THE UNIVERSITY OF ALABAMA
COLLEGE OF ENGINEERING
BUREAU OF ENGINEERING RESEARCH

FINAL REPORT

SURFACE COAL MINE BLASTING EFFECTS ON UNDERGROUND COAL MINE STABILITY

Submitted to

School of Mines and Energy Development
The University of Alabama

by

Asadollah Hayatdavoudi
Principal Investigator
Associate Professor of Mineral Engineering
The University of Alabama

and

Robert C. Brown
Co-Principal Investigator
Associate Professor of Civil Engineering
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BER 240-63

August 1979

Volume I

UA UNIVERSITY, ALABAMA 35486

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Volume I

This paper is dedicated to the Alabama miner and mine operator whose safety, prosperity, and productivity provided a great source of inspiration for our work

and

to my wife Zari and my children Maziar and Sawsawn, who waited for "Daddy" to come home and out of the mine alive!

A. Hayatdavoudi

ACKNOWLEDGMENT

Funding for this work was provided by the School of Mines and Energy Development. Bankhead Mining Company and Alabama By-Products Corporation, supported by the Alabama Power Company and Southern Services Company, provided the investigators with access to their mines, without which this work could not have been performed. Acknowledgment is made of the excellent cooperation and assistance given the investigators by the management and operating personnel of the mining companies in accumulating data in the field and giving physical assistance while working in low coal and carrying heavy instruments.

The principal investigator particularly wishes to express his appreciation to Russell McLean and Steve Sims, who trusted his theories, reasoning, and computations, had the courage to stand with him under direct blasts of the surface mine, shared moments of "fear and trembling" in sweat, silence, and darkness, and, above all, aided him in removing the myth of "it cannot be done" and proving that the ancient profession of mining engineering, the inner space engineering, is alive and well and at its best.

The principal investigator also wishes to express his thanks to laboratory assistants, Harold "Bo" Newhouse, Geoffrey McDuffie, Becky McBride, and Donna Marlowe.

Many thanks are extended to the rock mechanics students who worked hard in gathering rock physical property data.

They are as follows:

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Michael Short
Fred Porter
Gwen Hood
Billy Hood

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

Figure		Page

Figure		Page

LIST OF SYMBOLS

V_{AT} = PEAK GROUND PARTICLE VELOCITY FOR THE TRANSVERSE TRACE

V_{AV} = PEAK GROUND PARTICLE VELOCITY FOR THE VERTICAL TRACE

V_{AR} = PEAK GROUND PARTICLE VELOCITY FOR THE RADIAL TRACE

V_{MAX} = ALGEBRAIC SUM OF THE PEAK GROUND PARTICLE VELOCITIES (TRANSVERSE, VERTICAL, RADIAL)

V_{YT} = COMPONENT OF THE VECTOR SUM GROUND PARTICLE VELOCITY FOR THE TRANSVERSE TRACE

V_{YV} = COMPONENT OF THE VECTOR SUM GROUND PARTICLE VELOCITY FOR THE VERTICAL TRACE

V_{YR} = COMPONENT OF THE VECTOR SUM GROUND PARTICLE VELOCITY FOR THE RADIAL TRACE

V_P = VECTOR SUM GROUND PARTICLE VELOCITY

F_{AT} = FREQUENCY OF THE PEAK GROUND PARTICLE VELOCITY FOR THE TRANSVERSE TRACE

F_{AV} = FREQUENCY OF THE PEAK GROUND PARTICLE VELOCITY FOR THE VERTICAL TRACE

F_{AR} = FREQUENCY OF THE PEAK GROUND PARTICLE VELOCITY FOR THE RADIAL TRACE

F_{AVE} = AVERAGE FREQUENCY OF THE PEAK GROUND PARTICLE VELOCITY

F_{YT} = FREQUENCY OF THE VECTOR SUM GROUND PARTICLE VELOCITY FOR THE TRANSVERSE TRACE

F_{YV} = FREQUENCY OF THE VECTOR SUM GROUND PARTICLE VELOCITY FOR THE VERTICAL TRACE

F_{YR} = FREQUENCY OF THE VECTOR SUM GROUND PARTICLE VELOCITY FOR THE RADIAL TRACE

F_{AVE} = AVERAGE FREQUENCY OF THE VECTOR SUM GROUND PARTICLE VELOCITIES

V/P = RATIO OF THE PEAK GROUND PARTICLE VELOCITY TO THE CORRESPONDING PERIOD, TRANSVERSE TRACE

V/P = RATIO OF THE PEAK GROUND PARTICLE VELOCITY TO THE CORRESPONDING PERIOD, VERTICAL TRACE

V/P = RATIO OF THE PEAK GROUND PARTICLE VELOCITY TO THE CORRESPONDING PERIOD, RADIAL TRACE

V/P = RATIO OF THE ALGEBRAIC SUM OF THE PEAK GROUND PARTICLE VELOCITY FOR THE TRANSVERSE TRACE TO THE CORRESPONDING PERIOD

V/P = RATIO OF THE TRANSVERSE COMPONENT OF THE VECTOR SUM GROUND PARTICLE VELOCITY TO THE CORRESPONDING PERIOD

V/P = RATIO OF THE VERTICAL COMPONENT OF THE VECTOR SUM GROUND PARTICLE VELOCITY TO THE CORRESPONDING PERIOD

V/P = RATIO OF THE RADIAL COMPONENT OF THE VECTOR SUM GROUND PARTICLE VELOCITY TO THE CORRESPONDING PERIOD

V/P = RATIO OF THE VECTOR SUM GROUND PARTICLE VELOCITY TO THE CORRESPONDING PERIOD

K_{AT} = SITE DIRECTIONAL PROPERTIES RELATED TO THE PEAK GROUND PARTICLE VELOCITY OF THE TRANSVERSE TRACE

K_{AV} = SITE DIRECTIONAL PROPERTIES RELATED TO THE PEAK GROUND PARTICLE VELOCITY OF THE VERTICAL TRACE

K_{AR} = SITE DIRECTIONAL PROPERTIES RELATED TO THE PEAK GROUND PARTICLE VELOCITY OF THE RADIAL TRACE

K_{MAX} = SITE DIRECTIONAL PROPERTIES RELATED TO THE PEAK GROUND PARTICLE VELOCITIES OF THE ALGEBRAIC SUM OF THE THREE TRACES

K_{YT} = SITE DIRECTIONAL PROPERTIES RELATED TO THE VECTOR SUM GROUND PARTICLE VELOCITY COMPONENT OF THE TRANSVERSE TRACE

K_{YV} = SITE DIRECTIONAL PROPERTIES RELATED TO THE VECTOR SUM GROUND PARTICLE VELOCITY COMPONENT OF THE VERTICAL TRACE

K_{YR} = SITE DIRECTIONAL PROPERTIES RELATED TO THE VECTOR SUM GROUND PARTICLE VELOCITY COMPONENT OF THE RADIAL TRACE

K_P = SITE DIRECTIONAL PROPERTIES RELATED TO THE VECTOR SUM GROUND PARTICLE VELOCITY

ϵ_{AT} = MICRO STRAIN RELATED TO THE PEAK GROUND PARTICLE VELOCITY OF THE TRANSVERSE TRACE

ϵ_{AV} = MICRO STRAIN RELATED TO THE PEAK GROUND PARTICLE VELOCITY OF THE VERTICAL TRACE

ϵ_{AR} = MICRO STRAIN RELATED TO THE PEAK GROUND PARTICLE VELOCITY OF THE RADIAL TRACE

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ϵ_{YR} = MICRO STRAIN RELATED TO THE VECTOR SUM GROUND PARTICLE VELOCITY COMPONENT OF THE RADIAL TRACE

ϵ_{P} = MICRO STRAIN RELATED TO THE VECTOR SUM GROUND PARTICLE VELOCITY

σ = NORMAL STRESS

τ = SHEAR STRESS

γ = SHEAR STRAIN

ρ = MASS DENSITY (LBS PER SEC^2/FT^4)

C_p = COMPRESSIONAL WAVE VELOCITY, FT/SEC

C_S = SHEAR WAVE VELOCITY, FT/SEC

$\dot{A}$ = ANY PEAK PARTICLE VELOCITY

λ = LAME'S CONSTANT, PSI

ν = POISSON'S RATIO

E = MODULUS OF ELASTICITY, PSI

G = MODULUS OF RIGIDITY, PSI

K = BULK MODULUS, PSI

S_B = SURFACE BLAST

S_M = BLAST MONITORED AT SURFACE

U_B = UNDERGROUND BLAST

U_M = BLAST MONITORED UNDERGROUND

H_1 = ROOF/FLOOR CONVERGENCE

H_2 = PILLAR DILATION

H_3 = PILLAR SHORTENING

INTRODUCTION

By 1989 it is estimated that the yearly production of coal from underground mining will increase to about 25 million tons in Alabama. Some of the increased production will come from mines adjacent to, directly under, or intersecting ongoing surface mining activities. This requires establishing acceptable guidelines for surface mine blasting which will permit the underground and surface activities to be carried on concurrently without disrupting either operation.

The area in which the research work was carried out has an immediate potential of 3.5 million tons of coal and a long range potential of another 14 to 17 million tons of coal estimated at a value of nearly half a billion dollars. Maps given in references 1 and 2 show the details of mining at Cobb Mine overlying the Mary Lee No. 2 mine in Goodsprings, Walker County, Alabama.

The specific problems that confronted the investigators were defined by mine operators as:

1) Is it possible to safely operate surface and underground coal mines in the same locale?
2) If so, can the present scaled distance formula be used to estimate the ground particle velocity?
3) Can surface mine blasting be conducted directly above the underground mine?
4) If so, how heavy a charge can be detonated for better fragmentation and increased production?
5) Can multiple seam mining be conducted directly above the underground mine?

The first and second problems were the subject of Phase I of the study which started in 1976. The results of this phase of study were encouraging and permitted the mine operators to file and obtain a waiver from the blast regulations. However, this was not enough as the blasts were set off at angles and some horizontal distances from the underground mine. Consequently it was necessary to conduct Phase II of the investigation.

This final report describes the progress of the second phase which began in 1978. It contains documentation of field ground stresses, pre- and post-blast surveys of underground mine movements, three-dimensional ground particle velocity, and the computed one-dimensional dynamic stresses developed at the mine roof.

OBJECTIVES

In order to arrive at a reliable set of facts and figures, the following objectives were established:

1) measuring the approximate magnitude and direction of principal field stresses
2) keeping track of underground mine movements at some designated area prior to blasting; this pre-blast survey consisted of measuring load changes on the roof bolts, roof and floor convergence, roof strata separation, pillar shortening, and pillar dilation
3) measuring ground particle velocity
4) correlating the ground particle velocity with levels of strain as a result of dynamic loading
5) conducting a post-blast survey at the same designated area of the underground mine where pre-blast survey was conducted and measuring the same parameters as were measured in the pre-blast survey; relate the level of induced dynamic stresses with the strength of rock, and
6) analyzing the peak ground particle velocity data for the purpose of establishing a wave propagation law which will relate the peak particle velocity to the damage that might be caused by roof vibration.

During the course of investigation, the Federal law went into effect setting the maximum limit for vibration level to 1.0 inch per second. This level could not be violated in order to establish or note a higher level of vibration associated with a given damage, such as an underground roof fall. Therefore, the sixth objective was limited to the 1.0 inch per second peak particle velocity or lower.

APPARATUS AND EXPERIMENTAL PROCEDURE

Equipment

The equipment used in the laboratory for the purpose of determining rock mechanical properties included:

1) A 50 kip MTS load frame with servo-controlled pumps, function generator, pump controller, cyclic counter, a 4-level load stroke and strain programmer, limit detectors, LVDT, LVDT readout, multirange DVM, X-Y recorders, and strain readout devices.
2) A 300 kip Forney load frame with pump.
3) Rock preparation and testing equipment consisting of a heavy-duty drill press modified to a coring machine, rock saws, grinding machines, small lathes, end parallelism tester, calipers, Jolly balances, vacuum oven, core barrels, holding jigs, end caps, direct tension test assembly and many different size platens.
4) Complete strain gage installation kits tailored for individual instruction and independent work in stress-strain analysis.
5) Small brick testing machine.
6) A high capacity hot pack incubator with home-made auxiliary pumps, humidity chamber for generating a simulated mine humidity and temperature.
7) A pulse generator and conditoner (SBEL 2007H) with scope and combination P and S platens for dynamic testing.
8) Sprengnether engineering DVA seismographs with VS-6000 and VS-1400 transducers and L-10-3D downhole velocity meters.

9) TR-4A seismograph tape reader.

10) Borehole gage with complete overcoring assembly, biaxial modulus tester, calibration chamber, reverse case, pistons, and setting rods for in-situ field stress measurement.

11) Tape extensometer with calibration unit and readout gage for measuring sag, pillar shortening, and pillar dilation.

12) Continuous recording convergence meter.

13) Single-point extensometers of various lengths with mechanical gage for measuring separation of mine roof layers.

14) Vibrating wire extensometer with remote readout device.

15) Roof bolt load cells with remote readout devices.

Laboratory Procedure

All the rock samples were prepared and tested by rock mechanics students, laboratory assistants, and the principal investigator, following rigorous laboratory manuals. The rocks were gathered from the core holes drilled in the first phase of study. For the sake of keeping the work simple and quick, all of the tests, whether dynamic or static, were conducted in uniaxial mode.

Field Procedure

The field work consisted mainly of measuring three-dimensional ground particle velocity following a pattern set in Phase I of the study as shown in Figure 1, except that in this phase, the paths of underground blast - surface measurement and underground blast - underground measurement were not followed. The seismographic work was limited to underground monitoring

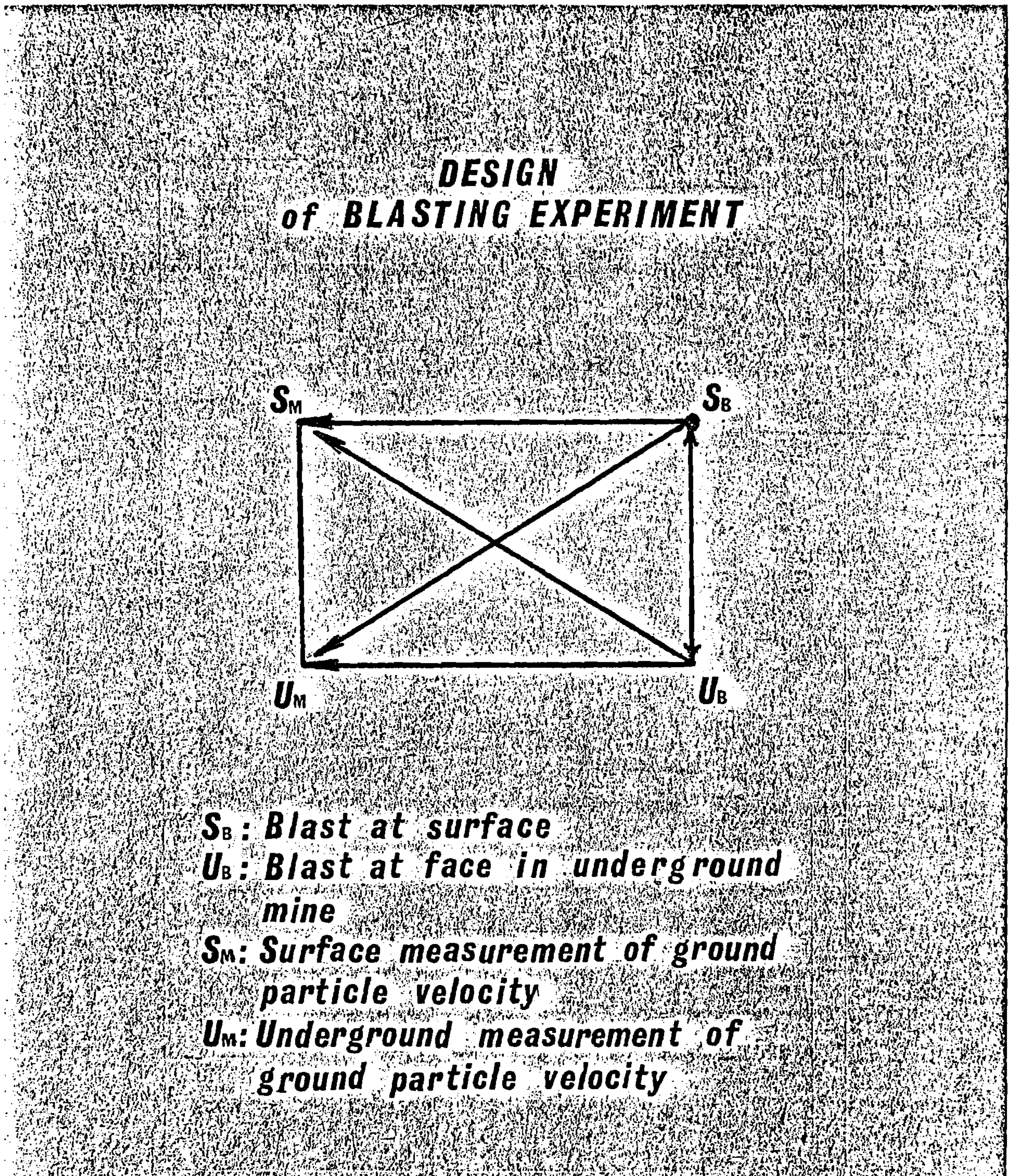


Figure 1 - Procedure for Field Blasting in Phase I and Phase II of Experiments

of blast vibration imparted to the rocks overlying the Pratt and Nickel Plate coal seams of the surface mine. The closest seam to the underground mine, the America seam, has not been monitored as of yet.

The timing of surface mine blast was scheduled for 3:00 P.M., just about the time no mine worker would be working at the face or directly beneath the blast, except for the principal investigator or his assistants.

The installation of equipment necessary for the pre- and post-blast survey of the underground mine was followed according to the plan shown in Figure 2. Daily checks of all equipment were made and data collected about one week before and after the heaviest experimental surface mine blast designed at a scaled distance of 25. At some selected points, a continuous recording convergence meter, at least one load cell, and three velocity meter responses were measured during the heaviest experimental blast as well. The VS-1400 velocity meters were glued to the mine roof while the VS-6000 velocity meters were held to the roof with a T-board and roof bolt, tightened to 200 inch-pound torque. This was done to compare the so-called effect of bolt ringing on the peak particle velocity obtained by VS-6000 and the peak particle velocity obtained by VS-1400.

While the blast monitoring was in progress, overcoring operations were conducted in the vicinity of the surface mine to determine the approximate magnitude and direction of field principal stresses. This particular step was necessary because the principal investigator had found that the average peak particle velocity in one direction was greater than in others and wondered whether a correlation existed between direction of field stresses and the ground peak particle velocity. Furthermore, determining the direction and the magnitude of field principal stresses could eventually

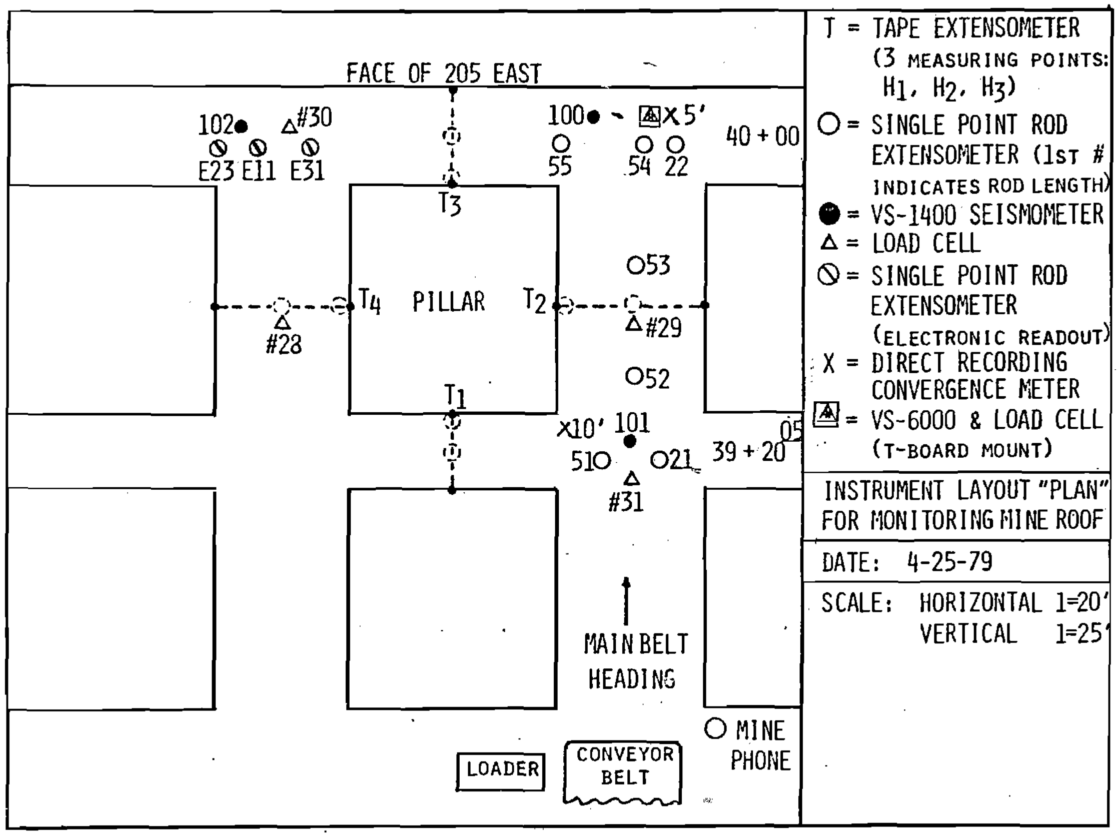


Figure 2 - Installation Plan for Pre- and Post-Blast Survey

answer some of the questions pertaining to the direction of roof falls in an underground mine.

During the course of investigation, a list of the sources or error that affect the findings of this work was compiled as shown on the following page.

Therefore, it is important to examine the data in the light of these possible errors and perhaps suggest further research topics considering the same specific areas for the purpose of refinement of the data.

SOURCES OF ERROR

1. DELAY MANUFACTURING
2. CHARGE WEIGHT
3. DISTANCE MEASUREMENT
4. SHOT PATTERN ORIENTATION
5. TYPE OF INITIATOR
6. HOLE CUT-OFF EFFECTS ON OTHER HOLES
7. SEISMOMETER NATURAL FREQUENCY
8. SEISMOMETER NOISE ERROR AT HIGH GAIN
9. SEISMOMETER CABLE LENGTH
10. SEISMOMETER COUPLING TO THE GROUND
11. INTERPRETATION ERROR
12. TYPE OF TERRAIN
13. TOPOGRAPHY OF TERRAIN
14. INTERACTION OF AIR BLAST WITH GROUND MOTION
15. DIRECTION OF PRINCIPAL HORIZONTAL STRESSES

RESULTS

A comprehensive study of this type and complexity of the vibration of multi-layered, anistropic material such as coal, clay, shales, and hard rock is bound to bring about many results and with it many controversial points of view. For the sake of brevity and considering an impartial point of view, the author presents herein the facts and figures as they are without lengthy discussion of their meaning and tries to give only an educated opinion about a particular phenomenon only when it is absolutely necessary.

Laboratory Results

Tables 1 - 3 show some of the typical results obtained from uniaxial compression, tension, and dynamic rock properties, respectively. If one compares the rock strength data with the peak 83-pound load that was recorded from roof bolt load cell during the heaviest blast, it is easily noticed that roof rock is several-fold stronger either in tension or compression. In reference to the previous work[1,2], it can be seen that the 83-pound load on the static stress-strain curve does not give a significant unrecoverable amount of elastic strain to cause any failure. Indeed, as it will be discussed later, the computed dynamic strain also bears the same insignificant result as far as stress-strain is concerned.

