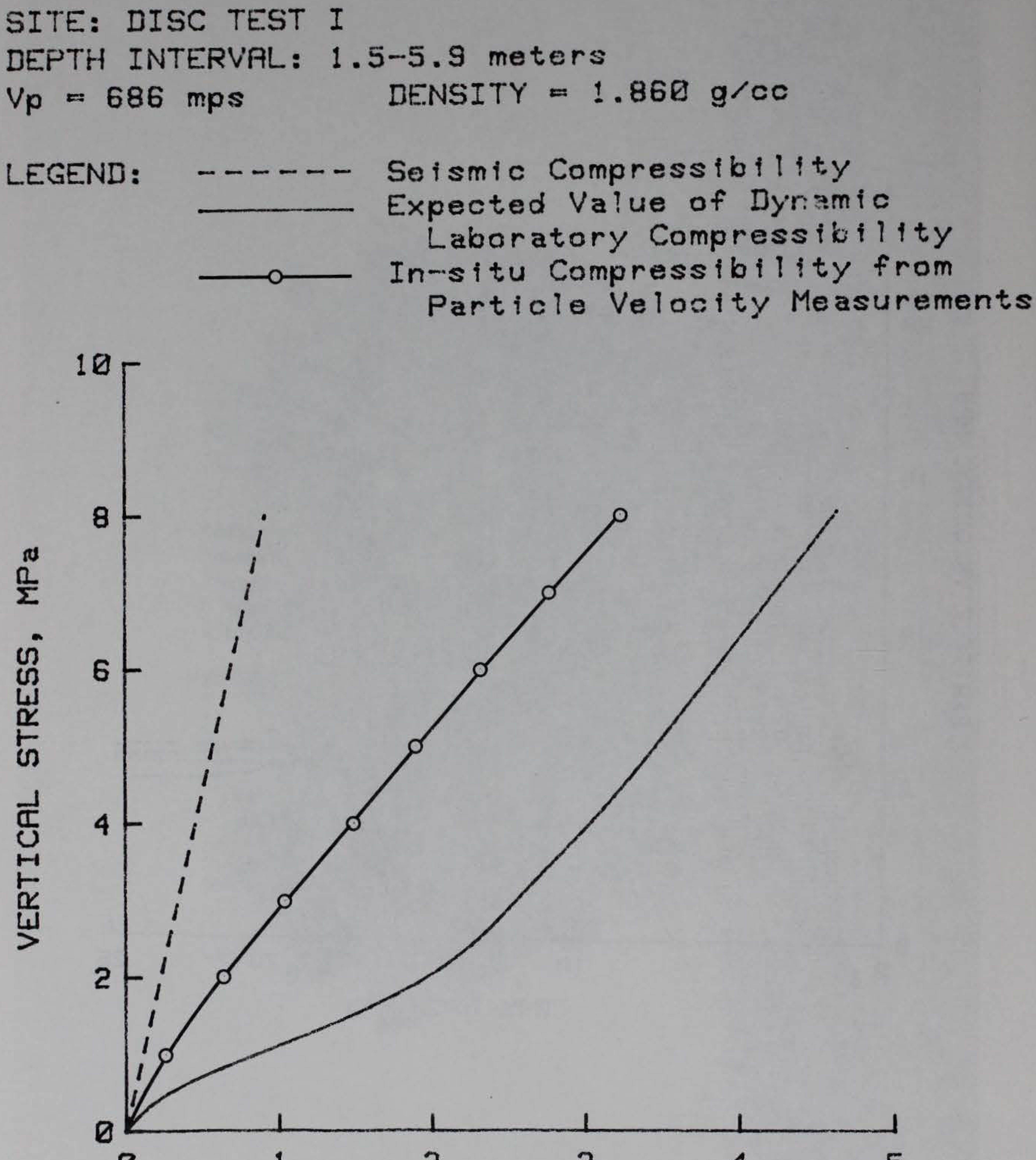
VIEWGRAPH 12

VIEWGRAPH 13

VIEWGRAPH 14

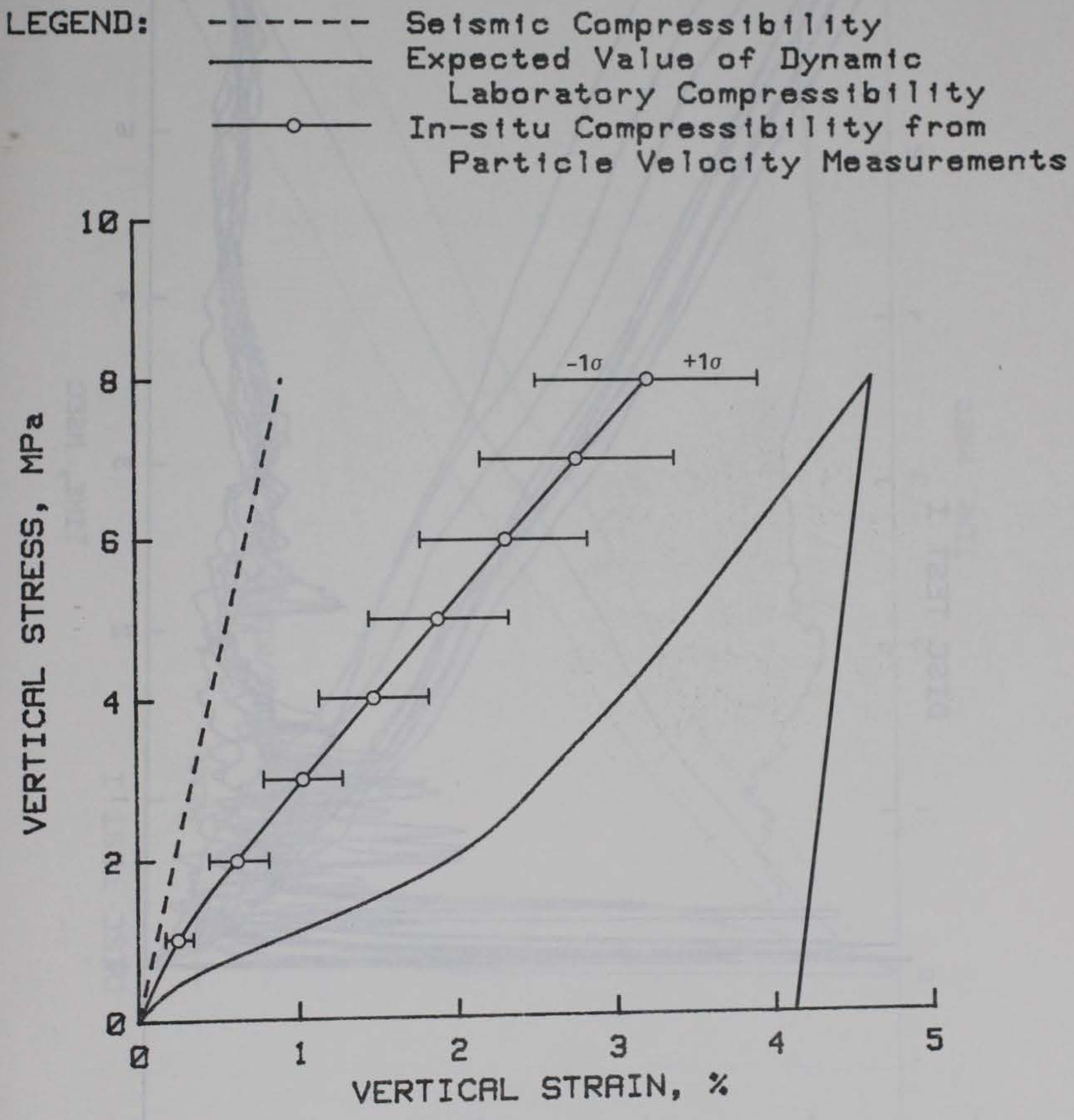



DISC TEST I