TABLE 1

COMPRESSION TEST

(POTTSVILLE FORMATION)

HOLE #	STRENGTH (PSI)	YOUNG'S MODULUS (PSI)	POISSON'S RATIO (AVERAGE)	REMARKS
2	18,949	2.63×10^6	0.220	*
2	19,585	3.30×10^6	0.180	*
2	17,675	3.50×10^6	0.092	*
2	17,435	3.70×10^6	0.250	*
MEAN STRENGTH: 18,411		STANDARD DEVIATION: 1,026.64		
3	23,459	3.50×10^6	0.092	*
3	21,401	2.75×10^6	0.067	*
3	9,500	7.44×10^6	0.180	**
3	18,250	6.50×10^6	0.230	*
3	17,300	4.80×10^6	0.095	*
3	14,669	7.35×10^6	0.260	*
3	19,175	4.20×10^6	0.120	*
3	18,635	3.30×10^6	0.170	*
3	30,573	19.50×10^6	0.340	*
3	22,616	3.60×10^6	0.076	*
MEAN STRENGTH: 19,558		STANDARD DEVIATION: 5,599.30		

*ALL SPECIMENS DRILLED PERPENDICULAR TO BEDDING PLANE

**DRILLED PARALLEL TO BEDDING

TABLE 2
TENSION TEST
(POTTSVILLE FORMATION)

HOLE #	STRENGTH (PSI)	YOUNG'S MODULUS (PSI)	POISSON'S RATIO (AVERAGE)	REMARKS*
2	490	3.23×10^6	0.160	
2	718	4.50×10^6	0.170	
2	524	2.16×10^6	0.026	
2	434	4.50×10^6	0.170	
2	389	4.50×10^6	0.210	

*ALL SPECIMENS DRILLED PERPENDICULAR TO BEDDING

MEAN STRENGTH: 511

STANDARD DEVIATION: 126.76

TABLE 3

DYNAMIC PROPERTIES OF ROCK - POTTSVILLE FORMATION

HOLE #	INCHES ABOVE COAL	ρ $\frac{LBS\text{-}SEC^2}{FT^4}$	V_P FT/SEC	V_S FT/SEC	(PSI x 10^6) λ	(PSI x 10^6) G	(PSI x 10^6) K	μ	E (PSI x 10^6)	REMARKS*
3	513	4.98	15,684	8,266	3.78	2.36	5.35	0.308	6.17	V_S/V_P = 0.53
3	476	4.98	18,021	8,650	6.06	2.59	7.79	0.350	6.99	V_S/V_P = 0.48
3	274	4.98	17,698	8,447	5.90	2.47	7.55	0.352	6.68	V_S/V_P = 0.48
3	492	4.98	19,923	8,818	8.35	2.69	10.14	0.378	7.41	V_S/V_P = 0.44
2	484	4.98	15,278	8,681	2.82	2.62	4.57	0.259	6.60	V_S/V_P = 0.57
2	466	4.98	20,967	9,609	8.82	3.19	10.95	0.367	8.72	V_S/V_P = 0.46
2	500	4.98	14,295	8,387	2.20	2.43	3.82	0.238	6.02	V_S/V_P = 0.59
2	531	4.98	20,185	8,790	8.75	2.67	10.53	0.383	7.72	V_S/V_P = 0.44

* NON-FISSURED

In-Situ Stress Determination
(Overcoring)

Although the available data is not enough for arriving at a definite conclusion, nonetheless some detailed selected data is presented herein. The reason for including the details is that the author strongly believed in using the research results as an integral part of teaching and as a reading assignment for the students. The overcoring data for the purpose of measuring in-situ field stresses bears the evidence that the major principal field stress is compressive and runs approximately N32 to 48E and the minor principal stress is compressive in two cases while it is tensile in the other. However, the importance of the field data lies in the direction of stresses and the magnitude of major principal stress which is about two to three times greater than the minor principal stresses.

Some benefits may be derived from the direction of stresses for surface and underground mine design. For example, the surface miner could throw the bench parallel to the major principal stresses for better breakage and fragmentation resulting in higher and more efficient coal production. Also, it is fair to say that vibration monitoring operations conducted by surface miners would be done more efficiently if they were conducted at random along the major and minor principal stresses simply because the effect of high and low field stresses on the magnitude of ground peak particle velocity cannot be ignored. The underground miners can utilize the data for the purpose of mine orientation by taking advantage of high compressive stresses for the purpose of putting the mine roof in compression and consequently decreasing the chances of roof falls.

The details of the in-situ field stress measurement are given in Tables 4 - 9 and Figures 3 - 11. Table 10 shows the details of biaxial modulus measured in the field. The biaxial modulus is about 9×10^6 psi which is surprisingly close to the uniaxial modulus measured in the rock mechanics laboratory.

Table 4

OVERCORE FIELD DATA SHEET

CLIENT'S NAME SOMED #1

JOB NUMBER ________ DATE STARTED 2/14/79 DATE COMPLETED ________

SITE Hole #2 (Near) HOLE 1

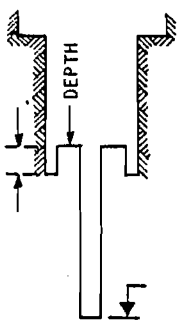
AZIMUTH DIRECTION OF HOLE Vertical COLLAR ELEVATION ________

TEST No. 1 GAUGE IDEN. B.H.G. READOUT IDEN. Vishay P-350A

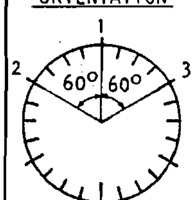
FIELD ENGINEER/GEOLOGIST Sellers, McLean, A. Hayatdavoudi

DISTANCE FROM START OF OVERCORE TO CANTILEVER TIPS 7"

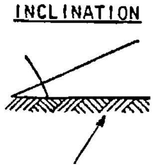
SKETCH OF BOREHOLE WITH DEPTHS (PRE-OVERCORE)



ORIENTATION



INCLINATION



SURFACE

DIST. OF OVER CORE	READING UNITS 1	2	3	TIME	REMARK
	8.50	4530	5455.	10:20	Out in the Open
	20660	5280	17120	10:25	Just in Hole
	28646	21360	20070		Recalibrated
Initial	29264	18513	19940		
	29275	18490	19890	11:50	Dry
	29270	18520	19918	11:50	Starting Water
	29335	18535	19930	11:54	
22'8"	29335	18510	19915	11:59	Starting Rotation
22'9"	29305	18530	19920	12:03	Starting Penetration
22'9.5"	29325	18540	19925	12:04	
22'10"	29345	18538	19925	12:05	Channel 1 Unsteady
22'11"	29355	18542	19934	12:06	
	29360	18540	19935	12:07	
23'0"	29360	18540	19940	12:08	
	29370	18535	19950	12:09	
23'1"	29365	18535	19968	12:10	
	29365	18535	19975	12:11	
23'2"	29370	18540	19990	12:12	
	29370	18535	19995	12:13	
23'3"	29360	18510	19950	12:14	
	29330	18475	19910	12:15	Readings Should Decrease
23'4"	29264	18415	19754	12:16	
	29110	18360	19610	12:17	
23'5"	28940	18335	19400	12:18	
	28775	18292	19315	12:19	
23'6"	28710	18255	19220	12:20	
	28650	18250	19185	12:21	
23'7"	28610	18250	19140	12:22	
	28590	18245	19130	12:23	
23'8"	28580	18266	19115	12:24	
	28570	18250	19110	12:25	
23'9"	28564	18245	19090	12:26	
	28550	18230	19085	12:27	
23'10"	28535	18215	19080	12:28	
	28500	18160	19070	12:29	
23'11"	28445	18030	19020	12:30	
	28400	17980	18990	12:32	Drill off
	8020	5400	5640		Out of Hole

DRILLING CO. ________

RIG TYPE ________ RECORDER(S)NAME(S) ________

PAGE___ OF___

DAMES & MOORE

Table 5

EVALUATION OF MAJOR AND MINOR PRINCIPAL STRESS VECTORS ASSUMING PLANE-STRAIN

BY Sellers DATE 2-15-79

CHECKED Sims, McLean DATE 5-31-79

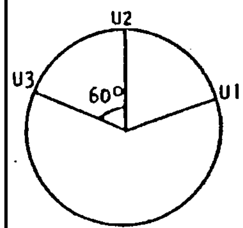
CALIBRATION X READOUT = DEFORMATION

$(K_1 = 0.985) \times (R_1 = 800) = (U_1 = 788)$

$(K_2 = 0.988) \times (R_2 = 290) = (U_2 = 287)$

$(K_3 = 0.979) \times (R_3 = 860) = (U_3 = 842)$

E MODULUS (ISOTROPIC) = 8.56 X 10^6 PSI



PLOT P
PLOT NORTH

DEFINITIONS:

$A = U_1 + U_2 + U_3$

$L = U_1 - U_2$

$m = U_2 - U_3$

$n = U_3 - U_1$

$B = \sqrt{L^2 + m^2 + n^2}$

$C = E/6d \times 10^6$ PSI/IN.

$\theta d = 1.5$ IN.

$P = C \times (A + (0.71 \times B))$

$Q = C \times (A - (0.71 \times B))$

$$\theta p = 0.5 \times \text{ARC TAN} \frac{1.73 \times (U_2 - U_3)}{(2U_1 - U_2 - U_3)}$$

θp = DIRECTION OF P OR Q COUNTER CLOCKWISE FROM U_1 (FOR POSITIVE θ)

U_i = DEFORMATION ALONG DIA.'S; (-) INDICATES DECREASING DIA.

LOCATION near Hole #2 SOMED project

HOLE NO. 1 TEST NO. 1 DEPTH 22'8"

A = 1917 (X 10^{-6} in.)

L =	501	L^2 =	251001
m =	-555	m^2 =	308025
n =	54	n^2 =	2916

$B = \sqrt{591942} = 749.63$

$C = 8.56/6 \times 1.53 \times 10^6 = 0.93 \times 10^6$

$P = (0.93 \times 10^6) \times 1917 + (0.71 \times 749.63)$

= 2277.79 psi

(+ IS COMPRESSIVE)

$Q = (0.93 \times 10^6) \times 1917 - (0.71 \times 749.63)$

= 1287.83 psi

(+ IS COMPRESSIVE)

$$\theta p \quad \frac{0.5 \times \tan^{-1} 1.73 \times (-555)/ 2(788)}{- 287 - 842} = 32\text{-}1/2^\circ$$

COMPASS DIRECTION IS: N 33° E

FILE

DAMES & MOORE

CALCULATION SHEET, SIMPLIFIED ANALYSIS

Table 6

OVERCORE FIELD DATA SHEET

CLIENT'S NAME SOMED #1

JOB NUMBER ________ DATE STARTED 2/15/79 DATE COMPLETED ________

SITE near Hole #2 HOLE #1

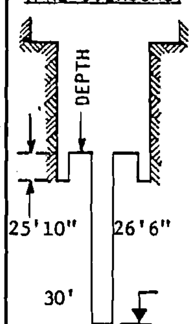
AZIMUTH DIRECTION OF HOLE vertical COLLAR ELEVATION ________

TEST No. 4 GAUGE IDEN. BHG READOUT IDEN. Vishay P-350A

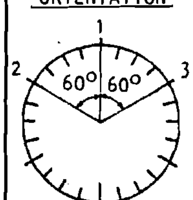
FIELD ENGINEER/GEOLOGIST Sellers, McLean, Hayatdavoudi

DISTANCE FROM START OF OVERCORE TO CANTILEVER TIPS 8"

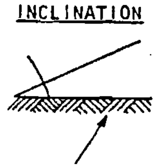
SKETCH OF BOREHOLE WITH DEPTHS (PRE-OVERCORE)



ORIENTATION



INCLINATION



SURFACE

DIST. OF OVER CORE	READING UNITS 1	2	3	TIME	REMARK
	8560	4520	4380	3:05	initial (out of hole)
	27750	24845	21065	3:21	in hole dry
	27955	24980	21300	3:26	water circulating
	27795	24815	20970	3:27	rotating
25' 10"	27800 27805	24820 24825	20965 20980	3:28 3:29	penetrating
25' 11"	27810 27810	24820 24825	20980 20980	3:30 3:31	
26'	27810 27820	24845 24830	20980 20980	3:32 3:35	drill stopped
26' 1"	27815 27815	24830 24830	20985 20990	3:36 3:37	gage may have been
26' 2"	27815 27810	24830 24830	20990 20995	3:38 3:39	lifted about 1"
26' 3"	27820 27820	24830 24830	21000 21010	3:40 3:41	
26' 4"	27830 27830	24830 24830	21015 21020	3:42 3:43	
26' 5"	27820 27800	24835 24815	21025 21000	3:44 3:45	may have hit overcore
26' 6"	27735 27700	24790 24740	20965 20860	3:46 3:47	
26' 7"	27630 27595	24700 24670	20780 20680	3:48 3:49	
26' 8"	27560 27555	24665 24670	20630 20590	3:50 3:51	
26' 9"	27545 27550	24675 24680	20570 20555	3:52 3:53	
26' 10"	27550 27545	24700 24690	20550 20540	3:54 3:55	
26' 11"	27535 27535	24700 24690	20535 20530	3:56 3:57	

DRILLING CO. ________

RIG TYPE ________ RECORDER(S)NAME(S) ________

PAGE___ OF ___

DAMES & MOORE

Table 7

EVALUATION OF MAJOR AND MINOR PRINCIPAL STRESS VECTORS ASSUMING PLANE-STRAIN

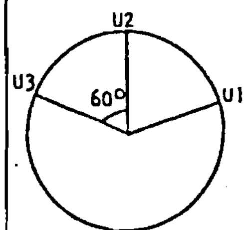
CALIBRATION X READOUT = DEFORMATION

$(K_1 = 0.985) \times (R_1 = 275) = (U_1 = 271)$

$(K_2 = 0.988) \times (R_2 = 150) = (U_2 = 148)$

$(K_3 = 0.979) \times (R_3 = 470) = (U_3 = 460)$

E MODULUS (ISOTROPIC) = 8.56 X 10^6 PSI



PLOT P
PLOT NORTH

DEFINITIONS:

$A = U_1 + U_2 + U_3$

$L = U_1 - U_2$

$m = U_2 - U_3$

$n = U_3 - U_1$

$B = \sqrt{L^2 + m^2 + n^2}$

$C = E/6d \times 10^6$ PSI/IN.

θd = 1.5 IN.

$P = C \times (A + (0.71 \times B))$

$Q = C \times (A - (0.71 \times B))$

$\theta p = 0.5 \times \text{ARC TAN} \dfrac{1.73 \times (U_2 - U_3)}{(2U_1 - U_2 - U_3)}$

θp = DIRECTION OF P OR Q COUNTER CLOCKWISE FROM U_1 (FOR POSITIVE θ)

U_1 = DEFORMATION ALONG DIA.'S; (-) INDICATES DECREASING DIA.

LOCATION near Hole #2 SOMED project

HOLE NO. 1 TEST NO. 4 DEPTH 25'10"

A =	879 (X 10^{-6} In.)		
L =	123	L^2 =	15129
m =	-312	m^2 =	97344
n =	189	n^2 =	35721

B = $\sqrt{148194}$ = 384.96

C = 8.56/6 x 1.53 x 10^6 = 0.93 x 10^6

P = 0.93 x 879 + (0.71 x 384.96) = 1071.66 psi (+ IS COMPRESSIVE)

Q = 0.93 x 879 - (0.71 x 384.96) = 563.28 psi (+ IS COMPRESSIVE)

θp = 0.5 x $\tan^{-1}$ 1.73 x (-312) / 2(271) - 148 - 460 = 42°

COMPASS DIRECTION IS: N 48° E

BY Sellers DATE 2-15-79

CHECKED Sims, McLean DATE 5-31-79

FILE

DAMES & MOORE

CALCULATION SHEET, SIMPLIFIED ANALYSIS

Table 8

OVERCORE FIELD DATA SHEET

CLIENT'S NAME SOMED #1

JOB NUMBER ______ DATE STARTED 2/15/79 DATE COMPLETED ______

SITE near Hole #2 HOLE #1

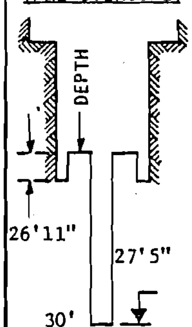
AZIMUTH DIRECTION OF HOLE vertical COLLAR ELEVATION ______

TEST No. 5 GAUGE IDEN. BHG READOUT IDEN. Vishay P-350A

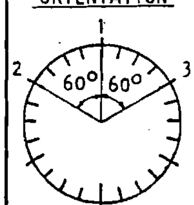
FIELD ENGINEER/GEOLOGIST Sellers, McLean, Hayatdavoudi

DISTANCE FROM START OF OVERCORE TO CANTILEVER TIPS 6"

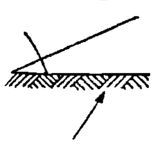
SKETCH OF BOREHOLE WITH DEPTHS (PRE-OVERCORE)



ORIENTATION



INCLINATION



SURFACE

DIST. OF OVER CORE	READING UNITS 1	2	3	TIME	REMARK
	33840	15930	18180	4:14	before circulation
					water circulating
	33880	15960	18120	4:20	rotating
26' 11"	33880 33880	15975 15960	18130 18135	4:21 4:22	penetrating
27'	33895 33895	15965 15970	18140 18150	4:23 4:24	#1 drifting some
27' 1"	33890 33890	15960 15970	18150 18130	4:25 4:26	decreasing abnormally
27' 2"	33860 33840	15960 15970	18095 18000	4:27 4:28	
27' 3"	33805 33790	15990 16020	17940 17810	4:29 4:30	
27' 4"	33770 33765	16040 16055	17760 17700	4:31 4:32	
27' 5"	33745 33740	16075 16095	17675 17640	4:33 4:34	
27' 6"	33740 33740	16105 16115	17630 17610	4:35 4:36	
27' 7"	33730 33730	16115 16110	17610 17600	4:37 4:38	
27' 8"	33730	16120	17570		
27' 9"					

DRILLING CO. ______

RIG TYPE ______ RECORDER(S)NAME(S) ______

PAGE ___ OF ___

DAMES & MOORE

EVALUATION OF MAJOR AND MINOR PRINCIPAL STRESS VECTORS ASSUMING PLANE-STRAIN

BY Sellers DATE 2-15-79

CHECKED Sims, McLean DATE 5-31-79

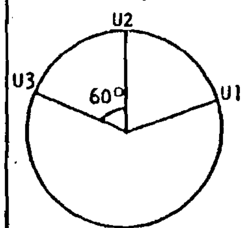
CALIBRATION X READOUT = DEFORMATION

(K_1 =0.985) X (R_1 = 160) = (U_1 = 158)

(K_2 =0.988) X (R_2 = -145) = (U_2 =-143)

(K_3 =0.979) X (R_3 = 550) = (U_3 = 538)

E MODULUS (ISOTROPIC) = 8.56 X 10^6 PSI



PLOT P
PLOT NORTH

DEFINITIONS:

$A = U_1 + U_2 + U_3$

$L = U_1 - U_2$

$m = U_2 - U_3$

$n = U_3 - U_1$

$B = \sqrt{L^2 + m^2 + n^2}$

C = E/6d X 10^6PSI/IN.

θd = 1.5 IN.

P = C X (A + (0.71 X B))

Q = C X (A - (0.71 X B))

$\theta p = 0.5 \times \text{ARC TAN} \dfrac{1.73 \times (U_2 - U_3)}{(2U_1 - U_2 - U_3)}$

θp = DIRECTION OF P OR Q COUNTER CLOCKWISE FROM U_1 (FOR POSITIVE θ)

U_i = DEFORMATION ALONG DIA.'S; (-) INDICATES DECREASING DIA.

LOCATION near Hole #2 SOMED Project

HOLE NO. 1 TEST NO. 5 DEPTH 26'11"

A = 553 (X 10^{-6} in.)

L =	301	L^2 =	90601
m =	-681	m^2 =	463761
n =	380	n^2 =	144400

B = $\sqrt{698762}$ = 835.92

C = 8.56/6 x 1.53 x 10^6 = 0.93 x 10^6

P = (0.93 x 10^6) x 553 + (0.71 x 835.92)
= 1066.25 psi
(+ IS COMPRESSIVE)

Q = (0.93 x 10^6) x 553 - (0-71 x 835.92)
= -37.67
(+ IS COMPRESSIVE)