PARTICLE VELOCITY, MPS
TIME, MSEC
0.46 M
1.52 M
3.05 M
4.57 M
6.10 M
0
5
10
15
20
25
0
5
10
15
20
25

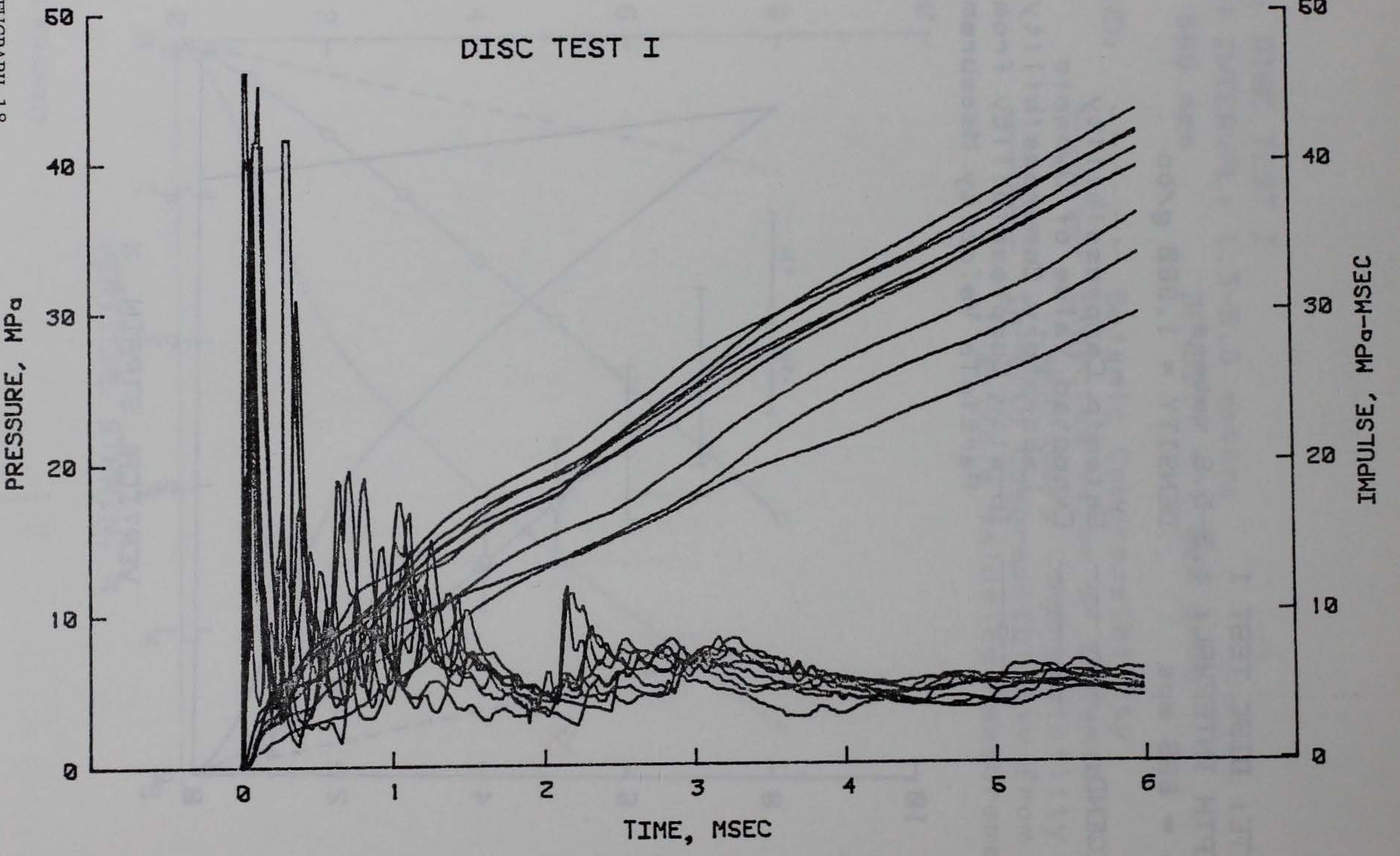


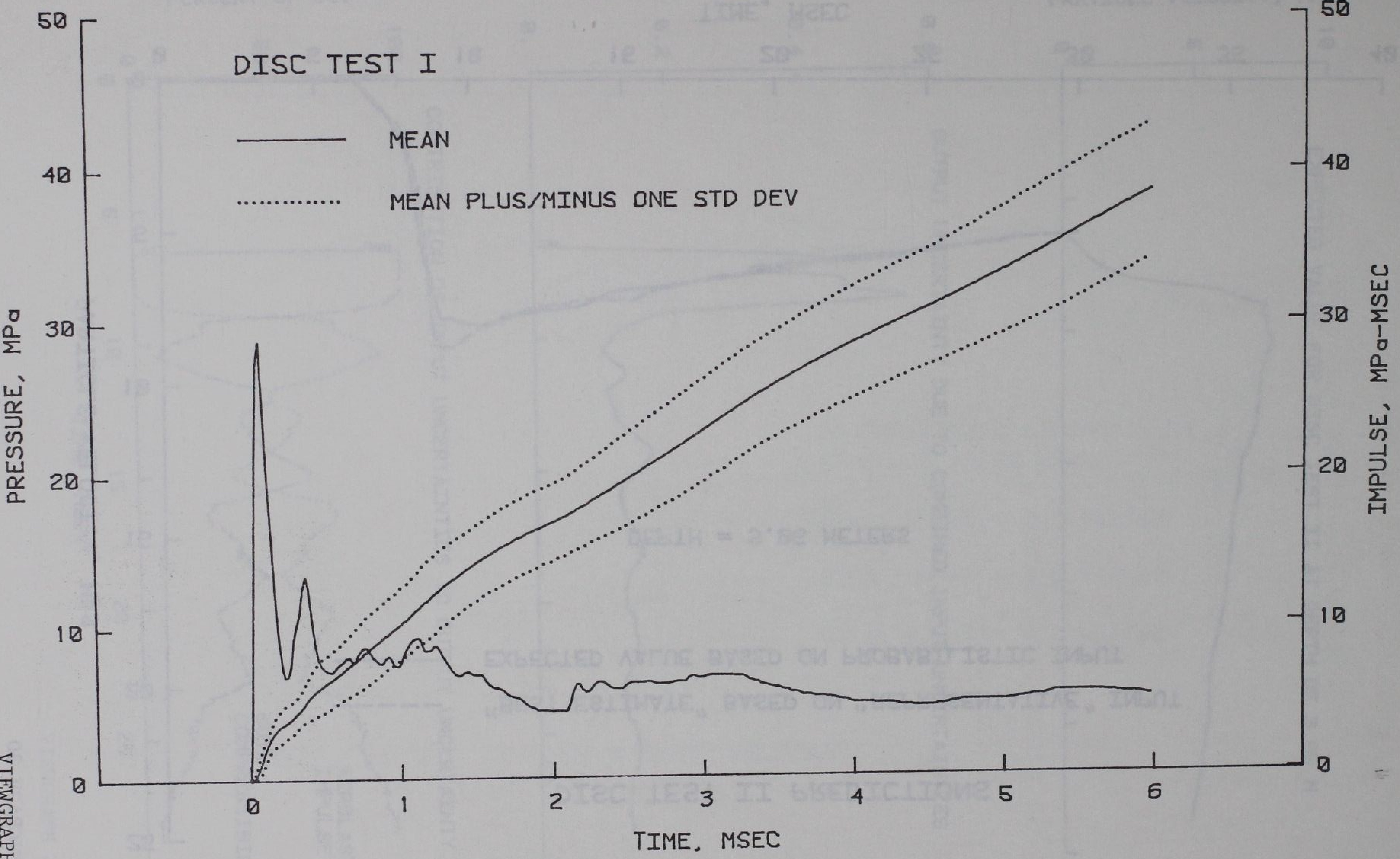
VIEWGRAPH 16

SITE: DISC TEST I
DEPTH INTERVAL: 1.5-5.9 meters
Vp = 686 mps   DENSITY = 1.860 g/cc