θp 0.5 x $\tan^{-1}$ 1.73 x (-681)/ 2(158)
+ 143 - 538 = 43°

COMPASS DIRECTION IS: N 47° E

FILE

CALCULATION SHEET, SIMPLIFIED ANALYSIS

DAMES & MOORE

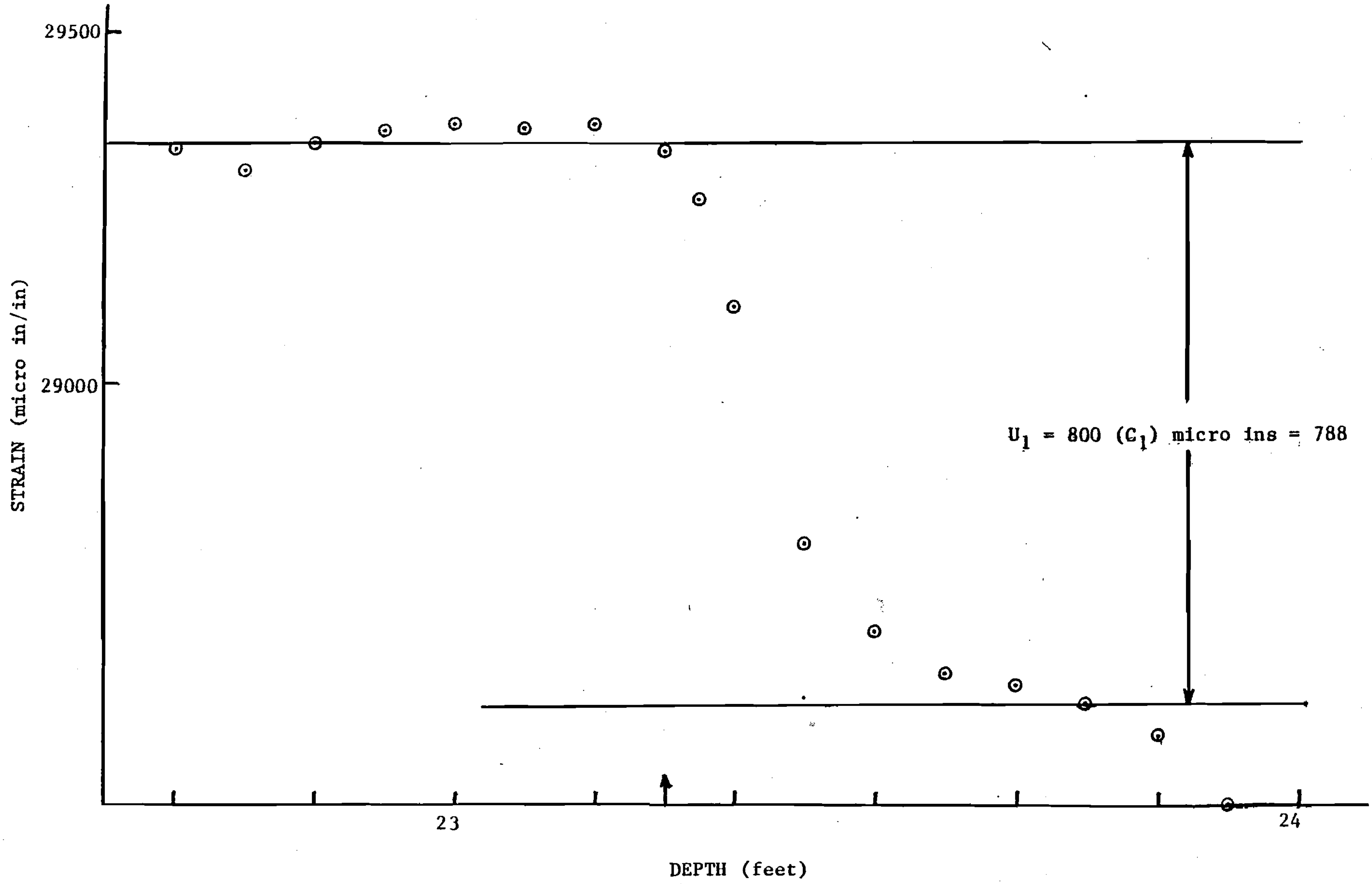


Figure 3 - In-Situ Stress Measurement - Strain vs. Depth

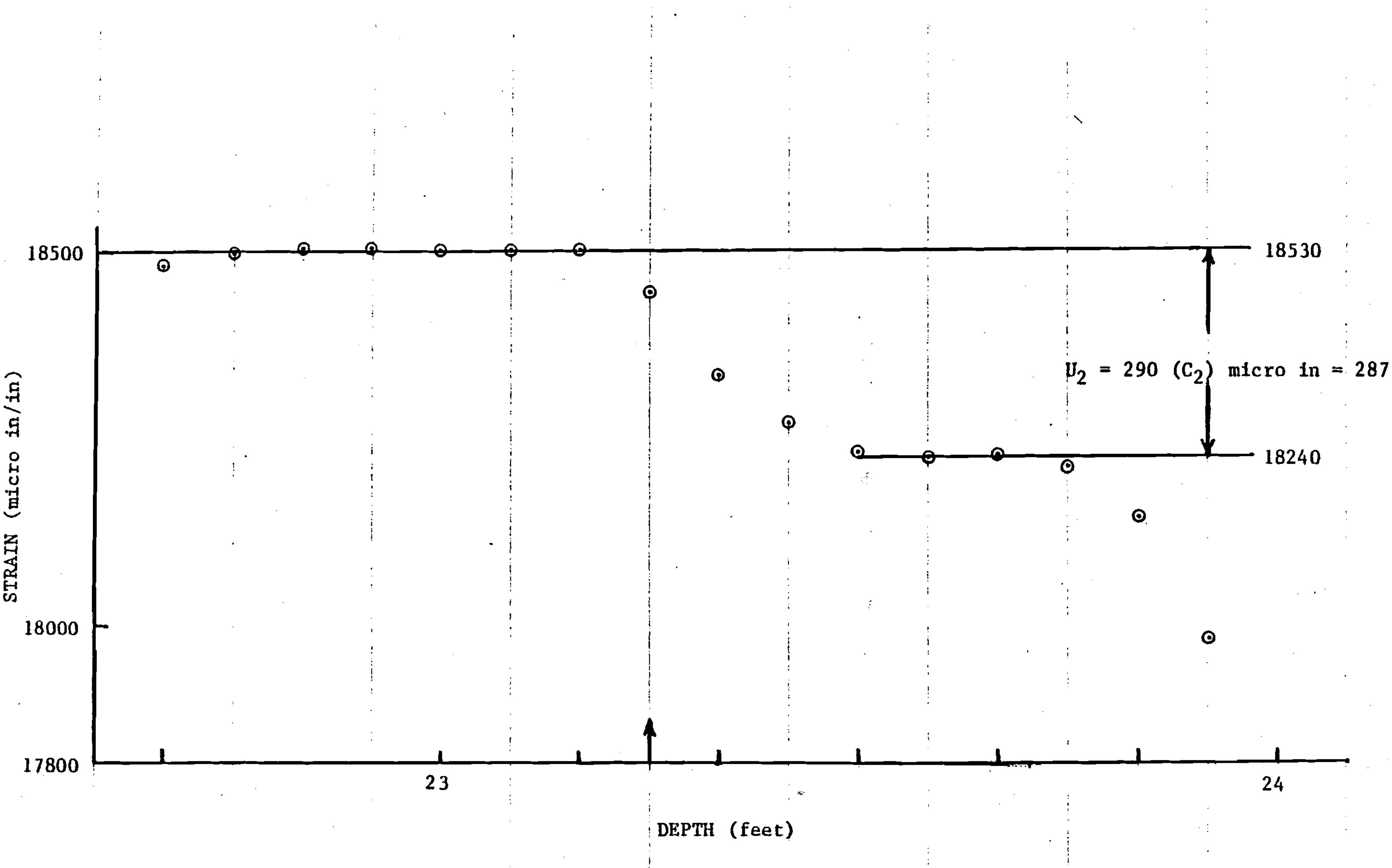


Figure 4 - In-Situ Stress Measurement - Strain vs. Depth

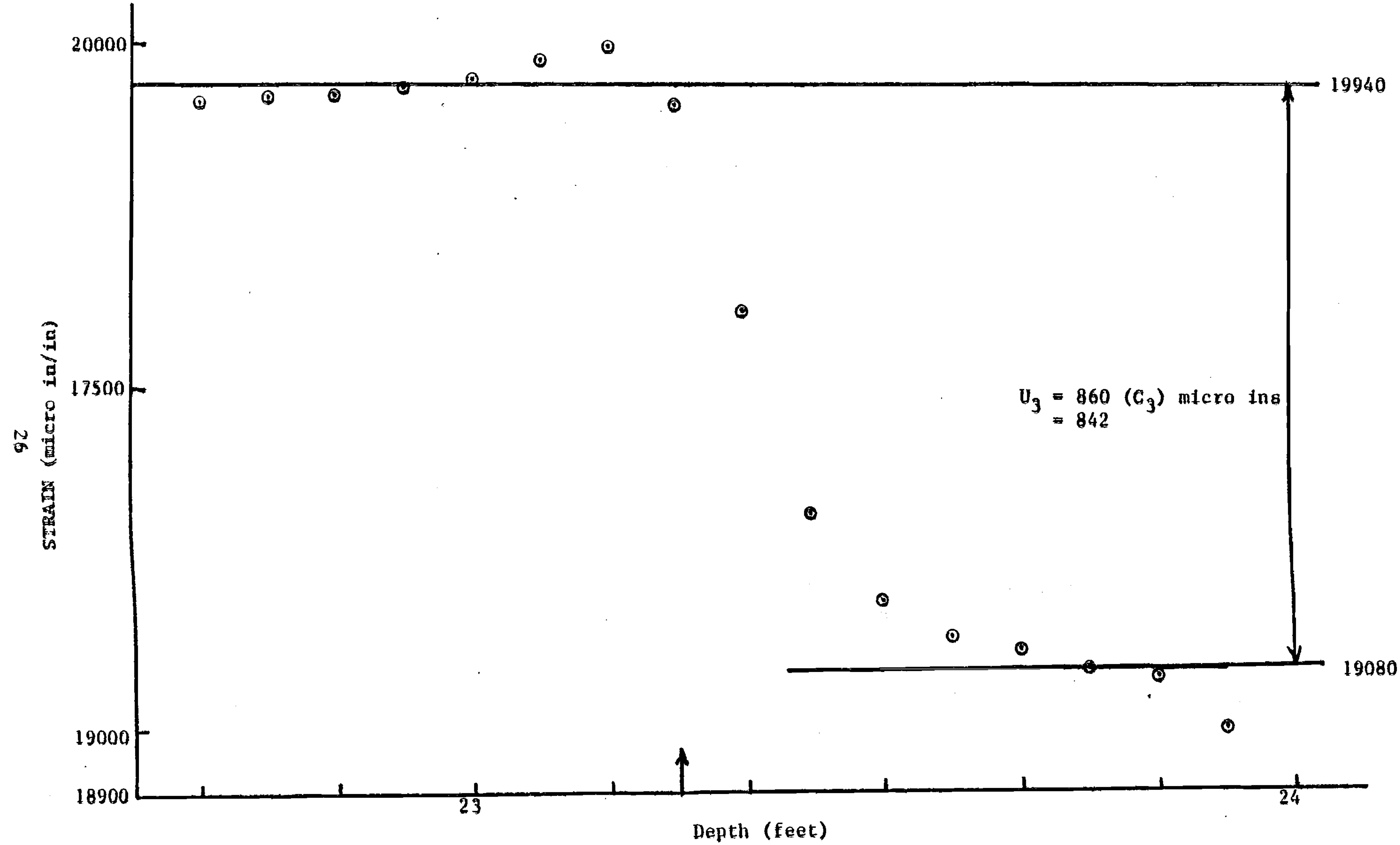


Figure 5 - In-Situ Stress Measurement - Strain vs. Depth

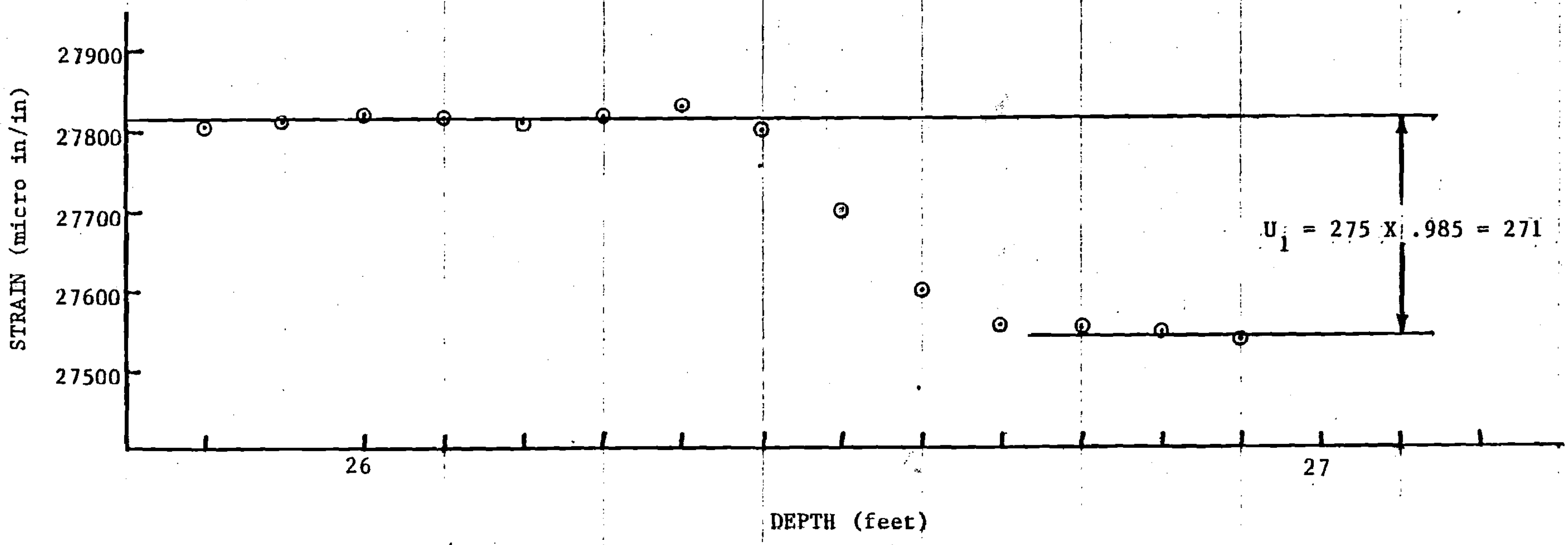


Figure 6 – In-Situ Stress Measurement – Strain vs. Depth

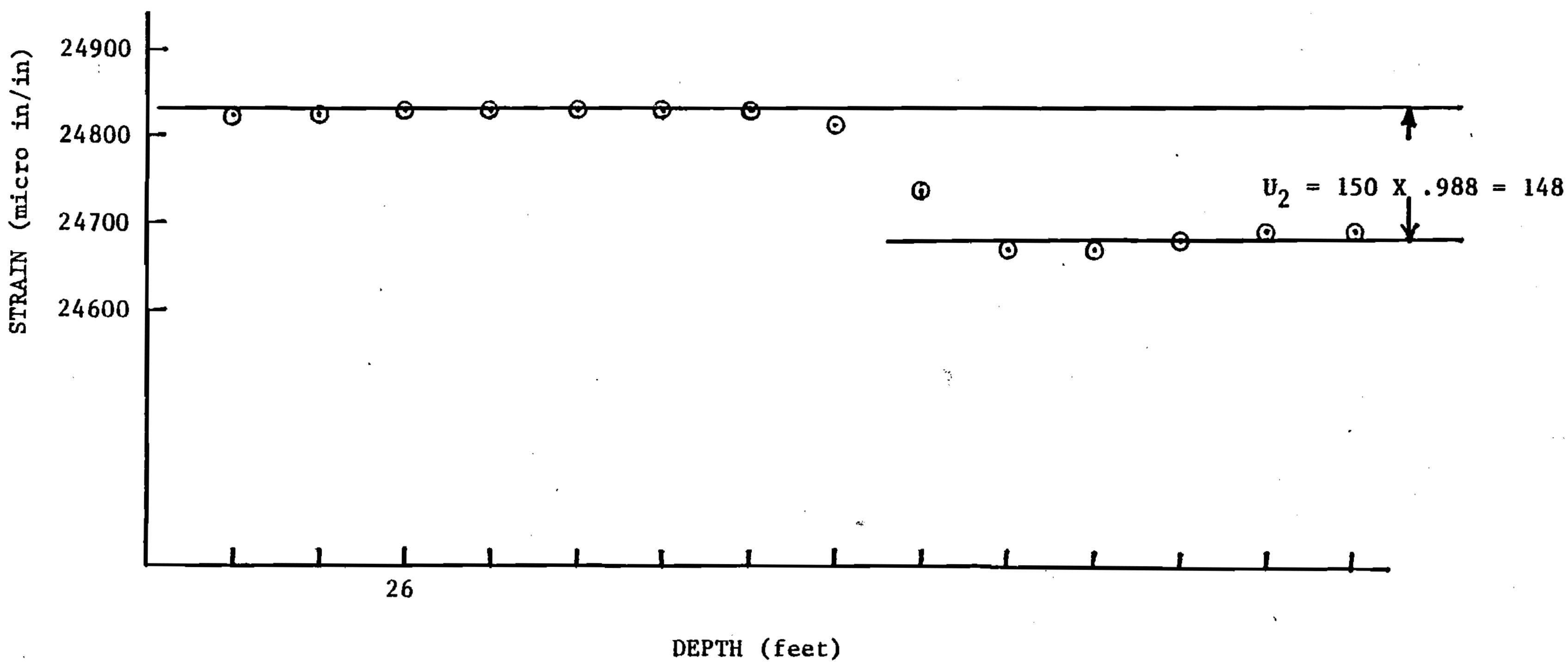


Figure 7 - In-Situ Stress Measurement - Strain vs. Depth

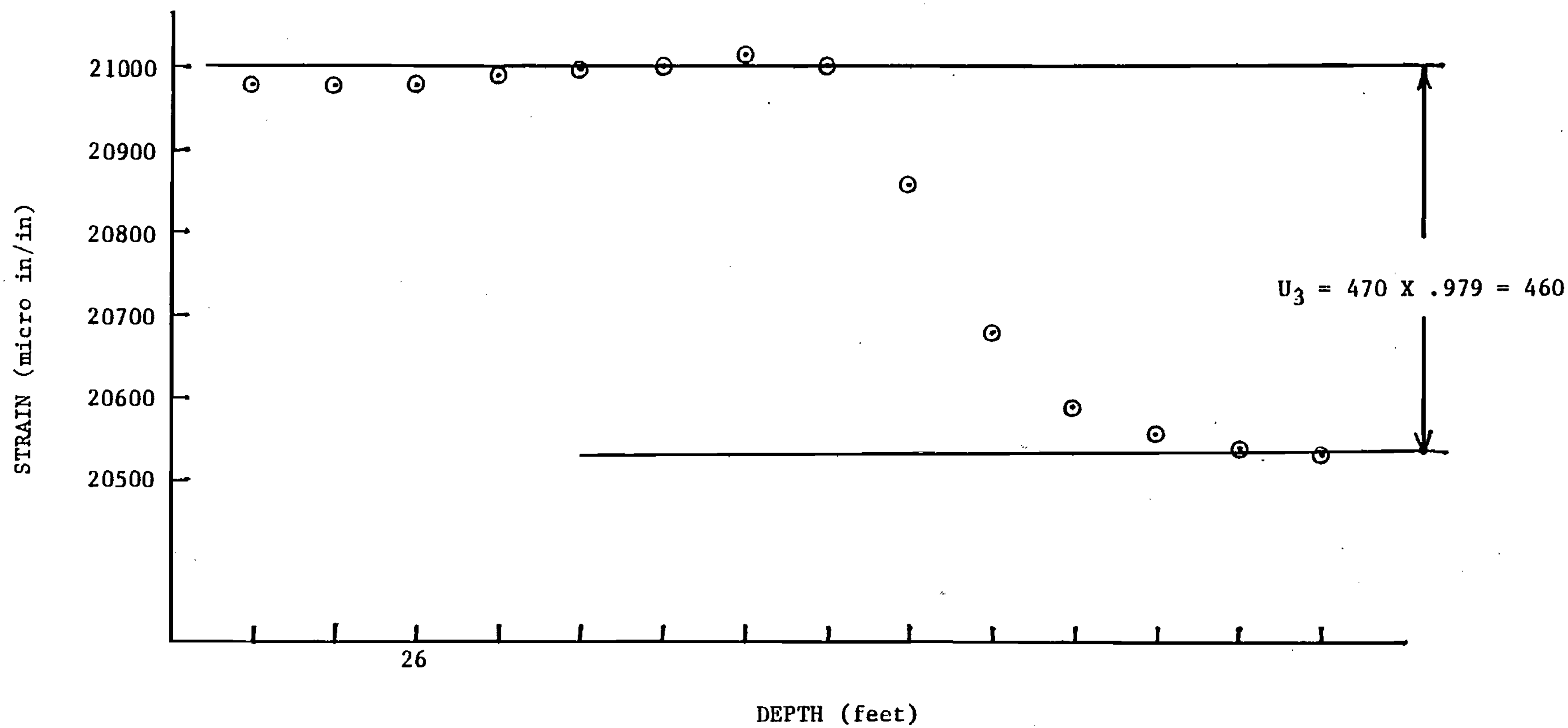


Figure 8 - In-Situ Stress Measurement - Strain vs. Depth

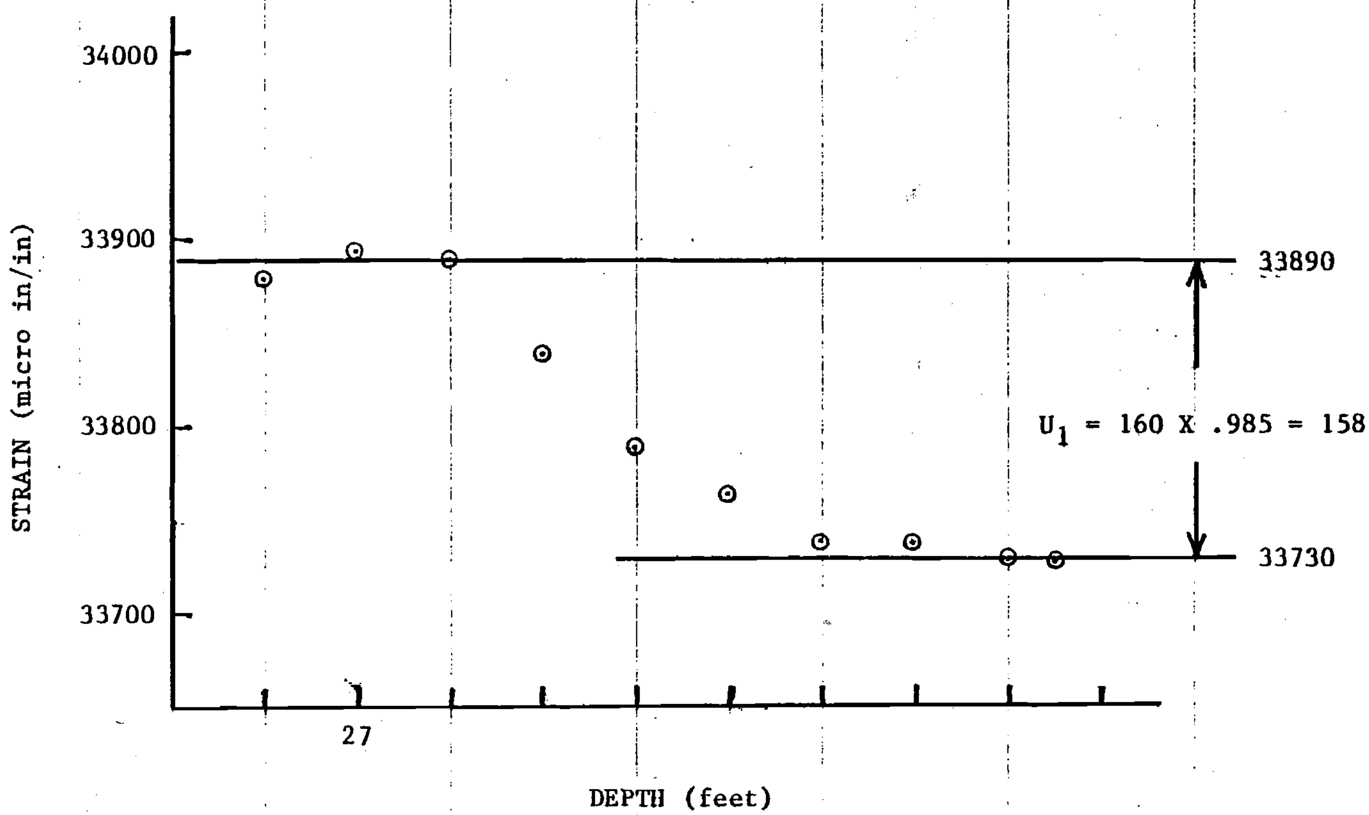


Figure 9 - In-Situ Stress Measurement - Strain vs. Depth

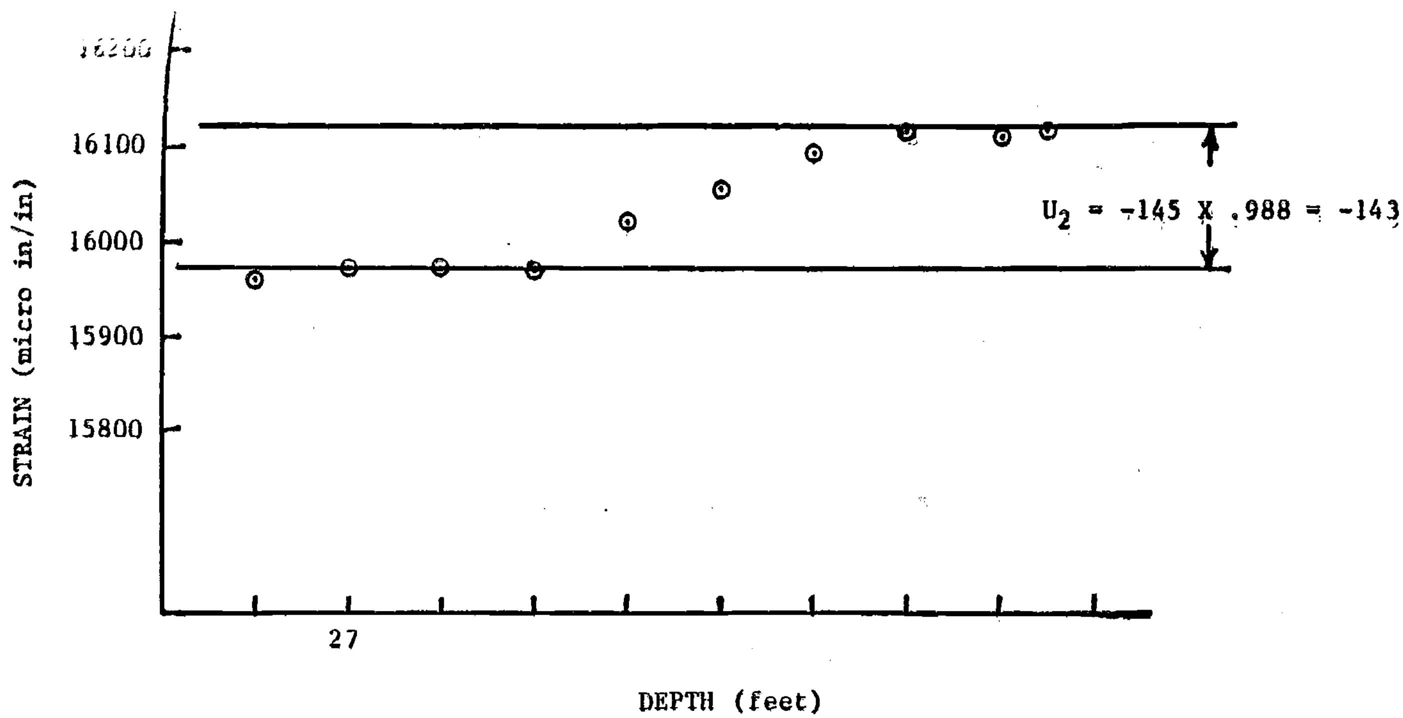


Figure 10 - In-Situ Stress Measurement - Strain vs. Depth

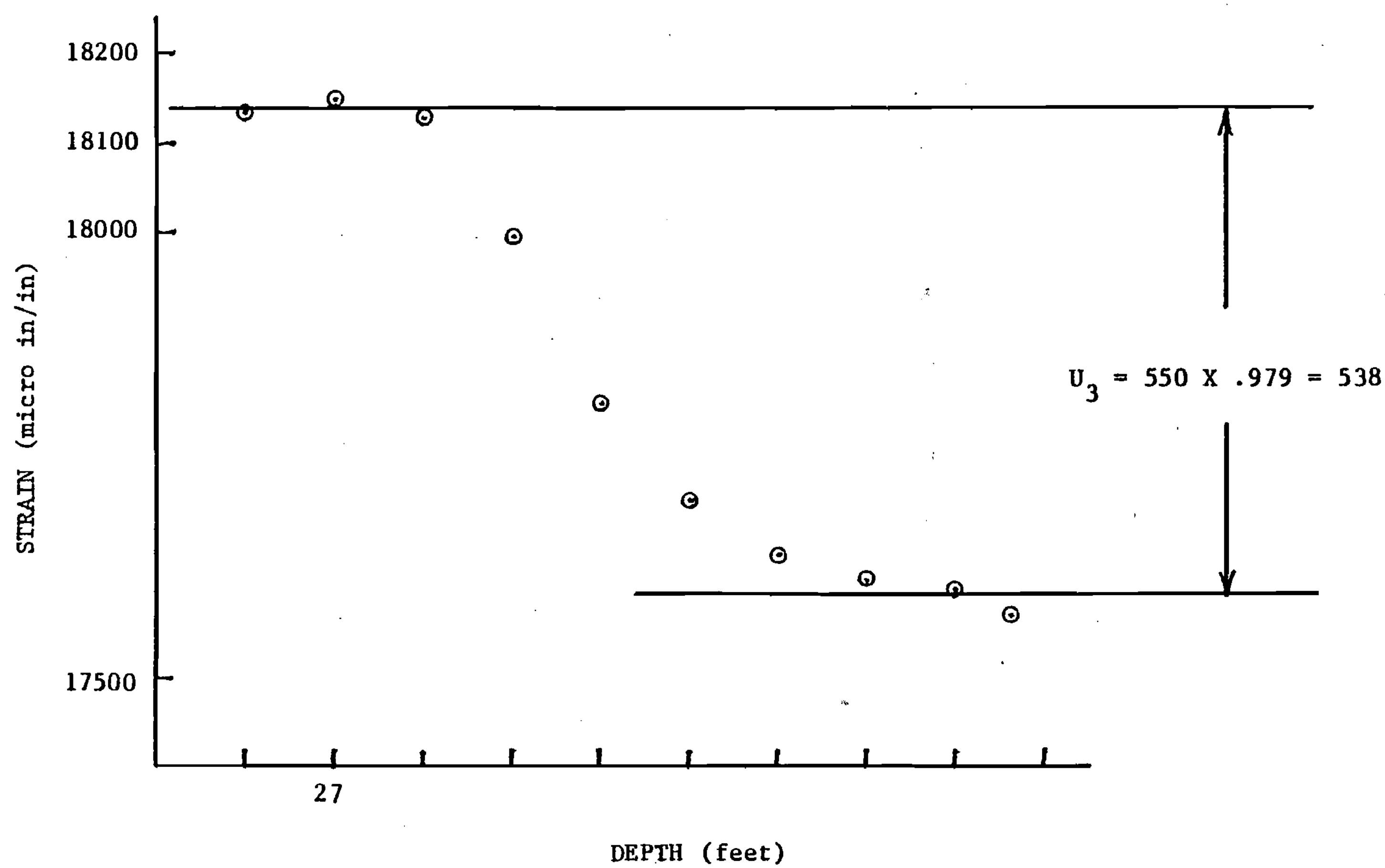


Figure 11 - In-Situ Stress Measurement - Strain vs. Depth

Table 10

DAMES & MOORE

BI-AXIAL TEST DATA SHEET

Gauge: BHG

Readout: Vishay P-350A

Chamber: BMC

Core diameter: 6"

Core length: 14'6"

File: SOMED

By: Sellers

Date: 2/15/79

Boring:

Depth:

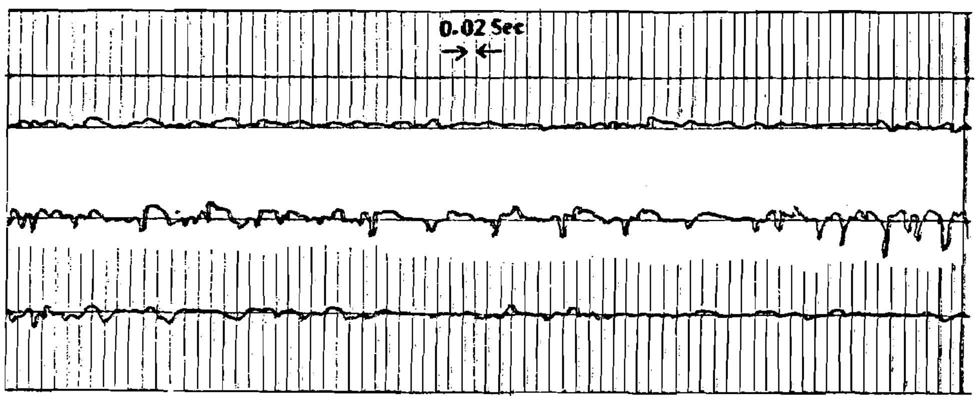
Applied Pressure	Axis no.1	ΔR_1	Axis no.2	ΔR_2	Axis no.3	ΔR_3	
0	33220		20980		30612		
0	33105		20778		30110		
0	33105		20780		30112		
200	33150		20830		30170		
400	33225		20905		30224		
600	33308		20982		30298		
800	33438		21072		30390		
1000	33505		21150		30467		
0	33126		20787		30097		
200	33184		20841		30160		
400	33236		20908		30214		
600	33322		20980		30284		
800	33402		21059		30358		
1000	33463		21130		30432		
0	33090		20764		30066		
0	33098		20767		30060		
200	33155		20820		30123		
400	33227		20895		30192		
600	33303		20966		30263		
800	33388		21048		30341		
1000	33468		21124		30414		
0	33042		20758		30057		

Field Measurement of Peak Ground Particle Velocity

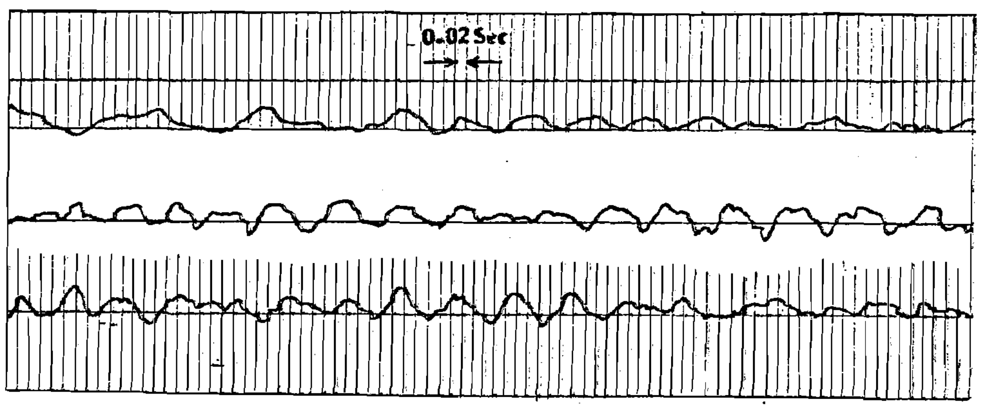