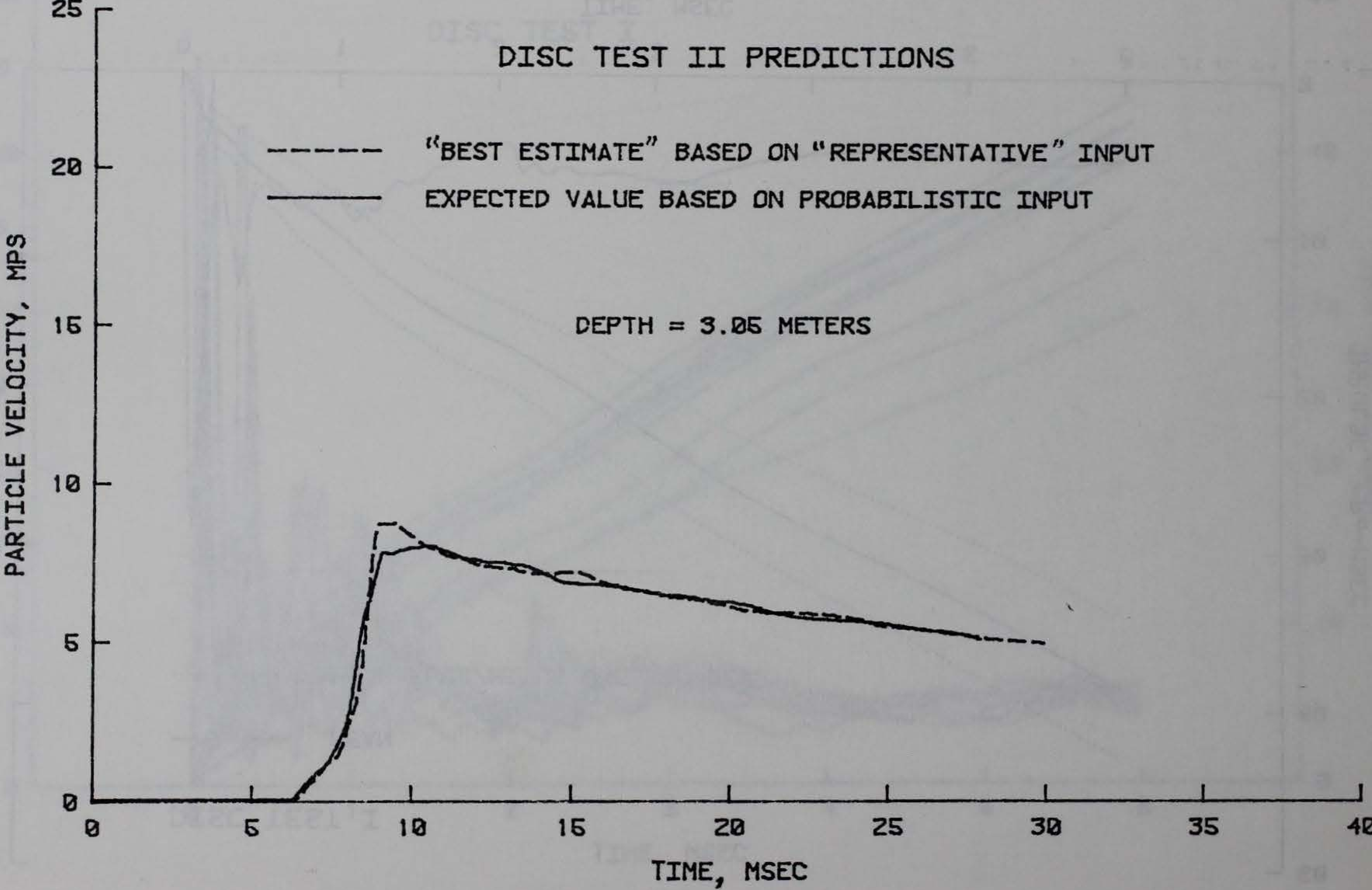
VIEWGRAPH 18

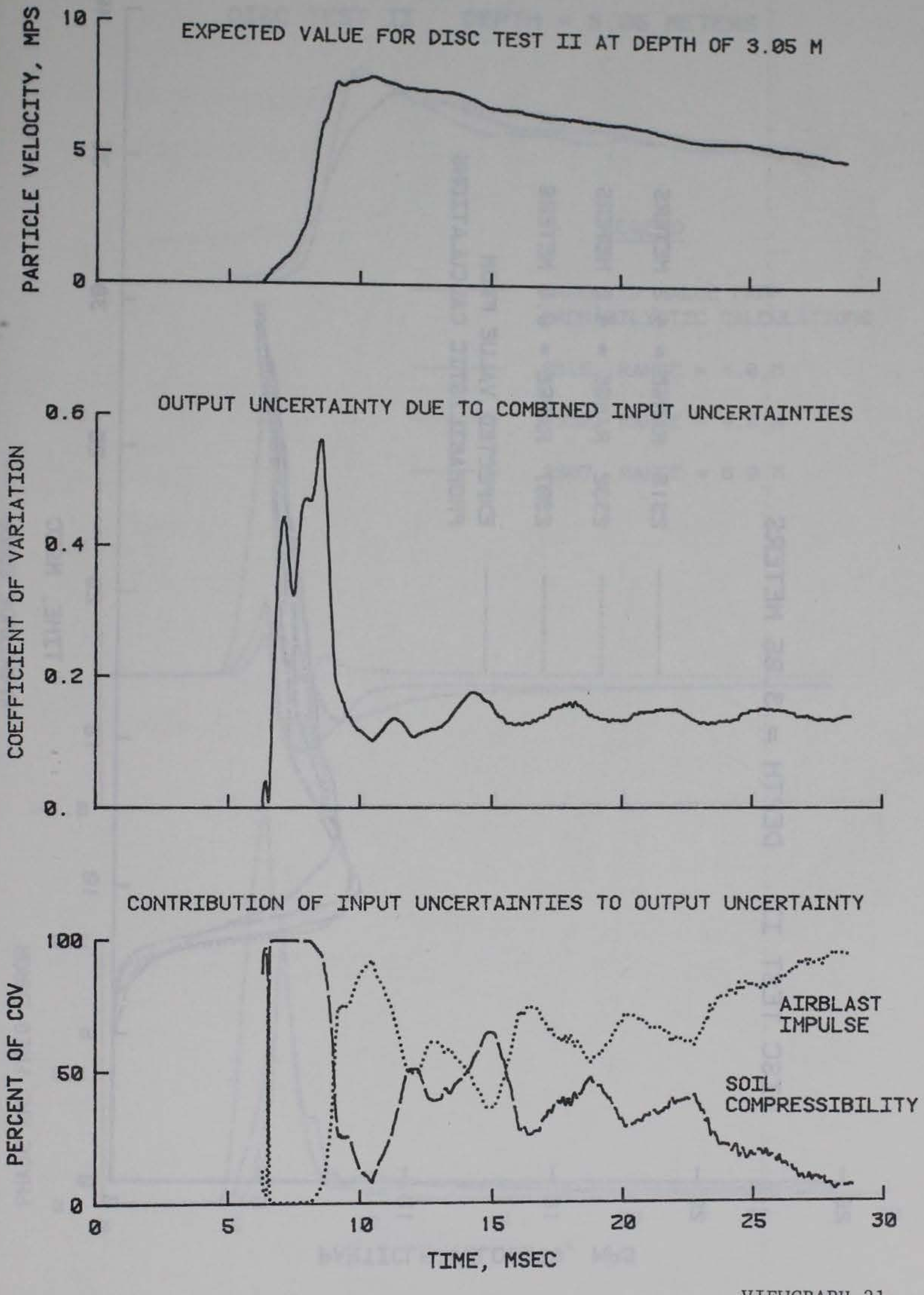




VIEWGRAPH 19

VIEWGRAPH 20





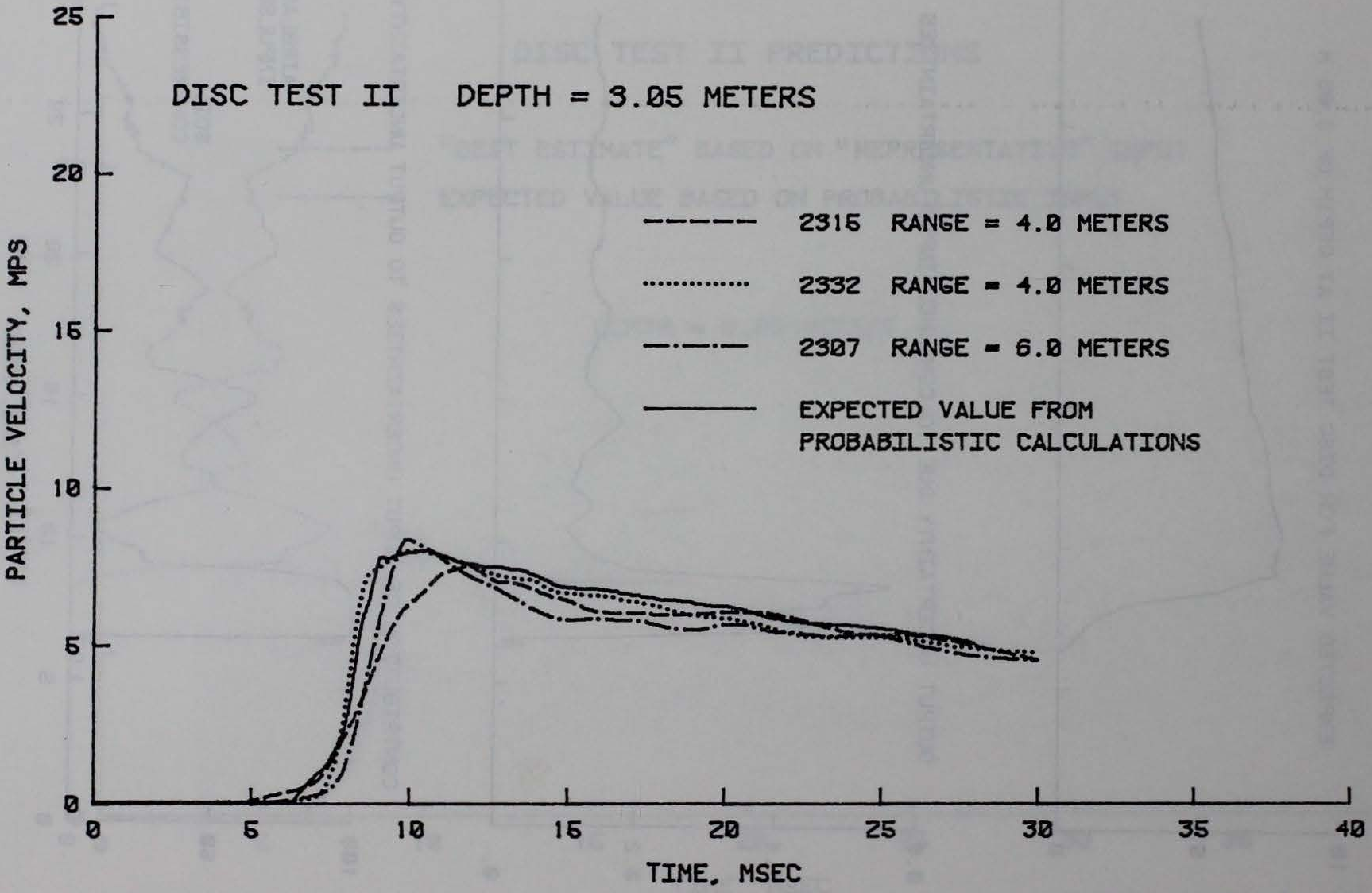
EXPECTED VALUE FOR DISC TEST II AT DEPTH OF 3.05 M

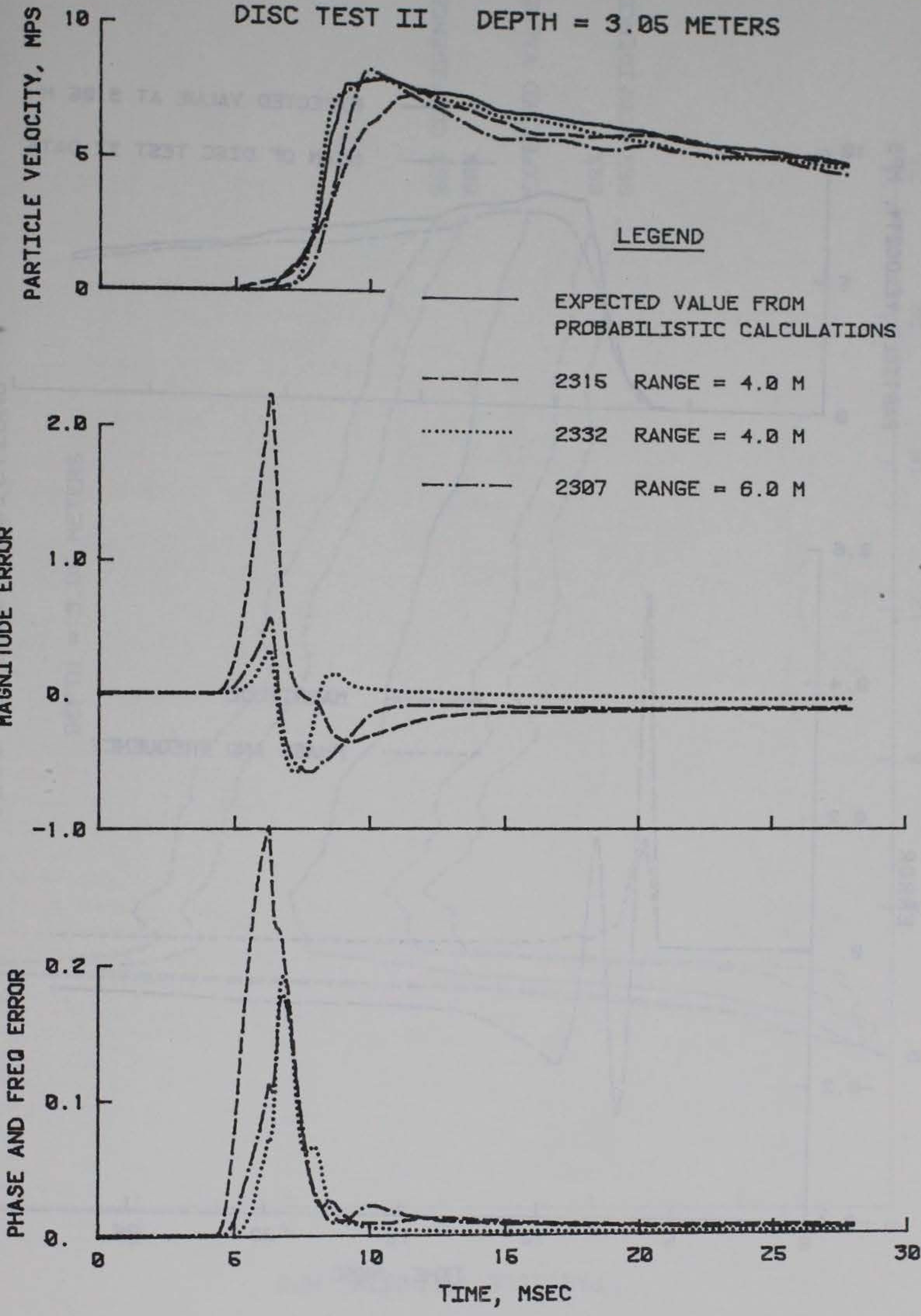