The first question that was answered was the difference between the amplitude and the frequency of seismograms obtained for the same blast and the same distance from the shot, one in underground and one at the surface, in a series of preliminary tests. The result is shown clearly in Figure 12. The waves recorded at the surface have lower frequency (average 14 HZ) and higher amplitude while the waves recorded at the mine roof in the underground mine have higher frequency (average 50 HZ) and lower amplitude. The second question that was addressed was the difference between the magnitude of peak ground particle velocity obtained by using a VS-6000 velocity meter mounted on the T-board at the center of the cross-cut and the VS-1400 velocity meter held by epoxy to the roof at the center of the cross-cut. Figures 13 - 16 clearly show that the roof bolt or type instrument used has a definite effect on the amplitude of peak ground particle velocity. Tables 11 - 18 give approximate peak particle velocities for approximate scaled distances which may be used for blast designs. Despite these facts, for practical design purposes with an added safety factor, the principal investigator favors the instrument giving higher peak particle velocities. During the course of underground work, it was also found that the highest amplitude of vibration, as was expected, came from the center of the cross-cut, not from places adjacent to the pillars.

The field work started after the preliminary measurement and analysis and with it several questions were asked that had to be answered. They are as follows:

Typical Vibration Trace for the Same Shot and Same Distance



Underground



Surface

Figure 12 - VS 1200 Seismograms

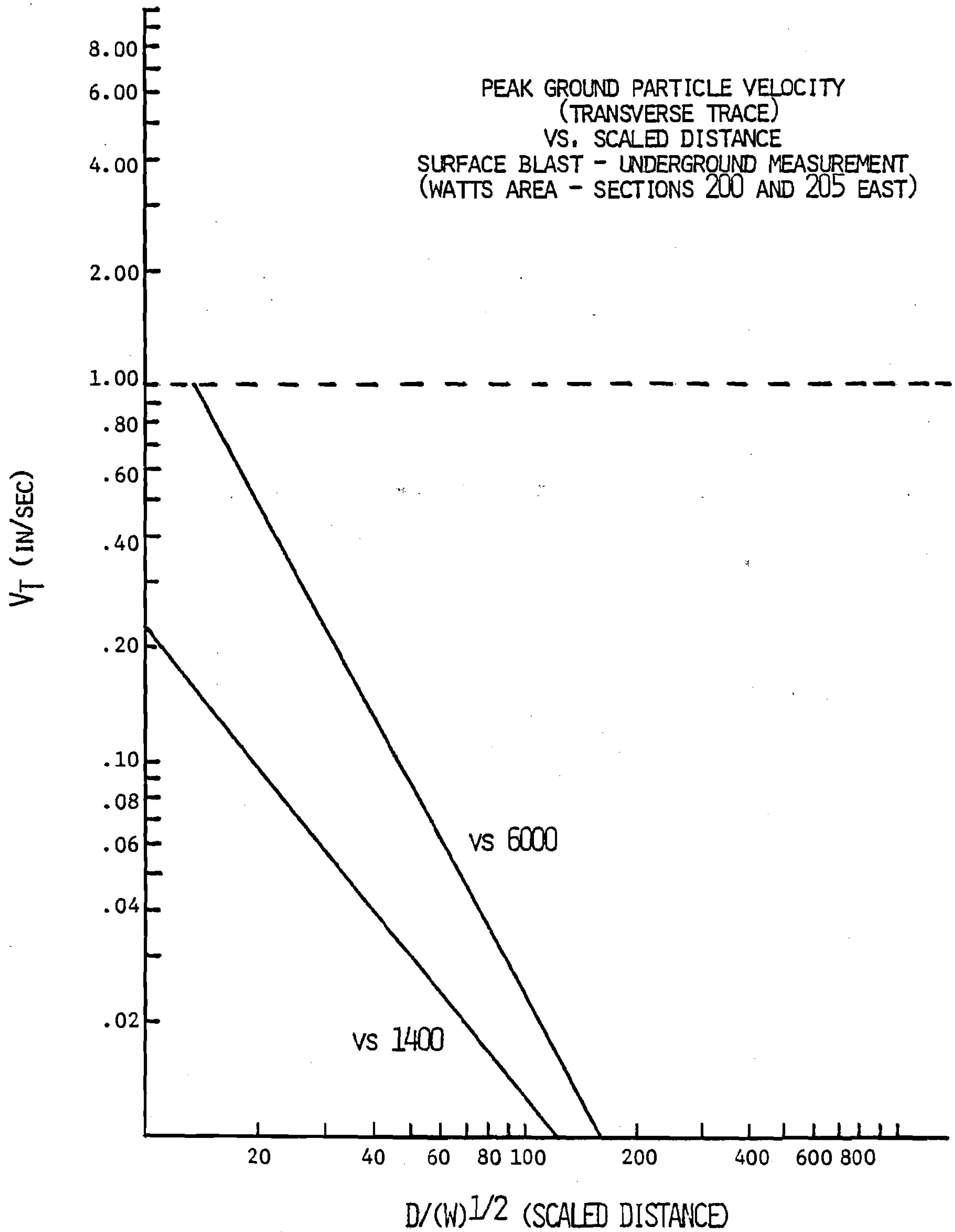


Figure 13 - Comparison of Transverse Trace of T-Board Mounted (Bolted) VS-6000 and Epoxy Held VS-1400 Velocity Meters

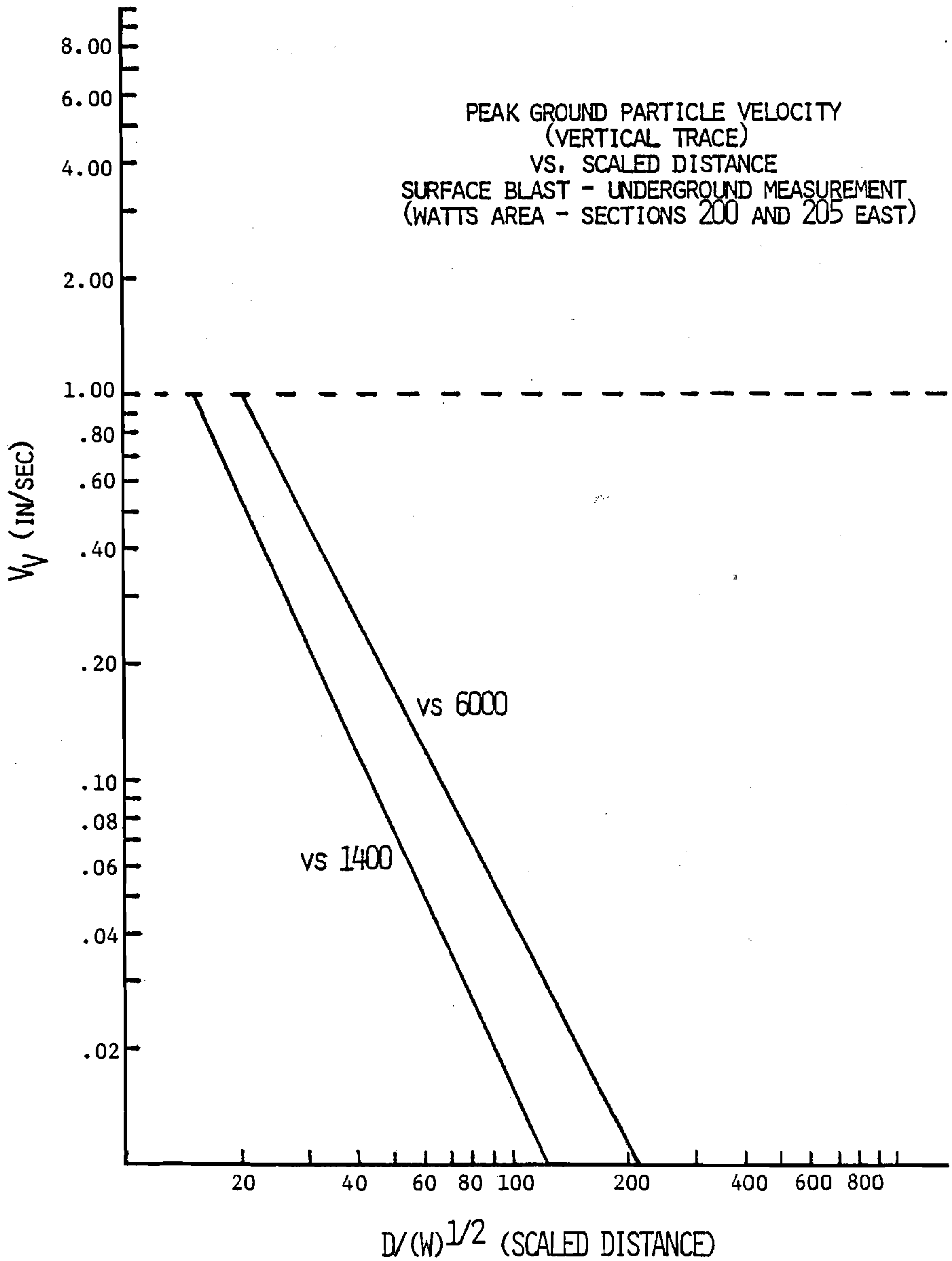


Figure 14 - Comparison of Vertical Trace of T-Board Mounted (Bolted) VS-6000 and Epoxy Held VS-1400 Velocity Meters

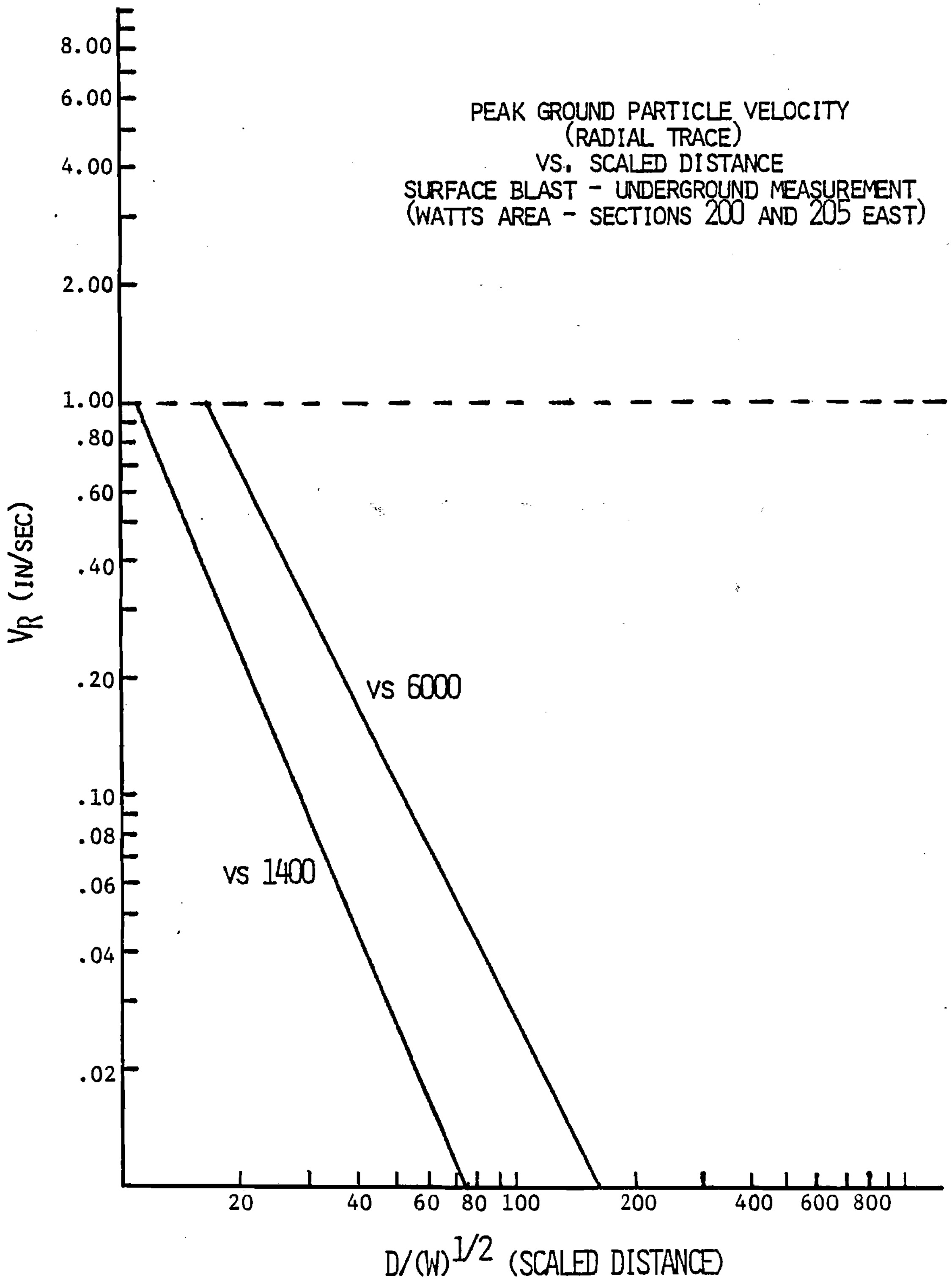


Figure 15 - Comparison of Radial Trace of T-Board Mounted (Bolted) VS-6000 and Epoxy Held VS-1400 Velocity Meters

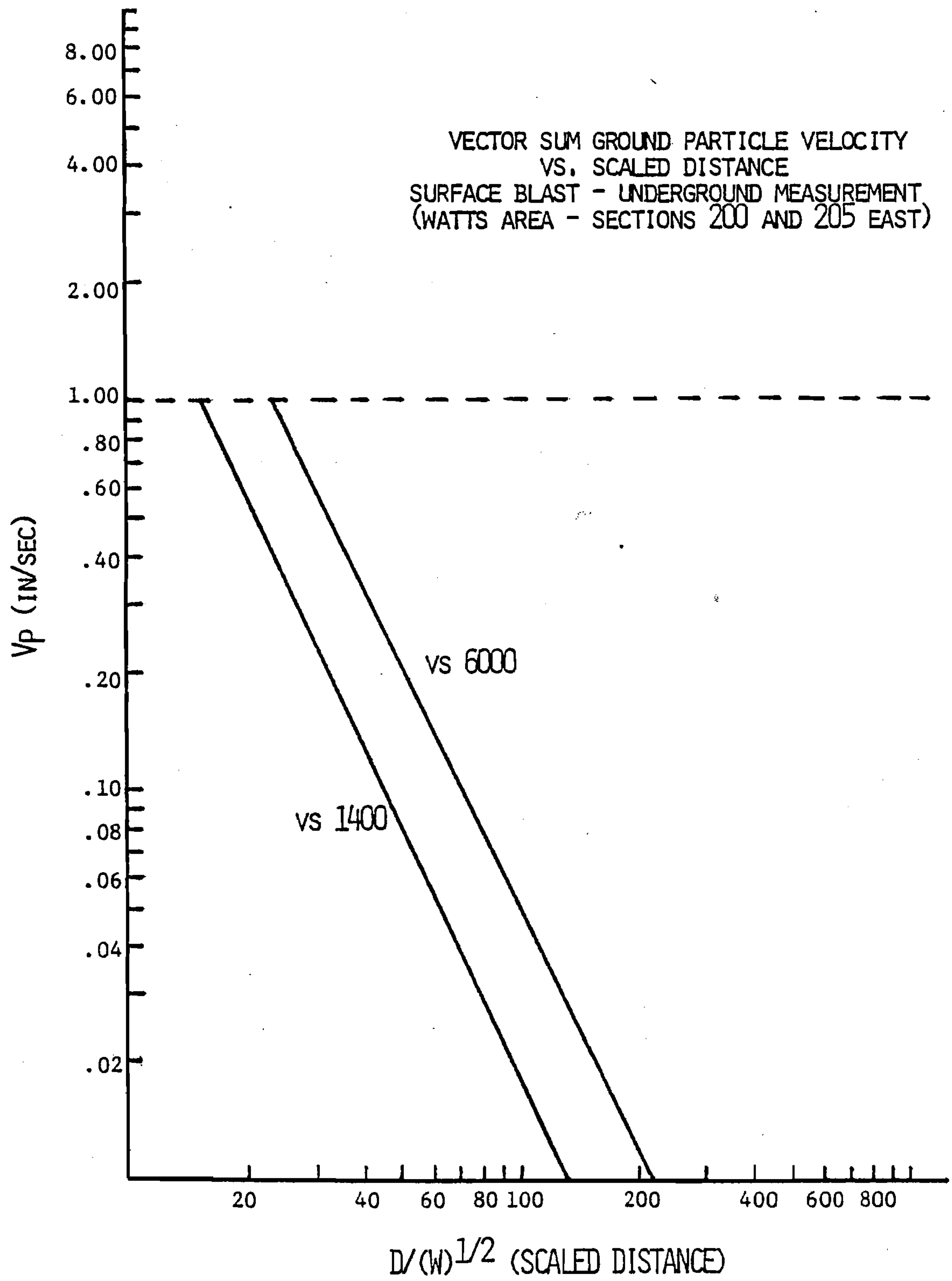


Figure 16 - Comparison of Vector Sum of T-Board Mounted (Bolted) VS-6000 and Epoxy Held VS-1400 Velocity Meters

Table 11 - Approximate Peak Ground Particle Velocity
and Approximate Equivalent Scaled Distance
Transverse Trace for VS-6000 Velocity Meter

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	13.543173	.06275361	60	.02139667	107	.01086955	154
.94016021	14	.06085364	61	.02102964	108	.01073948	155
.82693296	15	.0590407	62	.0206722	109	.01061178	156
.73339312	16	.0573095	63	.02032402	110	.01048641	157
.65518664	17	.05565514	64	.01998478	111	.0103633	158
.58910561	18	.05407319	65	.01965416	112	.01024249	159
.53274375	19	.05255915	66	.01933188	113	.01012364	160
.48426631	20	.05110942	67	.01901766	114	.010007	161
.44225438	21	.04972027	68	.01871122	115	.00989241	162
.40559615	22	.04838834	69	.01841231	116	.00977982	163
.37341027	23	.0471105	70	.01812067	117	.0096692	164
.34499048	24	.04588381	71	.01783608	118	.00956048	165
.3197655	25	.04470557	72	.01755831	119	.00945364	166
.29726898	26	.0435732	73	.01728713	120	.00934862	167
.27711717	27	.04248435	74	.01702234	121	.00924538	168
.25899185	28	.04143689	75	.01676374	122	.00914399	169
.24262734	29	.04042842	76	.01651112	123	.00904419	170
.22780041	30	.03945739	77	.01626431	124	.00894597	171
.21432227	31	.03852158	78	.01602313	125	.00884947	172
.20203242	32	.03761955	79	.01578741	126	.00875456	173
.19079373	33	.0367496	80	.01555697	127	.00866121	174
.18048838	34	.03591021	81	.01533167	128	.00856938	175
.1710147	35	.03509993	82	.01511135	129	.00847904	176
.16228461	36	.03431743	83	.01489585	130	.00839015	177
.15422146	37	.03356144	84	.01468505	131	.00830279	178
.14675826	38	.03283075	85	.0144788	132	.00821662	179
.13983628	39	.03212425	86	.01427697	133	.00813192	180
.13340388	40	.03144085	87	.01407943	134	.00804855	181
.12741545	41	.03077955	88	.01388607	135	.00796659	182
.12183069	42	.0301394	89	.01369676	136	.00788571	183
.11661347	43	.0295195	90	.01351138	137	.00780629	184
.11173211	44	.02891909	91	.01332984	138	.00772788	185
.10715804	45	.02833705	92	.01315202	139	.00765089	186
.10286568	46	.02777294	93	.01297783	140	.00757486	187
.0988321	47	.0272259	94	.01280715	141	.00750019	188
.0950367	48	.02669526	95	.0126399	142	.00742645	189
.09146087	49	.02618036	96	.01247609	143	.00735391	190
.08808781	50	.02568057	97	.01231532	144	.00728246	191
.08490231	51	.0251953	98	.01215782	145	.00721207	192
.08189055	52	.02472409	99	.01200349	146	.00714272	193
.07904	53	.0242661	100	.01185195	147	.00707449	194
.07633921	54	.02382113	101	.01170343	148	.00700706	195
.07377776	55	.02338857	102	.01155776	149	.00694071	196
.07134611	56	.02296798	103	.01141485	150	.00687532	197
.06903555	57	.02255891	104	.01127465	151	.00681087	198
.06683808	58	.02216093	105	.01113707	152	.00674735	199
.06474635	59	.02177365	106	.01100206	153	.00668474	200

Table 12 - Approximate Peak Ground Particle Velocity
and Approximate Equivalent Scaled Distance
Vertical Trace for VS-6000 Velocity Meter

Particle Velocity	Scaled Distance						
1	20.650397	.10615526	65	.03793464	110	.01939596	155
.96769639	21	.103032	66	.03726905	111	.01915351	156
.88352992	22	.10004554	67	.03662095	112	.01891561	157
.8099541	23	.09718809	68	.03598973	113	.01868215	158
.7452583	24	.09445202	69	.03537481	114	.01845301	159
.68806486	25	.09183078	70	.03477563	115	.0182281	160
.63725341	26	.08931794	71	.03419166	116	.0180073	161
.59190571	27	.08690769	72	.03362238	117	.01779052	162
.55126307	28	.08459429	73	.03306731	118	.01757766	163
.51469453	29	.0823726	74	.03252596	119	.01736863	164
.48167142	30	.08023803	75	.0319979	120	.01716333	165
.45174833	31	.07818594	76	.03148279	121	.01696167	166
.42454785	32	.07621214	77	.03097992	122	.01676358	167
.39974842	33	.07431279	78	.03048917	123	.01656895	168
.3770746	34	.07248399	79	.03001008	124	.01637773	169
.35628942	35	.07072224	80	.02954239	125	.01618982	170
.33718817	36	.06902451	81	.02908541	126	.01600515	171
.31959314	37	.06738763	82	.02863914	127	.01582364	172
.30334954	38	.0658087	83	.02820313	128	.01564523	173
.28832192	39	.06428502	84	.02777708	129	.01546983	174
.27439153	40	.06281402	85	.02736068	130	.0152974	175
.26145371	41	.06139332	86	.02695364	131	.01512785	176
.24941607	42	.06002061	87	.02655568	132	.01496113	177
.2381967	43	.05869376	88	.02616654	133	.01479717	178
.22772284	44	.05741074	89	.02578595	134	.0146359	179
.21792966	45	.05616964	90	.02541366	135	.01447728	180
.20875925	46	.05496865	91	.02504944	136	.01432124	181
.20015979	47	.05380605	92	.02469304	137	.01416774	182
.19208444	48	.0526802	93	.02434426	138	.0140167	183
.18449157	49	.05158958	94	.02400287	139	.01386808	184
.17734326	50	.05053272	95	.02366866	140	.01372183	185
.1706054	51	.04950825	96	.02334143	141	.01357791	186
.16424701	52	.04851483	97	.02302109	142	.01343624	187
.15824006	53	.04755124	98	.02270716	143	.0132968	188
.15255901	54	.04661628	99	.02239974	144	.01315954	189
.14718062	55	.04570882	100	.02209857	145	.01302441	190
.1420837	56	.0448278	101	.02180348	146	.01289136	191
.13724899	57	.04397229	102	.02151431	147	.01276036	192
.13265845	58	.04314102	103	.02123088	148	.01263135	193
.12829613	59	.04233337	104	.02095307	149	.01250431	194
.12414709	60	.04154835	105	.02068072	150	.01237929	195
.12019735	61	.04078513	106	.02041367	151	.01225596	196
.11643456	62	.04004299	107	.02015181	152	.01213456	197
.11284698	63	.03932087	108	.01989498	153	.01201498	198
.10942385	64	.03861836	109	.01964308	154	.01189716	199
						.01178119	200

Table 13 - Approximate Peak Ground Particle Velocity and Approximate Equivalent Scaled Distance Radial Trace for VS-6000 Velocity Meter

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	16.89727	.07369912	62	.02420761	108	.01188047	154
.98791482	17	.07137118	63	.02376416	109	.01172721	155
.88089343	18	.06915172	64	.02333277	110	.01157699	156
.79035157	19	.06703411	65	.02291301	111	.01142945	157
.71307278	20	.0650122	66	.02250447	112	.0112848	158
.64658871	21	.06308033	67	.02210674	113	.01114288	159
.58897941	22	.06123323	68	.02171945	114	.01100361	160
.53873352	23	.05946601	69	.02134225	115	.01086694	161
.49464801	24	.05777412	70	.02097478	116	.0107328	162
.45575596	25	.05615336	71	.0206167	117	.01060112	163
.42127286	26	.0545998	72	.02026771	118	.01047185	164
.3905569	27	.05310976	73	.0199275	119	.01034492	165
.3630789	28	.05167984	74	.01959578	120	.01022039	166
.33839942	29	.05030686	75	.01927226	121	.0100979	167
.31615117	30	.0489878	76	.01895668	122	.00997768	168
.29602505	31	.04771991	77	.01864878	123	.0098596	169
.27775964	32	.04650057	78	.01834831	124	.0097436	170
.26113258	33	.04532732	79	.01805505	125	.00962964	171
.24595367	34	.04419799	80	.01776874	126	.00951766	172
.23205958	35	.04311011	81	.01748929	127	.00940762	173
.21930937	36	.04206195	82	.01721618	128	.00929947	174
.20758088	37	.04105153	83	.01694951	129	.00919318	175
.19676785	38	.04007705	84	.01668898	130	.0090887	176
.18677744	39	.03913683	85	.0164344	131	.00898609	177
.17752834	40	.03822939	86	.0161856	132	.008885	178
.16894901	41	.03735291	87	.0159424	133	.00878571	179
.16097631	42	.0365063	88	.01570464	134	.00868807	180
.15355441	43	.03568812	89	.01547215	135	.00859205	181
.14663374	44	.03489712	90	.01524478	136	.00849761	182
.1401702	45	.0341321	91	.01502238	137	.00840472	183
.1341244	46	.03339194	92	.0148048	138	.00831334	184
.12846112	47	.03267558	93	.01459192	139	.00822344	185
.12314877	48	.03198209	94	.01438369	140	.00813509	186
.11815896	49	.03131025	95	.01417979	141	.00804796	187
.11346612	50	.03065942	96	.01398008	142	.00796232	188
.10904714	51	.03002866	97	.01378466	143	.00787803	189
.10488112	52	.02941715	98	.0135933	144	.00779508	190
.10094914	53	.02882411	99	.0134059	145	.00771342	191
.097234	54	.0282488	100	.01322234	146	.00763304	192
.09372005	55	.02769054	101	.01304252	147	.00755391	193
.090393	56	.02714864	102	.01286634	148	.00747601	194
.08723988	57	.02662248	103	.01269371	149	.0073993	195
.08424875	58	.02611146	104	.01252452	150	.00732377	196
.08140872	59	.025615	105	.01235879	151	.00724938	197
.07870977	60	.02513255	106	.01219612	152	.00717612	198
.07614272	61	.02466369	107	.01203675	153	.00710397	199
						.00703299	200

Table 14 - Approximate Vector Sum Ground Particle Velocity
and Approximate Equivalent Scaled Distance
Vector Sum for VS-6000 Velocity Meter

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	23.115453	.10948554	68	.03865354	113	.01944254	158
.92590617	24	.10625745	69	.03796165	114	.01919279	159
.85157523	25	.10316896	70	.03728803	115	.0189476	160
.7857867	26	.10021216	71	.03663205	116	.01870712	161
.72728448	27	.09737979	72	.03599308	117	.01847117	162
.67503465	28	.09466472	73	.03537056	118	.01823961	163
.62818	29	.09206085	74	.03476392	119	.01801234	164
.5860052	30	.08956214	75	.03417264	120	.01778927	165
.54790915	31	.087163	76	.03359629	121	.01757027	166
.51338425	32	.08485824	77	.0330341	122	.01735527	167
.48199932	33	.08264301	78	.03248588	123	.01714415	168
.45338617	34	.08051272	79	.03195119	124	.01693684	169
.42722881	35	.07846312	80	.03142939	125	.01673323	170
.40325511	36	.07649029	81	.03092007	126	.01653324	171
.38122948	37	.07459018	82	.03042303	127	.01633689	172
.3609472	38	.07275954	83	.02993778	128	.01614389	173
.34222961	39	.07099496	84	.02946396	129	.01595416	174
.32492045	40	.06929339	85	.02900121	130	.01576783	175
.30888249	41	.06765163	86	.0285492	131	.01558472	176
.29399434	42	.06606715	87	.02810758	132	.01540476	177
.28014942	43	.06453726	88	.02767606	133	.01522787	178
.26725265	44	.0630595	89	.02725431	134	.01505398	179
.25521981	45	.06163153	90	.02684206	135	.01488303	180
.24397564	46	.06025113	91	.02643902	136	.01471496	181
.23345297	47	.05891625	92	.02604491	137	.01454979	182
.2235916	48	.05762488	93	.02565959	138	.01438717	183
.21433745	49	.05637518	94	.02528248	139	.01422734	184
.20564185	50	.05516549	95	.02491366	140	.01407013	185
.19746092	51	.05399382	96	.02455289	141	.01391559	186
.18975496	52	.05285899	97	.02419964	142	.01376337	187
.18248807	53	.05175919	98	.023854	143	.01361371	188
.17562762	54	.05069309	99	.02351565	144	.01346646	189
.16914398	55	.04965924	100	.02318449	145	.01332156	190
.16301012	56	.04865654	101	.02286002	146	.01317898	191
.15720147	57	.04768367	102	.02254237	147	.01303865	192
.15169559	58	.04673947	103	.02223123	148	.01290053	193
.1464716	59	.04582281	104	.02192644	149	.01276458	194
.14151093	60	.04493265	105	.02162783	150	.01263075	195
.13679615	61	.04406797	106	.02133523	151	.012499	196
.13231134	62	.04322782	107	.02104848	152	.01236928	197
.12804184	63	.04241128	108	.02076742	153	.01224155	198
.12397413	64	.04161748	109	.02049192	154	.01211578	199
.12009575	65	.04084558	110	.02022181	155	.01199192	200
.11639518	66	.04009489	111	.01995697	156		
.11286173	67	.03936435	112	.01969726	157		

Table 15 - Approximate Peak Ground Particle Velocity and Approximate Equivalent Scaled Distance Transverse Trace for VS-1400 Velocity Meter

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	2.9729554	.02860381	52	.0123885	102	.00754832	152
.98881583	3	.02793505	53	.01223939	103	.00748719	153
.69173789	4	.02729409	54	.01209339	104	.00742676	154
.52429939	5	.026679	55	.01195041	105	.0073673	155
.41805763	6	.02608858	56	.01181055	106	.00730879	156
.34521388	7	.02552134	57	.01167362	107	.00725091	157
.29245715	8	.02497598	58	.01153952	108	.00719396	158
.2526567	9	.02445139	59	.01140818	109	.00713781	159
.22166647	10	.02394618	60	.01127951	110	.00708244	160
.19692021	11	.02345969	61	.01115344	111	.00702785	161
.17674898	12	.02299056	62	.01102999	112	.00697401	162
.16002309	13	.02253829	63	.01090889	113	.00692091	163
.14595164	14	.02210164	64	.01079007	114	.00686853	164
.13396603	15	.02168012	65	.01067366	115	.00681687	165
.12364683	16	.02127299	66	.0105595	116	.0067659	166
.11467862	17	.02087926	67	.01044752	117	.00671562	167
.10681975	18	.02049869	68	.01033767	118	.00666601	168
.09988229	19	.02013026	69	.01022988	119	.00661706	169
.09371752	20	.01977371	70	.01012411	120	.00656875	170
.08820712	21	.0194284	71	.0100203	121	.00652107	171
.08325514	22	.01909383	72	.00991849	122	.00647402	172
.07878328	23	.01876951	73	.00981834	123	.00642757	173
.07472702	24	.01845501	74	.00972019	124	.00638172	174
.07103273	25	.01814999	75	.00962361	125	.00633646	175
.0676555	26	.01785375	76	.00952884	126	.00629178	176
.06455743	27	.01756623	77	.00943574	127	.00624766	177
.06170633	28	.01728696	78	.00934427	128	.00620419	178
.05907473	29	.0170156	79	.00925449	129	.00616108	179
.05663898	30	.01675183	80	.00916605	130	.00611869	180
.0543787	31	.01649535	81	.00907923	131	.00607664	181
.05227617	32	.01624588	82	.00899388	132	.0060352	182
.05031595	33	.01600313	83	.00890997	133	.00599426	183
.04848453	34	.01576686	84	.00882746	134	.00595383	184
.04677001	35	.0155368	85	.00874632	135	.00591388	185
.04516191	36	.01531274	86	.00866652	136	.00587442	186
.04365093	37	.01509444	87	.00858802	137	.00583543	187
.04222881	38	.0148817	88	.0085108	138	.0057969	188
.04088818	39	.01467431	89	.00843482	139	.00575883	189
.03962247	40	.01447208	90	.00836005	140	.00572121	190
.03842576	41	.01427482	91	.00828648	141	.00568403	191
.03729275	42	.01408236	92	.00821406	142	.00564739	192
.03621865	43	.01389454	93	.00814278	143	.00561097	193
.03519912	44	.01371129	94	.00807261	144	.00557507	194
.03423025	45	.01353217	95	.00800352	145	.00553958	195
.03330848	46	.01335731	96	.00793559	146	.0055045	196
.03243056	47	.0131865	97	.0078685	147	.00546982	197
.03159355	48	.01301969	98	.00780252	148	.00543553	198
.03079474	49	.01285645	99	.00773754	149	.00540163	199
.03003166	50	.01269697	100	.00767352	150	.0053681	200
.02930204	51	.01254102	101	.00761046	151		

Table 16 - Approximate Peak Ground Particle Velocity and Approximate Equivalent Scaled Distance Vertical Trace for VS-1400 Velocity Meter

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	15.067181	.04545945	62	.01325022	109	.00605373	156
.87699647	16	.04389762	63	.01298844	110	.00596989	157
.76819091	17	.04241278	64	.01273413	111	.00588755	158
.6779999	18	.04100005	65	.01248702	112	.00580694	159
.60245337	19	.03965487	66	.01224683	113	.00572793	160
.53857911	20	.03837308	67	.01201332	114	.00565048	161
.48411762	21	.03715089	68	.01178624	115	.00557455	162
.43732718	22	.03598444	69	.01156537	116	.00550019	163
.39684859	23	.03487072	70	.01135047	117	.00542708	164
.36160837	24	.03380653	71	.01114135	118	.00535547	165
.33075096	25	.03278903	72	.0109378	119	.00528523	166
.30358706	26	.03181556	73	.01073962	120	.00521633	167
.27955691	27	.03088366	74	.01054664	121	.00514872	168
.25820208	28	.02999102	75	.01035867	122	.00508249	169
.23914451	29	.0291355	76	.01017554	123	.00501739	170
.22207011	30	.02831508	77	.00999719	124	.0049534	171
.20671631	31	.02752792	78	.00982317	125	.00489079	172
.19286239	32	.02677225	79	.00965363	126	.00482914	173
.18032132	33	.02604644	80	.00948831	127	.0047687	174
.16893461	34	.02534897	81	.00932719	128	.00470936	175
.15856647	35	.02467849	82	.00916984	129	.00465119	176
.14910048	36	.02403336	83	.00901641	130	.00459387	177
.14043626	37	.02341261	84	.00886671	131	.00453766	178
.13248699	38	.02281496	85	.00872069	132	.00448246	179
.12517682	39	.02223939	86	.00857797	133	.00442823	180
.11844016	40	.02168455	87	.00843871	134	.00437494	181
.11221925	41	.02114976	88	.00830273	135	.00432269	182
.1064634	42	.02063397	89	.00816992	136	.00427115	183
.10112802	43	.02013632	90	.00804018	137	.00422069	184
.09617361	44	.01965598	91	.00791342	138	.0041709	185
.09156525	45	.01919215	92	.00778956	139	.00412206	186
.08727185	46	.01874411	93	.0076685	140	.00407405	187
.08326572	47	.01831115	94	.00755016	141	.00402685	188
.07952212	48	.01789262	95	.00743447	142	.00398044	189
.0760189	49	.01748799	96	.00732134	143	.00393481	190
.07273629	50	.01709637	97	.00721071	144	.00388993	191
.06965611	51	.01671759	98	.0071025	145	.0038458	192
.06676252	52	.01635073	99	.00699663	146	.0038024	193
.06404087	53	.01599558	100	.00689306	147	.0037597	194
.06147809	54	.01565157	101	.0067917	148	.0037177	195
.05906192	55	.01531823	102	.0066925	149	.00367638	196
.05678181	56	.01499515	103	.00659549	150	.00363573	197
.05462778	57	.0146819	104	.00650033	151	.00359573	198
.05259081	58	.0143781	105	.00640725	152	.00355636	199
.05066271	59	.01408338	106	.0063161	153	.00351762	200
.04883594	60	.01379738	107	.00622683	154		
.04710363	61	.01351976	108	.00613949	155		

Table 17 - Approximate Peak Ground Particle Velocity
and Approximate Equivalent Scaled Distance
Radial Trace for VS-1400 Velocity Meter

Particle Velocity	Scaled Distance						
1	11.004308	.01759261	59	.00420052	107	.00172211	155
.81187653	12	.01689549	60	.00410755	108	.00169567	156
.66965692	13	.01623665	61	.00401746	109	.0016698	157
.56029404	14	.01561379	62	.00393015	110	.00164459	158
.47459648	15	.01502404	63	.0038455	111	.00161972	159
.40633794	16	.01446542	64	.00376341	112	.00159547	160
.35118825	17	.01393576	65	.00368378	113	.00157173	161
.30606553	18	.01343314	66	.00360651	114	.00154859	162
.26873172	19	.0129558	67	.00353152	115	.00152573	163
.23753188	20	.01250212	68	.00345871	116	.00150344	164
.21122263	21	.01207061	69	.00338801	117	.00148161	165
.18885612	22	.01165988	70	.00331934	118	.00146023	166
.16970042	23	.01126867	71	.00325263	119	.00143928	167
.15318344	24	.01089577	72	.00318789	120	.00141875	168
.13885337	25	.01054011	73	.00312477	121	.00139864	169
.1263497	26	.01020067	74	.0030635	122	.00137892	170
.11538221	27	.00987659	75	.00300392	123	.0013596	171
.1057153	28	.00956671	76	.00294596	124	.00134066	172
.09715629	29	.0092705	77	.00288958	125	.00132219	173
.08954604	30	.00898712	78	.00283471	126	.00130388	174
.08275302	31	.00871584	79	.0027813	127	.00128603	175
.07666713	32	.00845601	80	.00272931	128	.00126852	176
.07119609	33	.00820701	81	.00267868	129	.00125134	177
.06626169	34	.00796827	82	.00262937	130	.0012345	178
.06179771	35	.00773924	83	.00258134	131	.00121797	179
.0577479	36	.00751942	84	.00253454	132	.00120175	180
.05406382	37	.00730833	85	.00248893	133	.00118584	181
.05070383	38	.00710554	86	.00244448	134	.00117022	182
.04763198	39	.00691062	87	.00240114	135	.0011549	183
.0448171	40	.00672318	88	.00235888	136	.00113985	184
.04223205	41	.00654286	89	.00231766	137	.00112508	185
.03985312	42	.00636931	90	.00227746	138	.00111069	186
.03765954	43	.00620221	91	.00223824	139	.00109635	187
.03563304	44	.00604125	92	.00219997	140	.00108237	188
.03375754	45	.00588613	93	.00216261	141	.00106864	189
.03201877	46	.0057366	94	.00212615	142	.00105516	190
.03040413	47	.00559249	95	.00209055	143	.00104192	191
.02890238	48	.00545325	96	.0020558	144	.00102891	192
.02750352	49	.00531897	97	.00202185	145	.00101613	193
.02619861	50	.00518932	98	.00198879	146	.00100357	194
.02497964	51	.00506419	99	.0019563	147	.00099124	195
.02383944	52	.00494311	100	.00192464	148	.00097911	196
.02277154	53	.00482617	101	.00189371	149	.0009672	197
.02177011	54	.00471312	102	.00186348	150	.00095548	198
.02082992	55	.00460377	103	.00183392	151	.00094397	199
.01994618	56	.00449798	104	.00180503	152	.00093266	200
.0191146	57	.00439561	105	.00177678	153		
.01833126	58	.00429659	106	.00174914	154		