OUTPUT UNCERTAINTY DUE TO COMBINED INPUT UNCERTAINTIES

CONTRIBUTION OF INPUT UNCERTAINTIES TO OUTPUT UNCERTAINTY

VIEWGRAPH 21

VIEWGRAPH 22





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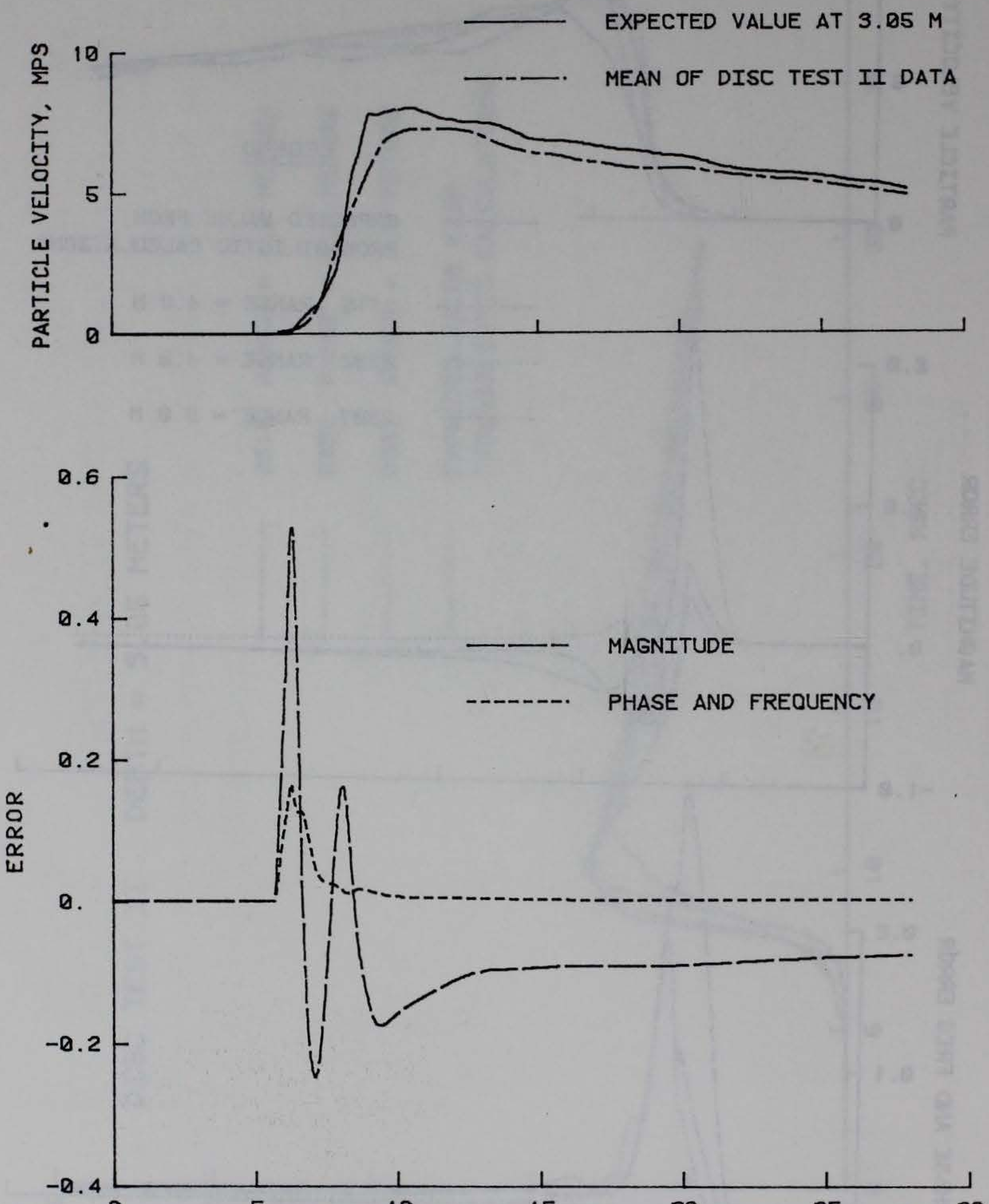