Table 18 - Approximate Vector Sum Ground Particle Velocity and Approximate Equivalent Scaled Distance Vector Sum for VS-1400 Velocity Meter

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	15.411605	.05150258	61	.01533376	107	.0070926	153
.92239583	16	.04972839	62	.01502939	108	.00699367	154
.80937948	17	.04804219	63	.01473369	109	.00689676	155
.7155377	18	.04643827	64	.01444633	110	.00680189	156
.6368062	19	.04491163	65	.01416729	111	.00670873	157
.57013721	20	.04345736	66	.01389588	112	.00661752	158
.51321018	21	.042071	67	.01363211	113	.00652812	159
.46423376	22	.04074843	68	.0133756	114	.00644047	160
.42180802	23	.03948585	69	.01312619	115	.00635453	161
.38482616	24	.03827972	70	.01288335	116	.00627026	162
.35240446	25	.03712676	71	.01264711	117	.00618762	163
.32383031	26	.03602394	72	.01241717	118	.00610656	164
.29852437	27	.03496842	73	.01219339	119	.00602705	165
.27601169	28	.03395756	74	.01197527	120	.00594904	166
.2558998	29	.03298891	75	.01176291	121	.00587251	167
.23786287	30	.03206018	76	.01155602	122	.0057974	168
.2216278	31	.03116923	77	.01135441	123	.00572379	169
.2069649	32	.03031406	78	.01115791	124	.00565135	170
.19367965	33	.0294928	79	.01096635	125	.00558034	171
.18160656	34	.02870371	80	.01077956	126	.00551062	172
.17060405	35	.02794515	81	.0105974	127	.00544218	173
.16055056	36	.02721557	82	.0104197	128	.00537497	174
.15134118	37	.02651354	83	.01024634	129	.00530897	175
.142885	38	.02583771	84	.01007716	130	.00524415	176
.13510293	39	.02518689	85	.00991204	131	.00518048	177
.12792597	40	.02455961	86	.00975085	132	.00511793	178
.12129365	41	.02395502	87	.00959348	133	.00505659	179
.11515282	42	.02337197	88	.00943989	134	.00499612	180
.10945663	43	.02280947	89	.00928968	135	.0049368	181
.10416362	44	.02226656	90	.00914303	136	.0048785	182
.09923706	45	.02174237	91	.00899975	137	.00482121	183
.09464424	46	.02123604	92	.00885974	138	.00476499	184
.09035601	47	.02074689	93	.00872299	139	.00470953	185
.08634634	48	.02027386	94	.00858911	140	.00465511	186
.08259187	49	.01981655	95	.00845831	141	.00460161	187
.07907164	50	.01937418	96	.00833041	142	.004549	188
.07576677	51	.01894612	97	.00820532	143	.00449726	189
.07266024	52	.01853176	98	.00808296	144	.00444649	190
.06973668	53	.01813053	99	.00796326	145	.00439635	191
.06698216	54	.0177419	100	.00784613	146	.00434713	192
.06438403	55	.01736534	101	.0077315	147	.00429871	193
.0619308	56	.01700036	102	.00761931	148	.00425108	194
.05961203	57	.0166465	103	.00750959	149	.00420422	195
.05741817	58	.01630333	104	.00740197	150	.00415811	196
.05534051	59	.01597041	105	.00729679	151	.00411274	197
.05337108	60	.01564734	106	.00719358	152	.00406808	198
						.00402414	199
						.00398088	200

1) How does the average surface ground particle velocity compare with the average ground particle velocity at the underground mine roof for the same blast monitored simultaneously at the same distance from the blast? Based on VS-6000 data, Figures 17 - 20 show that on the average the surface blasts give higher peak particle velocity for transverse trace up to about 140 scaled distance, 45 scaled distance for vertical trace, 450 scaled distance for radial trace, and 50 scaled distance for vector sum ground particle velocity. It should be noted that caution must be exercised for the regions near the surface and underground lines intersection. Tables 19 - 26 give approximate ground particle velocities at an equivalent scaled distance for simultaneous blasts monitored at the same distance from the blast.

   Appendixes A and B show the statistical analysis of data for Figures 17 - 20 for two different models. The analysis points to the fact that the square root scaled distance wave propagation law predicts the surface ground particle velocity invariably better than ground particle velocity at the underground mine roof.

2) How does the average ground particle velocity at the underground mine roof measured at some angle to the surface blast compare with the average ground particle velocity measured at the underground mine roof directly beneath the surface blast? Figures 21 - 24 depict the fact that up to some scaled distance

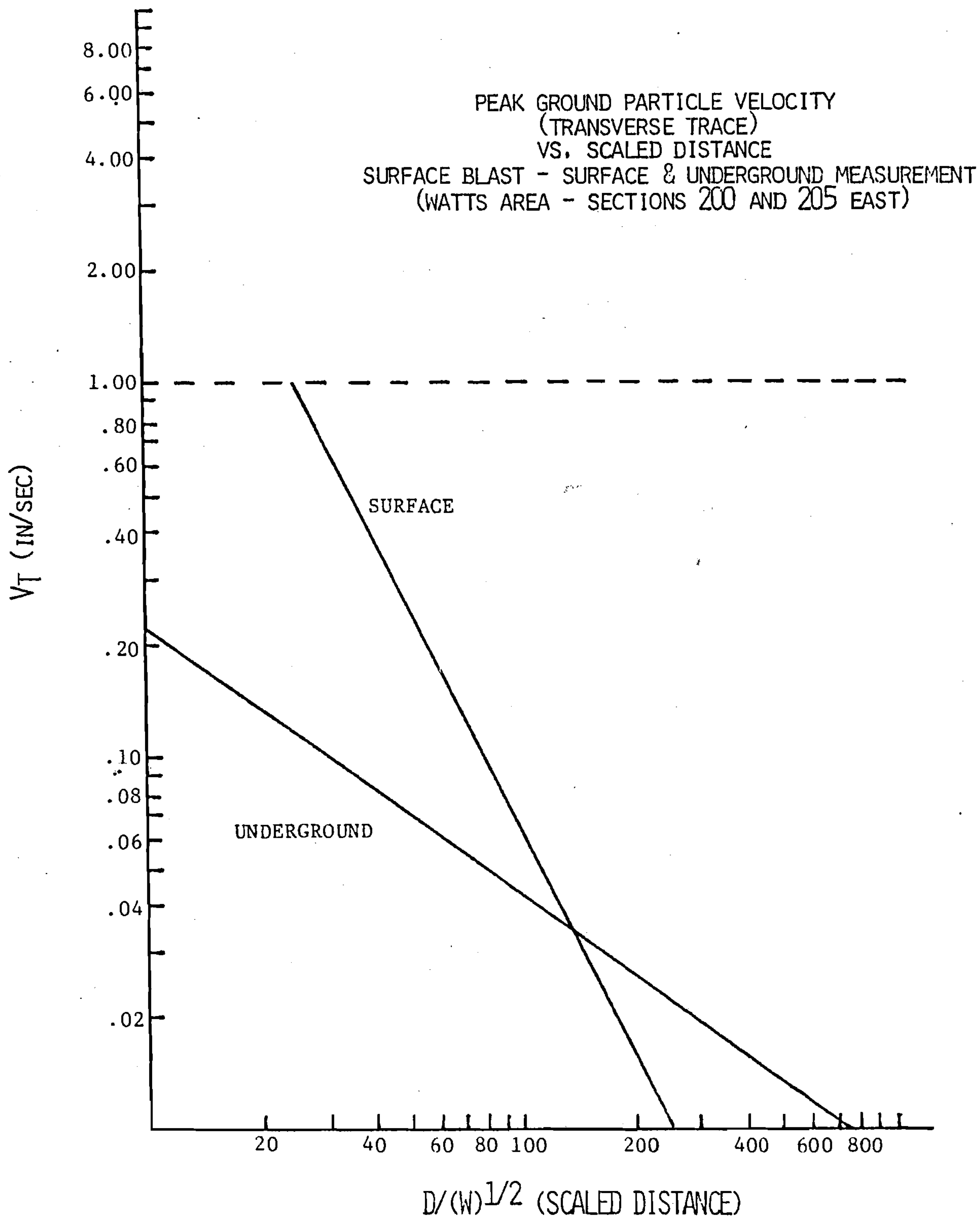


Figure 17 - Comparison of Transverse Trace of Simultaneous Monitoring Experiment

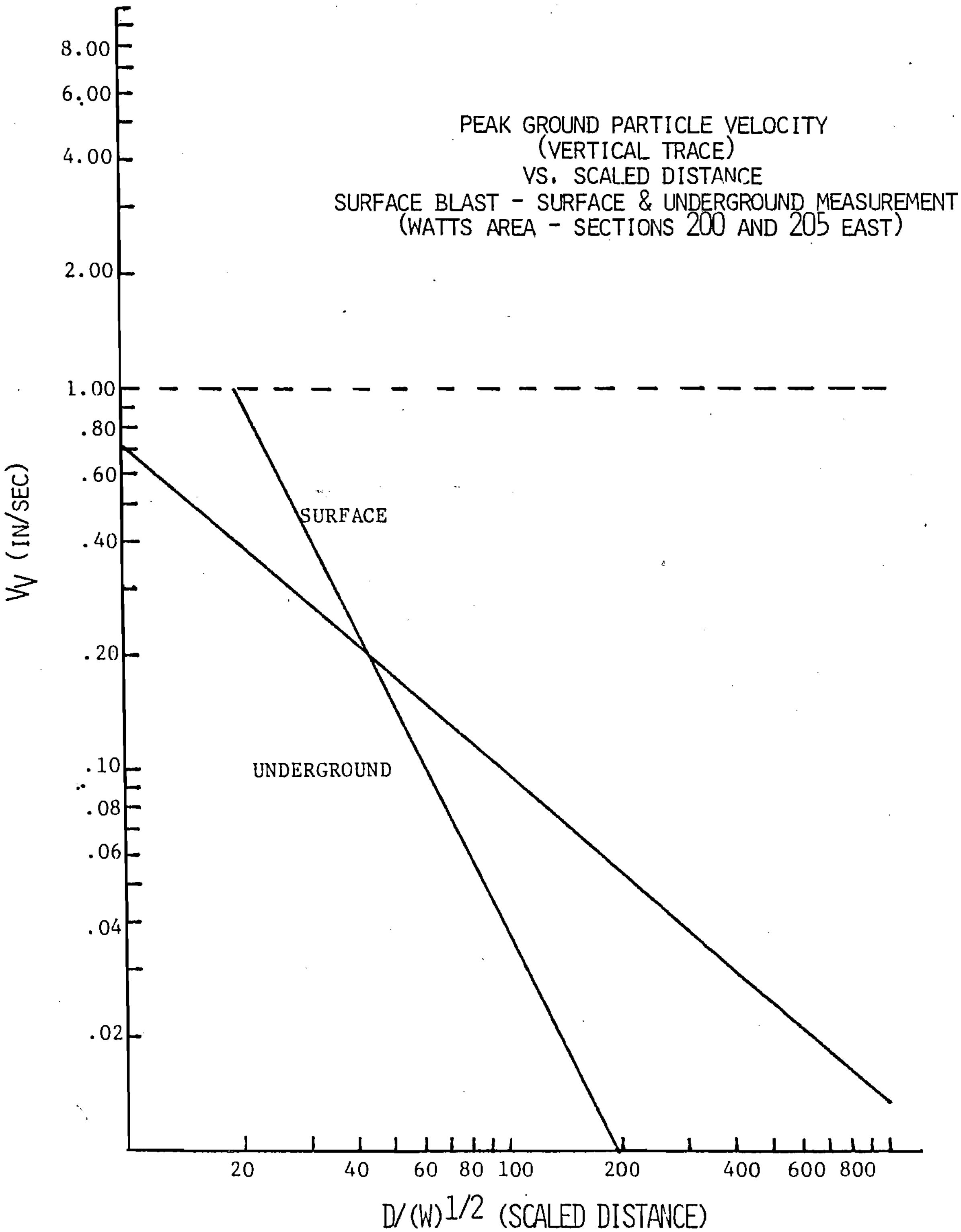


Figure 18 - Comparison of Vertical Trace of Simultaneous Monitoring Experiment

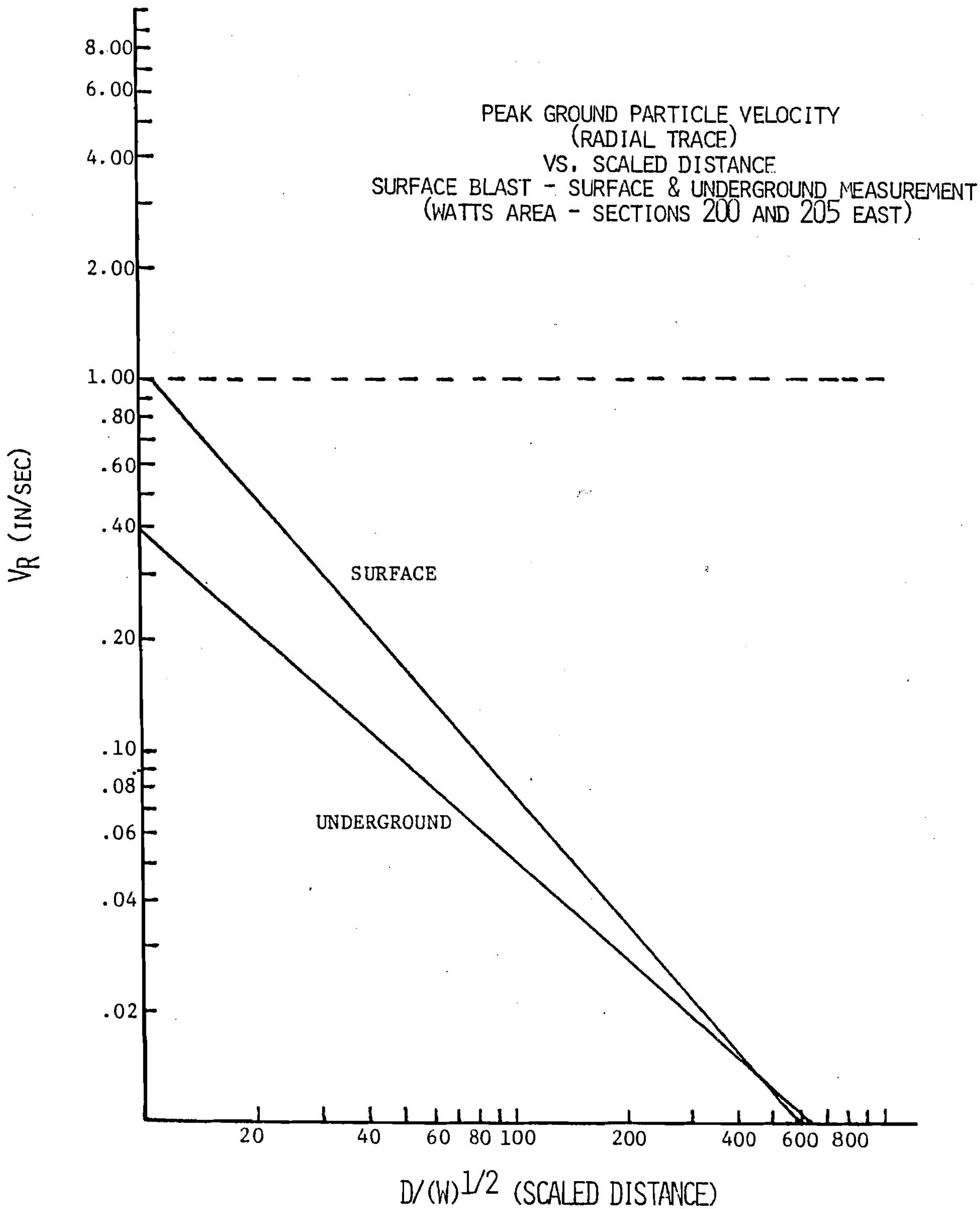


Figure 19 - Comparison of Radial Trace of Simultaneous Monitoring Experiment

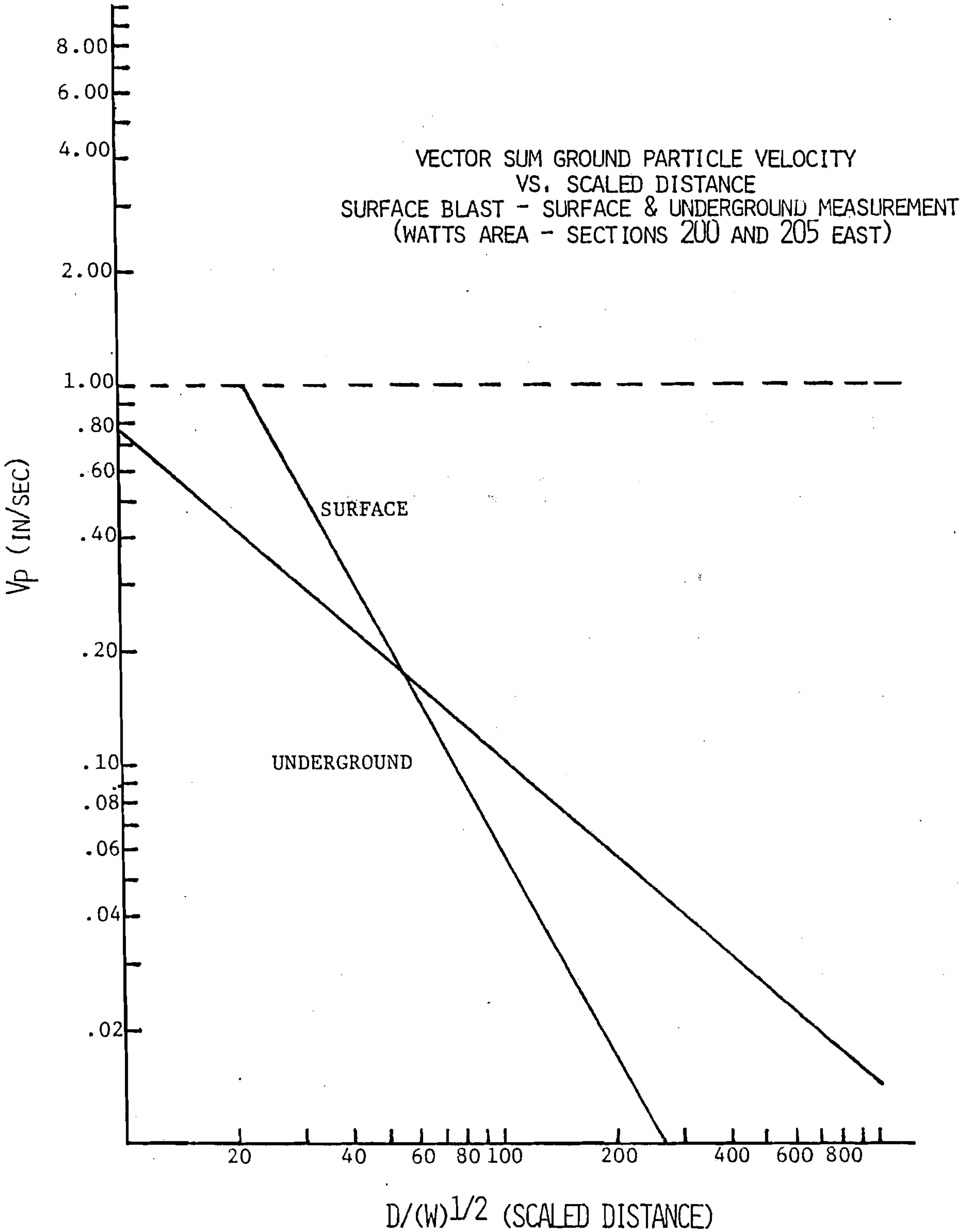


Figure 20 - Comparison of Vector Sum of Simultaneous Monitoring Experiment

Table 19 - Simultaneous Monitoring
Transverse Trace at the Surface

Particle Velocity	Scaled Distance
1	19.23065
.92479889	20
.83910639	21
.76480654	22
.69996529	23
.64304151	24
.59279644	25
.54822413	26
.50850139	27
.47294871	28
.44100225	29
.41216993	30
.38611455	31
.36244009	32
.34088017	33
.32119041	34
.30316035	35
.28660852	36
.27137758	37
.25733055	38
.2443477	39
.23232421	40
.22116776	41
.21079699	42
.20113952	43
.1921316	44
.18371622	45
.17584243	46
.16846474	47
.16154239	48
.15503838	49
.14891992	50
.14315702	51
.13772264	52
.13259227	53
.12774364	54
.12315647	55
.11881227	56
.1146942	57
.11076681	58
.10707596	59
.10354879	60
.10019308	61
.09699814	62
.09395389	63
.09105071	64
.08828028	65
.08563454	66
.08310611	67
.08068816	68
.07837432	69
.07615872	70
.07403586	71
.07200064	72
.07004839	73
.06817438	74
.06637476	75
.06464554	76
.06298319	77
.06138405	78
.05984529	79
.05836355	80
.05693632	81
.05556087	82
.05423472	83
.05295555	84
.05172114	85
.05052946	86
.04937853	87
.04826653	88
.04719171	89
.04615244	90
.04514717	91
.04417443	92
.04323282	93
.04232103	94
.04143782	95
.040582	96
.03975245	97
.03894812	98
.03816797	99
.03741106	100
.03667647	101
.03596333	102
.03527081	103
.03459813	104
.03394453	105
.03330939	106
.03269175	107
.03209124	108
.03150714	109
.03093887	110
.03038585	111
.02984754	112
.02932343	113
.02881301	114
.02831583	115
.02783141	116
.02735934	117
.02689929	118
.02645056	119
.02601308	120
.02558637	121
.0251701	122
.02476391	123
.02436748	124
.02398051	125
.02360279	126
.02323374	127
.02287349	128
.02252137	129
.02217741	130
.02184139	131
.02151276	132
.0211916	133
.02087758	134
.0205705	135
.02027015	136
.01997634	137
.01968886	138
.01940769	139
.01913239	140
.01886281	141
.01859909	142
.01834067	143
.01808771	144
.01783995	145
.01759725	146
.01735947	147
.01712659	148
.01689818	149
.0166744	150
.01645504	151
.01624009	152
.01602913	153
.01582236	154
.01561957	155
.01542065	156
.01522552	157
.01503407	158
.01484621	159
.01466185	160
.01448092	161
.01430331	162
.01412896	163
.01395778	164
.01378979	165
.01362463	166
.01346251	167
.01330328	168
.01314685	169
.01299318	170
.01284218	171
.01269381	172
.01254809	173
.01240467	174
.0122638	175
.01212532	176
.01198918	177
.01185531	178
.01172368	179
.01159423	180
.01146692	181
.01134179	182
.01121851	183
.01109732	184
.01097819	185
.01086077	186
.01074535	187
.01063172	188
.0105199	189
.01040984	190
.0103015	191
.01019485	192
.01008984	193
.00998645	194
.00988465	195
.00978449	196
.00968565	197
.0095884	198
.00949262	199
.00939826	200

Table 20 - Simultaneous Monitoring Vertical Trace at the Surface

Particle Velocity	Scaled Distance
1	10.878112
.98727889	11
.89334829	12
.8148527	13
.74833999	14
.69130734	15
.64189829	16
.59870683	17
.5606501	18
.52688052	19
.49672561	20
.46964538	21
.44520121	22
.42303348	23
.40284436	24
.38438546	25
.36744778	26
.35185445	27
.33745467	28
.32411917	29
.31173654	30
.30021029	31
.28945608	32
.2794007	33
.26997948	34
.26113544	35
.25281826	36
.24498316	37
.23759028	38
.23060397	39
.2239923	40
.21772655	41
.2117808	42
.20613179	43
.20075801	44
.19564053	45
.19076174	46
.18610566	47
.18165771	48
.17740453	49
.17333399	50
.16943451	51
.16569605	52
.16210897	53
.15866444	54
.15535431	55
.15217102	56
.14910761	57
.14615754	58
.14331481	59
.14057375	60
.13792914	61
.13537619	62
.13291002	63
.13052665	64
.128222	65
.12599231	66
.12383405	67
.12174392	68
.11971881	69
.11775582	70
.11585217	71
.11400528	72
.11221271	73
.11047213	74
.1087814	75
.10713841	76
.10554123	77
.10398802	78
.10247702	79
.10100657	80
.0995751	81
.0981811	82
.09682317	83
.09549995	84
.09421014	85
.09295255	86
.09172598	87
.09052935	88
.08935169	89
.08822179	90
.08710868	91
.08602166	92
.08495973	93
.08392205	94
.08290784	95
.08191631	96
.08094672	97
.07999849	98
.07907062	99
.07816278	100
.07727424	101
.07640441	102
.07555271	103
.0747186	104
.07390154	105
.07310104	106
.07231661	107
.07154777	108
.07079419	109
.07005511	110
.06933043	111
.06861965	112
.06792238	113
.06723824	114
.06656688	115
.06590795	116
.06526111	117
.06462605	118
.06400244	119
.06339	120
.06278843	121
.06219745	122
.06161689	123
.06104618	124
.06048538	125
.05993414	126
.05939222	127
.05885949	128
.05833544	129
.05782013	130
.05731328	131
.05681468	132
.05632413	133
.05584144	134
.05536644	135
.05489892	136
.05443874	137
.05398573	138
.05353971	139
.05310054	140
.05266805	141
.05224211	142
.05182257	143
.05140928	144
.05100211	145
.05060094	146
.05020563	147
.04981605	148
.04943219	149
.04905363	150
.04868056	151
.04831275	152
.0479501	153
.04759252	154
.04723999	155
.04689212	156
.0465491	157
.04621075	158
.04587697	159
.04554767	160
.04522276	161
.04490216	162
.04458589	163
.04427356	164
.0439654	165
.04366122	166
.04336095	167
.04306452	168
.04277187	169
.04248291	170
.04219758	171
.04191581	172
.04163754	173
.0413627	174
.04109125	175
.0408231	176
.04055821	177
.04029651	178
.04003795	179
.03978259	180
.03953005	181
.03928069	182
.03903406	183
.03879041	184
.03854958	185
.03831155	186
.03807623	187
.03784362	188
.03761364	189
.03738627	190
.03716145	191
.03693915	192
.03671932	193
.03650193	194
.03628694	195
.03607439	196
.03586397	197
.03565593	198
.03545013	199
.03524654	200

Table 21 - Simultaneous Monitoring
Radial Trace at the Surface

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	21.065023	.12684245	66	.04955142	111	.02678125	156
.9244849	22	.12344026	67	.04875441	112	.02647363	157
.85309259	23	.12017772	68	.04797713	113	.02617147	158
.78991092	24	.11704717	69	.04721893	114	.02587463	159
.7337101	25	.11404147	70	.04647917	115	.02558298	160
.68348382	26	.11115397	71	.04575726	116	.02529641	161
.63840217	27	.10837844	72	.04505262	117	.02501489	162
.59777577	28	.10570919	73	.04436479	118	.02473802	163
.56102799	29	.10314046	74	.04369293	119	.02446597	164
.52767296	30	.10066751	75	.04303684	120	.02419854	165
.4972996	31	.09828542	76	.04239592	121	.02393562	166
.46955758	32	.09598974	77	.04176971	122	.02367711	167
.4441471	33	.09377628	78	.04115775	123	.02342291	168
.42081011	34	.0916411	79	.0405596	124	.02317293	169
.39932362	35	.08958047	80	.03997485	125	.02292706	170
.37949416	36	.08759094	81	.03940308	126	.02268523	171
.36115306	37	.08566918	82	.03884391	127	.02244733	172
.34415282	38	.08381213	83	.03829697	128	.02221328	173
.32836378	39	.08201686	84	.0377619	129	.021983	174
.31367187	40	.0802806	85	.03723835	130	.02175641	175
.29997623	41	.07860089	86	.03672609	131	.02153343	176
.28718736	42	.07697492	87	.0362245	132	.02131397	177
.27522577	43	.0754007	88	.03573356	133	.02109797	178
.26402047	44	.07387592	89	.03525288	134	.02088535	179
.25350819	45	.0723985	90	.03478217	135	.02067604	180
.24363175	46	.07096647	91	.03432114	136	.02046997	181
.23434038	47	.06957796	92	.03386954	137	.02026707	182
.22558795	48	.06823118	93	.0334271	138	.02006728	183
.21733293	49	.06692446	94	.03299357	139	.01987053	184
.20953775	50	.06565621	95	.03256871	140	.01967676	185
.20216836	51	.06442499	96	.03215239	141	.01948591	186
.19519378	52	.06322907	97	.03174408	142	.01929792	187
.18858592	53	.06206737	98	.03134386	143	.01911273	188
.18231908	54	.06093848	99	.03095143	144	.01893028	189
.17636985	55	.05984117	100	.03056657	145	.01875053	190
.17071673	56	.05877424	101	.0301891	146	.01857341	191
.16534015	57	.05773657	102	.02981881	147	.01839888	192
.16022204	58	.05672707	103	.02945553	148	.01822688	193
.15534585	59	.05574473	104	.02909908	149	.01805737	194
.15069631	60	.05478855	105	.02874939	150	.0178903	195
.14625938	61	.05385761	106	.02840598	151	.01772561	196
.14202208	62	.05295101	107	.028069	152	.01756326	197
.13797244	63	.05206788	108	.02773818	153	.01740321	198
.13409934	64	.05120743	109	.02741338	154	.01724542	199
.13039253	65	.05036886	110	.02709445	155	.01708983	200

Table 22 - Simultaneous Monitoring
Vector Sum at the Surface

Particle Velocity	Scaled Distance
1	24.800385
.98421319	25
.91049582	26
.84477873	27
.78594353	28
.73306084	29
.68535319	30
.64216566	31
.60294446	32
.56721783	33
.53458219	34
.5046903	35
.4772429B	36
.4519804	37
.42867646	38
.40713359	39
.38717827	40
.36865837	41
.35143922	42
.33540164	43
.3204398	44
.30645969	45
.29337689	46
.28111615	47
.26961012	48
.25879795	49
.24862488	50
.23904147	51
.23000293	52
.22146875	53
.21340198	54
.2057691	55
.19853944	56
.19168516	57
.18518061	58
.1790024	59
.173129	60
.16754071	61
.16221931	62
.15714807	63
.15231153	64
.14769543	65
.14328653	66
.1390726	67
.13504231	68
.13118514	69
.12749127	70
.12395162	71
.12055773	72
.11730166	73
.11417607	74
.11117407	75
.10828929	76
.10551542	77
.10284716	78
.10027907	79
.09780621	80
.09542393	81
.09312785	82
.09091385	83
.08877807	84
.08671685	85
.08472677	86
.08280458	87
.08094722	88
.07915182	89
.07741563	90
.07573619	91
.07411076	92
.07253731	93
.07101355	94
.06953744	95
.06810709	96
.06672032	97
.06537579	98
.0640714	99
.06280584	100
.06157752	101
.06038495	102
.05922689	103
.05810171	104
.05700846	105
.05594586	106
.05491277	107
.05390808	108
.05293081	109
.05197992	110
.05105459	111
.05015362	112
.04927645	113
.04842214	114
.04758991	115
.04677901	116
.04598871	117
.04521831	118
.04446715	119
.04373462	120
.04302007	121
.04232294	122
.04164266	123
.04097868	124
.04033051	125
.03969763	126
.03907956	127
.03847585	128
.03788607	129
.03730977	130
.03674655	131
.03619602	132
.0356578	133
.03513153	134
.03461686	135
.03411343	136
.03362093	137
.03313906	138
.03266759	139
.03220594	140
.03175413	141
.03131178	142
.03087863	143
.03045443	144
.03003894	145
.02963191	146
.02923312	147
.02884234	148
.02845938	149
.028084	150
.02771602	151
.02735524	152
.02700148	153
.02665455	154
.02631439	155
.02598051	156
.02565307	157
.02533178	158
.02501651	159
.02470711	160
.02440342	161
.02410531	162
.02381265	163
.02352539	164
.02324312	165
.02296601	166
.02269384	167
.02242648	168
.02216384	169
.02190589	170
.02165224	171
.02140307	172
.02115829	173
.0209175	174
.02068091	175
.02044831	176
.02021963	177
.01999477	178
.01977365	179
.01955629	180
.0193423	181
.01913191	182
.01892495	183
.01872133	184
.01852109	185
.01832386	186
.01812986	187
.01793894	188
.01775102	189
.01756605	190
.01738396	191
.0172047	192
.0170282	193
.01685441	194
.01668328	195
.01651474	196
.01634875	197
.01618526	198
.01602422	199
.01586557	200

Table 23 - Simultaneous Monitoring
Transverse Trace at Underground Mine Roof

Particle Velocity	Scaled Distance
1	1.1952092
.69422434	2
.52079732	3
.42471703	4
.36257693	5
.31861674	6
.28563407	7
.25983612	8
.23902189	9
.22181965	10
.20732741	11
.1949254	12
.18417284	13
.17474705	14
.16640598	15
.15896421	16
.15227716	17
.14623039	18
.14073169	19
.13570625	20
.13109278	21
.1268401	22
.12290545	23
.11925271	24
.11585115	25
.11267444	26
.1096999	27
.10690787	28
.10428121	29
.10180492	30
.09946578	31
.09725214	32
.09515366	33
.0931611	34
.09126624	35
.0894617	36
.08774084	37
.08609768	38
.08452678	39
.08302324	40
.0815826	41
.08020078	42
.07887406	43
.07759905	44
.07637261	45
.07519199	46
.07405423	47
.07295729	48
.07189853	49
.07087616	50
.06988814	51
.06893279	52
.06800813	53
.06711291	54
.06624558	55
.06540478	56
.06458926	57
.06379783	58
.06302938	59
.06228287	60
.06155732	61
.06085182	62
.0601655	63
.05949754	64
.05884729	65
.05821372	66
.05759643	67
.0569947	68
.0564079	69
.05583545	70
.05527681	71
.05473146	72
.05419899	73
.05367866	74
.0531703	75
.05267349	76
.05218753	77
.05171234	78
.05124744	79
.05079259	80
.05034716	81
.04991113	82
.04948419	83
.04906575	84
.04865584	85
.04825408	86
.04786023	87
.04747405	88
.04709539	89
.04672373	90
.04635916	91
.04600138	92
.04565018	93
.04530537	94
.04496678	95
.04463422	96
.04430753	97
.04398655	98
.04367111	99
.04336107	100
.04305639	101
.04275662	102
.04246193	103
.04217219	104
.04188697	105
.04160645	106
.04133043	107
.04105877	108
.04079138	109
.04052815	110
.04026897	111
.04001376	112
.03976241	113
.03951483	114
.03927094	115
.03903065	116
.03879387	117
.03856052	118
.03833053	119
.03810381	120
.0378803	121
.03765993	122
.03744262	123
.03722831	124
.03701694	125
.03680843	126
.03660274	127
.03639989	128
.03619953	129
.03600191	130
.03580687	131
.03561436	132
.03542433	133
.03523672	134
.03505159	135
.03486858	136
.03468796	137
.03450969	138
.0343334	139
.03415937	140
.03398745	141
.0338176	142
.03364978	143
.03348396	144
.0333201	145
.03315815	146
.03299819	147
.03283987	148
.03268348	149
.03252887	150
.03237601	151
.03222487	152
.03207541	153
.03192762	154
.03178146	155
.0316369	156
.03149392	157
.03135259	158
.03121258	159
.03107416	160
.03093721	161
.03080171	162
.03066763	163
.03053495	164
.03040365	165
.03027379	166
.03014507	167
.03001776	168
.02989174	169
.02976698	170
.02964347	171
.02952129	172
.02940012	173
.02928024	174
.02916153	175
.02904398	176
.02892756	177
.02881226	178
.02869806	179
.02858494	180
.0284729	181
.02836191	182
.02825195	183
.02814302	184
.02803519	185
.02792816	186
.0278222	187
.02771721	188
.02761317	189
.02751006	190
.02740788	191
.02730661	192
.02720623	193
.02710675	194
.02700813	195
.02691037	196
.02681346	197
.02671749	198
.02662215	199
.02652772	200

Table 24 - Simultaneous Monitoring Vertical Trace at Underground Mine Roof

Particle Velocity	Scaled Distance
1	6.7931029
.97463625	7
.86932877	8
.78592699	9
.71812493	10
.66184372	11
.61432347	12
.57362798	13
.53835727	14
.50747316	15
.48016885	16
.45589688	17
.43412638	18
.41447975	19
.39666878	20
.38043777	21
.36558088	22
.35192691	23
.33933224	24
.32767551	25
.31685337	26
.30677731	27
.29737109	28
.28850839	29
.28031161	30
.2725505	31
.26524065	32
.2583429	33
.25182256	34
.24564874	35
.23979392	36
.23423343	37
.22894519	38
.22390892	39
.21910699	40
.21452267	41
.21014141	42
.20594962	43
.20193495	44
.19808616	45
.19439294	46
.19084581	47
.18743606	48
.18415568	49
.18099726	50
.17795397	51
.17501946	52
.17218799	53
.16945378	54
.16681206	55
.16425803	56
.16178739	57
.15939571	58
.15707948	59
.15483509	60
.15265899	61
.15054801	62
.1484994	63
.14651028	64
.14457803	65
.14270029	66
.14087443	67
.13909856	68
.13737052	69
.13568835	70
.13405021	71
.13245434	72
.13089919	73
.1293829	74
.12790428	75
.1264618	76
.12505412	77
.12367998	78
.12233816	79
.1210275	80
.11974691	81
.11849533	82
.11727177	83
.11607526	84
.11490491	85
.11375985	86
.11263924	87
.11154228	88
.11046822	89
.10941633	90
.10838592	91
.10737632	92
.10638688	93
.105417	94
.10446608	95
.10353357	96
.10261891	97
.10172169	98
.1008411	99
.09997698	100
.09912875	101
.09829597	102
.0974782	103
.09667504	104
.09588619	105
.09511097	106
.09434931	107
.09360073	108
.09286493	109
.09214154	110
.09143026	111
.09073078	112
.0900428	113
.08936602	114
.08870017	115
.08804509	116
.08740021	117
.08676558	118
.08614085	119
.0855258	120
.08492018	121
.08432389	122
.0837364	123
.08315781	124
.08258782	125
.08202622	126
.08147285	127
.0809275	128
.08039001	129
.07986029	130
.07933788	131
.07882293	132
.07831517	133
.07781444	134
.0773206	135
.07683351	136
.07635302	137
.075879	138
.0754113	139
.07494982	140
.07449442	141
.07404496	142
.07360135	143
.07316346	144
.07273118	145
.07230449	146
.071883	147
.07146699	148
.07105598	149
.07065015	150
.07024931	151
.06985337	152
.06946224	153
.06907582	154
.06869403	155
.06831689	156
.06794401	157
.06757561	158
.06721151	159
.06685164	160
.06649593	161
.06614428	162
.06579665	163
.06545295	164
.06511313	165
.06477719	166
.06444481	167
.06411629	168
.06379118	169
.06346972	170
.06315176	171
.06283723	172
.06252607	173
.06221824	174
.06191367	175
.06161231	176
.06131412	177
.06101904	178
.06072702	179
.06043801	180
.06015197	181
.05986885	182
.0595886	183
.05931118	184
.05903654	185
.05876465	186
.05849545	187
.05822891	188
.05796509	189
.05770366	190
.05744485	191
.05718856	192
.05693473	193
.05668334	194
.05643434	195
.05618779	196
.05594337	197
.05570134	198
.05546157	199
.05522402	200

Table 25 - Simultaneous Monitoring
Radial Trace at Underground Mine Roof

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	3.4600327	.08988956	53	.04999979	103	.03546243	152
.87983543	4	.08841843	54	.04957503	104	.03525774	153
.72251903	5	.08699772	55	.04915809	105	.03505554	154
.61510333	6	.08562481	56	.04874836	106	.03485581	155
.5368432	7	.08429731	57	.04834594	107	.03465859	156
.47714696	8	.08301294	58	.04795054	108	.03446353	157
.43002601	9	.0817696	59	.04756198	109	.0342709	158
.3918321	10	.08056532	60	.04718007	110	.03408055	159
.36021231	11	.07939824	61	.04680464	111	.03389245	160
.33357919	12	.07826663	62	.04643553	112	.03370654	161
.31082134	13	.07716888	63	.04607256	113	.03352289	162
.29113752	14	.07610345	64	.0457156	114	.03334117	163
.27393445	15	.07506891	65	.04536448	115	.03316163	164
.25876343	16	.07406391	66	.04501907	116	.03298414	165
.24527863	17	.07308718	67	.04467922	117	.03280867	166
.23320908	18	.07213751	68	.04434489	118	.03263518	167
.22233936	19	.07121378	69	.04401565	119	.03246363	168
.21249609	20	.07031492	70	.04369179	120	.03229409	169
.20353768	21	.06943991	71	.04337276	121	.03212623	170
.19534813	22	.0685878	72	.04305877	122	.03196032	171
.18783075	23	.06775779	73	.04274957	123	.03179622	172
.18090456	24	.06694871	74	.04244508	124	.03163391	173
.17450127	25	.06616007	75	.04214518	125	.03147336	174
.16856273	26	.06539097	76	.04184975	126	.03131454	175
.16303922	27	.06464079	77	.04155872	127	.03115742	176
.15788792	28	.06390854	78	.04127196	128	.03100197	177
.15307175	29	.06319385	79	.04098949	129	.03084816	178
.14855846	30	.06249609	80	.04071091	130	.03069597	179
.1443198	31	.06181437	81	.04043644	131	.03054538	180
.14033109	32	.06114841	82	.04016599	132	.03039635	181
.13657029	33	.06049757	83	.03989917	133	.03024886	182
.13301801	34	.05986132	84	.03963629	134	.03010299	183
.12965723	35	.05923917	85	.03937699	135	.02995842	184
.12647252	36	.05863066	86	.03912117	136	.02981541	185
.12345012	37	.05803533	87	.03886898	137	.02967386	186
.12057772	38	.05745274	88	.03862022	138	.02953373	187
.11784429	39	.05688248	89	.03837484	139	.029395	188
.11523952	40	.05632416	90	.03813276	140	.02925766	189
.11275464	41	.0557774	91	.03789391	141	.02912168	190
.11038131	42	.05524184	92	.03765823	142	.02898703	191
.10811204	43	.05471713	93	.03742565	143	.02885371	192
.10594	44	.05420293	94	.03719612	144	.02872179	193
.10385897	45	.05369893	95	.03696956	145	.02859096	194
.10186322	46	.05320482	96	.03674594	146	.02846148	195
.09994752	47	.05272031	97	.03652517	147	.02833325	196
.09810706	48	.05224511	98	.03630722	148	.02820624	197
.0963374	49	.05177895	99	.03609202	149	.02808045	198
.09463446	50	.05132158	100	.03587952	150	.02795584	199
.09299446	51	.05087274	101	.03566968	151	.02783241	200
.0914139	52	.05043229	102				

Table 26 - Simultaneous Monitoring
Vector Sum at Underground Mine Roof

Particle Velocity	Scaled Distance						
1	7.379698	.17771091	55	.10359976	103	.07455246	151
.93293697	8	.17497802	56	.10274249	104	.0741304	152
.84305523	9	.17233444	57	.10190022	105	.07371348	153
.77001645	10	.16977573	58	.10107284	106	.0733016	154
.70941138	11	.16729789	59	.10025985	107	.07289466	155
.65825811	12	.16489677	60	.09946086	108	.07249258	156
.61446526	13	.16256904	61	.09867554	109	.07209526	157
.5765212	14	.16031122	62	.09790359	110	.07170263	158
.54330528	15	.15812015	63	.09714449	111	.07131469	159
.51396849	16	.15599282	64	.09639791	112	.07093106	160
.48785516	17	.15392645	65	.09566372	113	.07055196	161
.46445125	18	.15191837	66	.09494152	114	.07017722	162
.44334739	19	.14996619	67	.094231	115	.06980676	163
.42421314	20	.14806728	68	.09353199	116	.0694405	164
.40677964	21	.14621971	69	.0928439	117	.06907837	165
.39082493	22	.14442128	70	.09216676	118	.0687203	166
.37616469	23	.14267001	71	.09150021	119	.06836623	167
.36264385	24	.14096404	72	.090844	120	.06801607	168
.35013201	25	.13930157	73	.09019787	121	.06766977	169
.33851775	26	.13768094	74	.08956162	122	.06732726	170
.32770574	27	.13610054	75	.08893509	123	.06698847	171
.31761382	28	.13455885	76	.08831776	124	.06665336	172
.30817081	29	.13305443	77	.08770972	125	.06632184	173
.2993147	30	.13158593	78	.08711066	126	.06599387	174
.29099118	31	.13015204	79	.08652049	127	.06566949	175
.28315257	32	.12875151	80	.08593879	128	.06534834	176
.27575676	33	.12738317	81	.08536549	129	.06503067	177
.26876642	34	.1260459	82	.08480039	130	.06471632	178
.26214833	35	.12473863	83	.08424322	131	.06440523	179
.25587286	36	.12346033	84	.08369401	132	.06409736	180
.24991359	37	.12221001	85	.08315259	133	.06379266	181
.24424649	38	.12098678	86	.08261848	134	.06349107	182
.23885006	39	.11978971	87	.08209184	135	.06319255	183
.23370512	40	.11861796	88	.0815724	136	.06289705	184
.228794	41	.11747073	89	.08106001	137	.06260451	185
.22410075	42	.11634723	90	.08055454	138	.06231491	186
.21961086	43	.11524671	91	.08005583	139	.06202818	187
.21531107	44	.11416845	92	.07956376	140	.0617443	188
.21118931	45	.11311178	93	.07907818	141	.06146321	189
.20723448	46	.11207603	94	.07859896	142	.06118487	190
.20343649	47	.11106069	95	.07812598	143	.06090925	191
.19978571	48	.11006482	96	.07765911	144	.06063639	192
.19627382	49	.10908817	97	.07719824	145	.06036597	193
.19289275	50	.10813007	98	.07674324	146	.06009824	194
.18963518	51	.10718998	99	.076294	147	.05983307	195
.18649428	52	.10626749	100	.07585041	148	.05957041	196
.18346378	53	.10536181	101	.07541236	149	.05931023	197
.1805378	54	.10447275	102	.07497974	150	.0590525	198
						.05879718	199
						.05854423	200