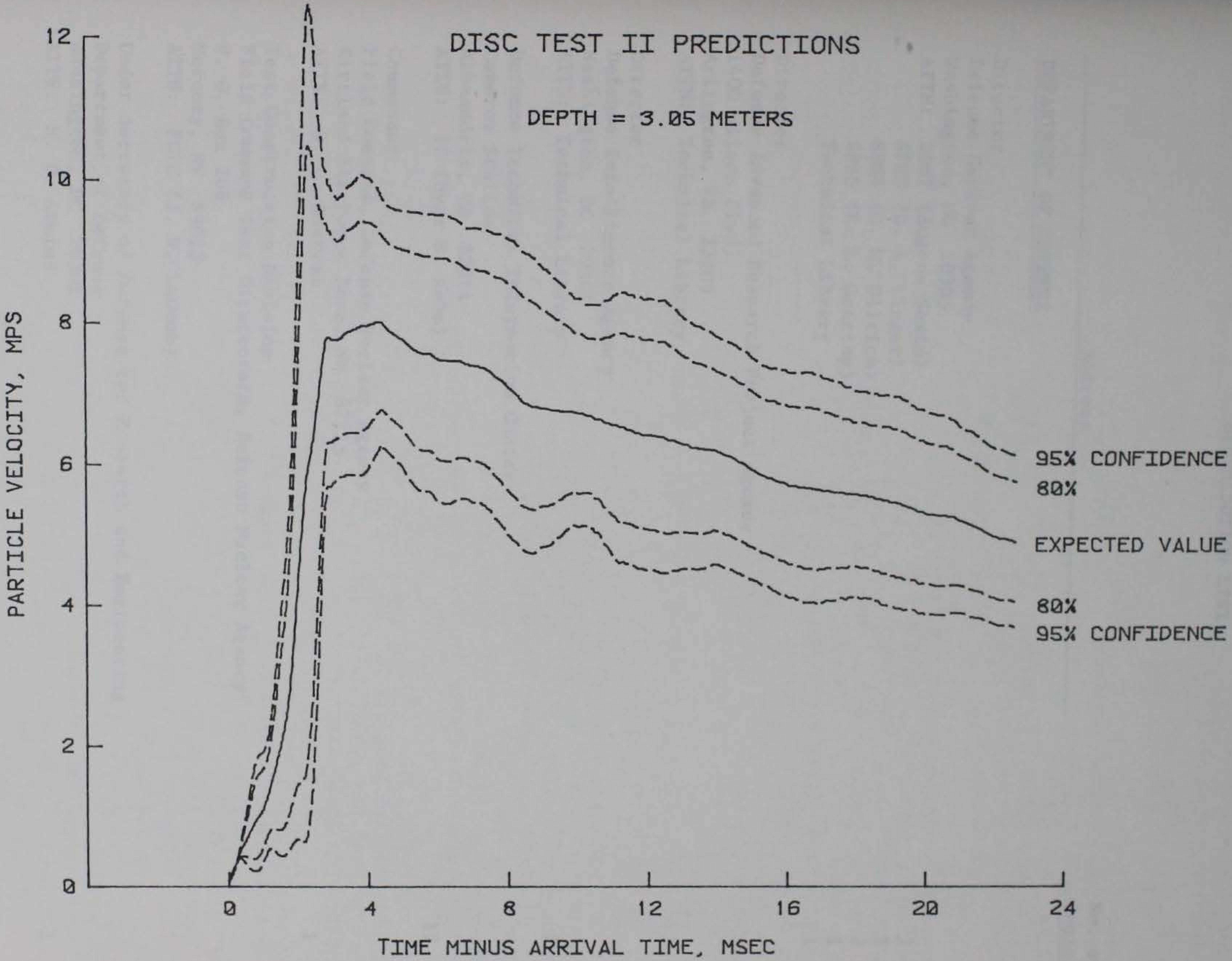


VIEWGRAPH 24



VIEWGRAPH 25

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