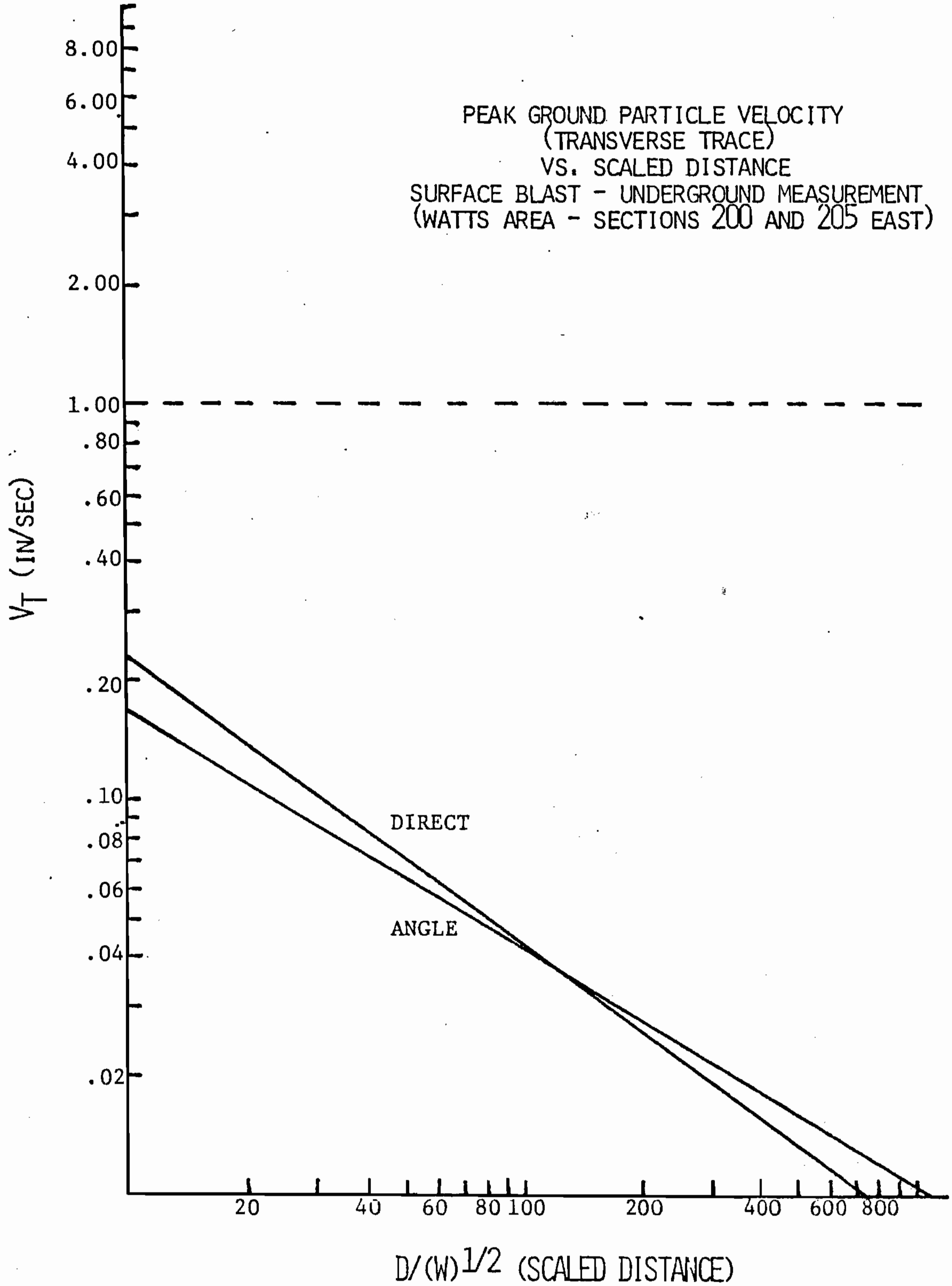


Figure 21 - Comparison of Direct and Angle Particle Velocity - Transverse Trace

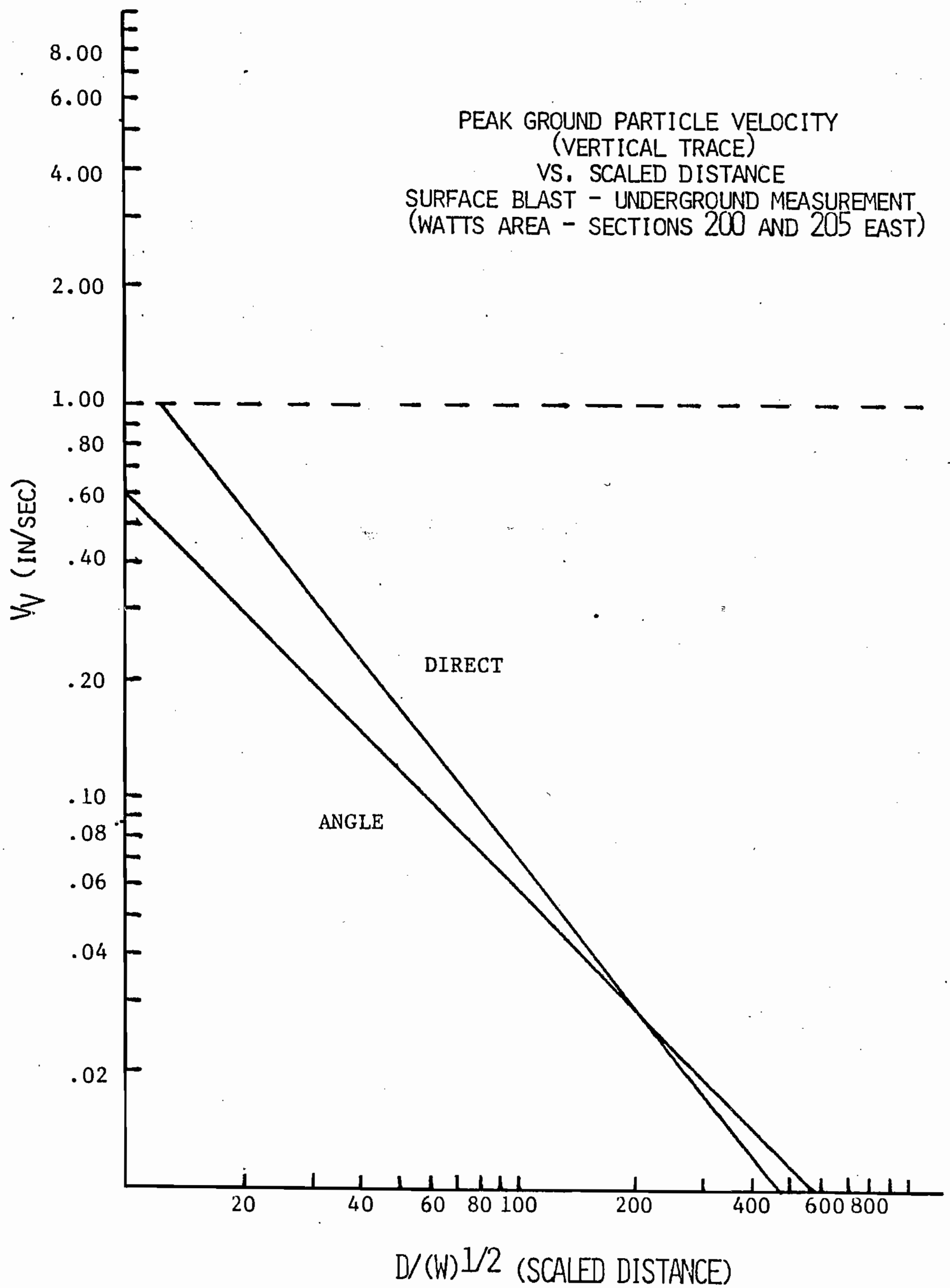


Figure 22 - Comparison of Direct and Angle Particle Velocity - Vertical Trace

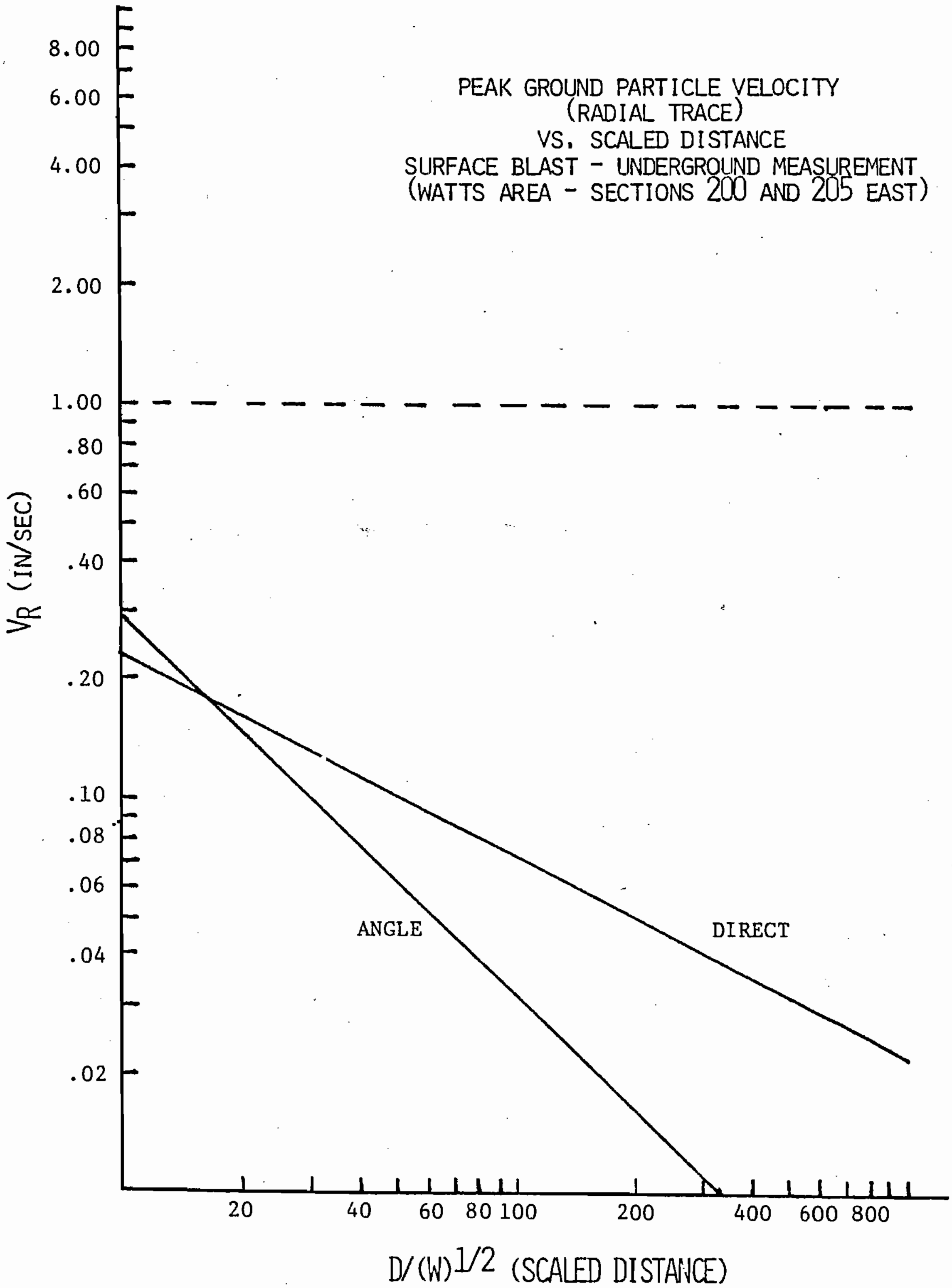


Figure 23 - Comparison of Direct and Angle Particle Velocity - Radial Trace

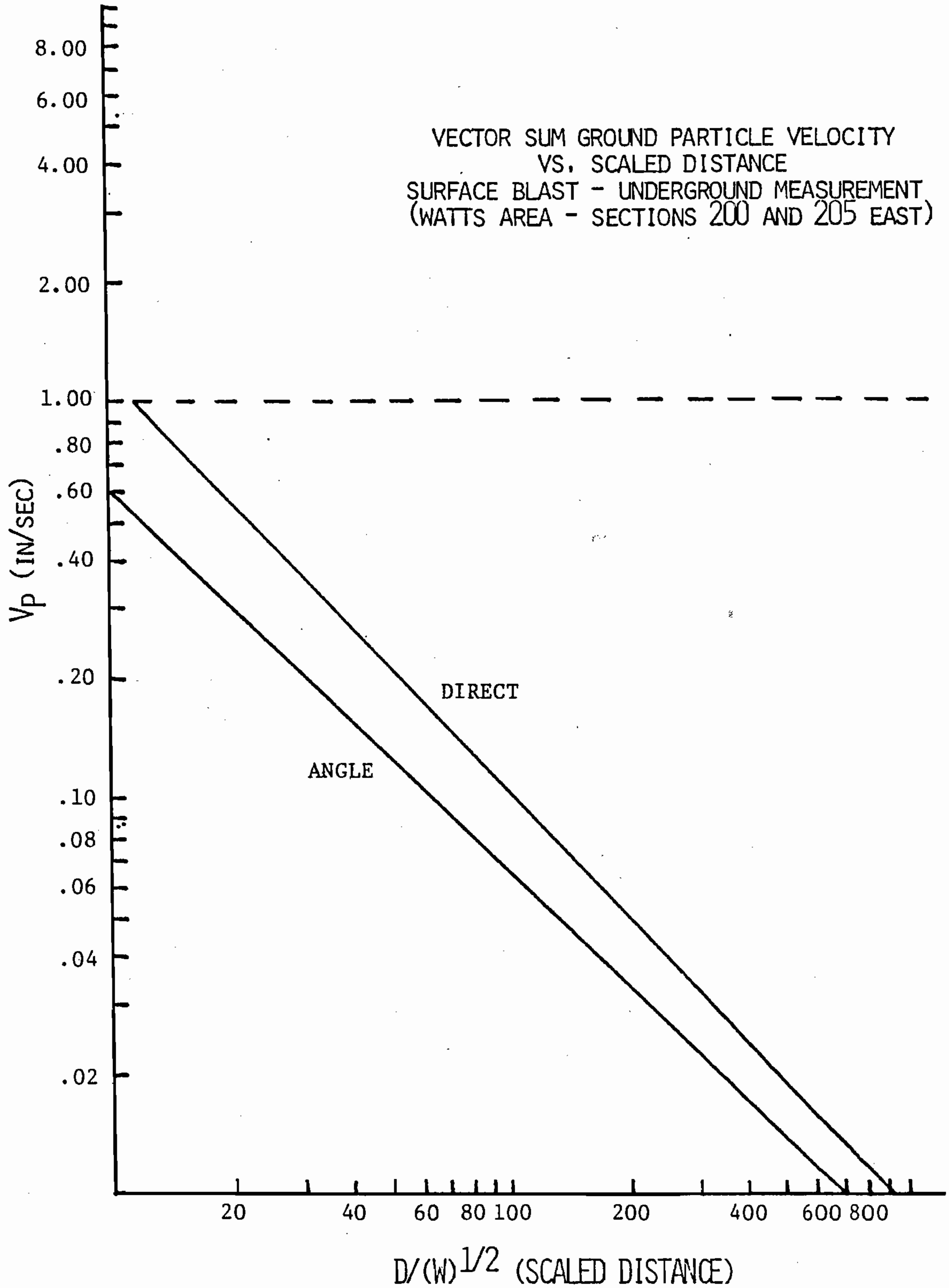


Figure 24 - Comparison of Direct and Angle Particle Velocity - Vector Sum

the blasts directly on top of the underground monitoring station at the mine roof result in higher ground particle velocity. However, caution must be exercised when the ground particle velocity lies near the intersecting lines or where the difference between the two lines becomes small.

Tables 27 - 34 give approximate ground particle velocity at an equivalent scaled distance for blasts monitored at the underground mine roof at an angle and directly beneath the surface mine blast.

Appendixes C and D show that particle velocity monitored at some angle have a poorer correlation with the scaled distance law than the particle velocity monitored at the underground mine roof directly beneath the surface mine blast. However, it should be noted that the number of data for angle blasts is 18 compared to 25 for direct blasts.

3) Does the composite angle and direct blast have a good correlation with the scaled distance wave propagation model?

Figures 25 - 28 show a fair fit to the data. Tables 11 - 14 given previously may be used for approximating the ground particle velocity and equivalent scaled distance for Figures 25 - 28.

Appendix E shows the statistical analysis of composite data for angle and direct blasts. It is noted that the correlation with the scaled distance model is fair.

Table 27 - Transverse Trace Monitored
at an Angle to the Blast

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	5.3777184	.11941136	54	.06586789	103	.04602222	152
.90404335	6	.11740967	55	.06528407	104	.04574502	153
.78435232	7	.1154767	56	.06471103	105	.04547128	154
.69355866	8	.11360894	57	.06414838	106	.04520094	155
.62223789	9	.11180319	58	.06359585	107	.04493392	156
.56467687	10	.11005619	59	.06305314	108	.04467018	157
.51720763	11	.10836506	60	.06252	109	.04440964	158
.47736473	12	.10672733	61	.06199618	110	.04415225	159
.44342891	13	.10514038	62	.06148143	111	.04389795	160
.4141639	14	.10360187	63	.06097551	112	.04364679	161
.38865758	15	.10210956	64	.0604782	113	.04339841	162
.36622186	16	.10066149	65	.05998927	114	.04315306	163
.34632786	17	.09925541	66	.05950851	115	.04291058	164
.32856219	18	.09788977	67	.05903572	116	.04267093	165
.31259666	19	.09656274	68	.0585707	117	.04243405	166
.29816803	20	.09527268	69	.05811325	118	.0421999	167
.28506203	21	.09401804	70	.05766318	119	.04196842	168
.27310279	22	.09279738	71	.05722033	120	.04173957	169
.26214415	23	.0916093	72	.05678451	121	.04151332	170
.25206433	24	.09045252	73	.05635555	122	.04128961	171
.24276042	25	.08932578	74	.0559333	123	.04106849	172
.2341451	26	.08822793	75	.05551769	124	.04084963	173
.22614375	27	.08715784	76	.05510828	125	.04063339	174
.21869221	28	.08611447	77	.0547052	126	.04041933	175
.21173504	29	.08509681	78	.05430823	127	.0402077	176
.20522403	30	.08410391	79	.05391722	128	.03999837	177
.19911707	31	.08313487	80	.05353203	129	.03979139	178
.19337723	32	.08218883	81	.05315254	130	.03958645	179
.18797198	33	.08126496	82	.05277861	131	.03938389	180
.18287254	34	.08036259	83	.05241013	132	.03918328	181
.17805334	35	.07948067	84	.05204698	133	.03898488	182
.17349163	36	.07861889	85	.05168903	134	.03878858	183
.16916704	37	.07777618	86	.05133618	135	.03859432	184
.16506135	38	.07695218	87	.05098831	136	.03840208	185
.16115812	39	.07614618	88	.05064533	137	.03821183	186
.15744256	40	.07535769	89	.05030712	138	.03802352	187
.15390139	41	.07458584	90	.04997358	139	.03783715	188
.15052216	42	.07383049	91	.04964463	140	.03765267	189
.14729416	43	.07309073	92	.04932016	141	.03747006	190
.14420723	44	.07236635	93	.04900008	142	.03728928	191
.14125223	45	.07165678	94	.0486843	143	.03711031	192
.13842076	46	.07096158	95	.04837274	144	.03693313	193
.13570513	47	.07028039	96	.0480653	145	.0367577	194
.13309828	48	.0696125	97	.04776192	146	.036584	195
.13059374	49	.06895781	98	.0474625	147	.036412	196
.12818551	50	.06831582	99	.04716696	148	.03624168	197
.12586808	51	.06768618	100	.04687524	149	.03607301	198
.12363634	52	.06706852	101	.04658726	150	.03590597	199
.12148556	53	.0664625	102	.04630294	151	.03574054	200

Table 28 - Vertical Trace Monitored
at an Angle to the Blast

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	5.9695875	.10909677	54	.05697529	103	.03851815	152
.99490094	6	.10710141	55	.05642408	104	.03826499	153
.85198388	7	.1051775	56	.0558835	105	.03801493	154
.74480886	8	.10332132	57	.05535315	106	.03776821	155
.66165567	9	.10152932	58	.05483274	107	.03752465	156
.59511378	10	.09979625	59	.05432209	108	.03728421	157
.54070324	11	.09812505	60	.05382066	109	.03704683	158
.49538594	12	.09650687	61	.05332845	110	.03681243	159
.45705989	13	.09494104	62	.05284515	111	.03658098	160
.42422398	14	.09342507	63	.0523705	112	.03635241	161
.39577852	15	.09195661	64	.05190427	113	.03612667	162
.37089879	16	.09053348	65	.05144625	114	.03590371	163
.34895429	17	.08915369	66	.05099622	115	.03568347	164
.32945483	18	.08781502	67	.05055397	116	.03546592	165
.31201388	19	.08651593	68	.05011931	117	.03525109	166
.29632197	20	.0852546	69	.04969203	118	.03503864	167
.28212889	21	.08402943	70	.04927195	119	.03482883	168
.26922969	22	.08283886	71	.0488589	120	.03462151	169
.25745539	23	.08168147	72	.04845279	121	.03441663	170
.24666498	24	.08055588	73	.04805317	122	.03421416	171
.2367404	25	.0794608	74	.04766016	123	.03401406	172
.22758144	26	.07839501	75	.0472735	124	.03381627	173
.21910288	27	.07735735	76	.04689306	125	.03362076	174
.21123167	28	.07634671	77	.04651866	126	.03342759	175
.20390499	29	.07536208	78	.04615029	127	.03323642	176
.19706797	30	.07440244	79	.04578759	128	.03304752	177
.19067342	31	.07346686	80	.04543042	129	.03286075	178
.18467979	32	.07255446	81	.04507887	130	.03267607	179
.17905027	33	.07166437	82	.0447327	131	.03249345	180
.17375297	34	.0707958	83	.04439189	132	.03231286	181
.16875924	35	.06994796	84	.04405602	133	.03213425	182
.16404375	36	.06912013	85	.04372528	134	.03195761	183
.1595839	37	.06831162	86	.04339946	135	.03178299	184
.15535947	38	.06752174	87	.04307843	136	.03161006	185
.1513523	39	.06674987	88	.04276211	137	.03143919	186
.14754608	40	.0659954	89	.04245049	138	.03126996	187
.14392607	41	.06525775	90	.04214316	139	.03110264	188
.14047894	42	.06453635	91	.04184034	140	.03093719	189
.13719263	43	.06383068	92	.04154183	141	.03077339	190
.13405611	44	.06314024	93	.04124753	142	.03061121	191
.13105942	45	.06246452	94	.04095736	143	.03045082	192
.1281934	46	.06180308	95	.04067123	144	.0302921	193
.12544968	47	.06115545	96	.04038907	145	.03013502	194
.12282064	48	.06052122	97	.04011078	146	.02997956	195
.12029921	49	.05989997	98	.03983628	147	.02982579	196
.11787893	50	.0592913	99	.0395655	148	.02967338	197
.11555385	51	.05869485	100	.03929838	149	.02952262	198
.11331846	52	.05811025	101	.03903483	150	.02937337	199
.11116767	53	.05753714	102	.03877477	151	.02922563	200

Table 29 - Radial Trace Monitored at an Angle to the Blast

Particle Velocity	Scaled Distance						
1	2.6560878	.05748079	52	.03009825	102	.02051992	152
.88965262	3	.05643882	53	.02981758	103	.02039111	153
.67490367	4	.05543478	54	.02954221	104	.02026394	154
.54472727	5	.05446654	55	.02927197	105	.02013838	155
.45723709	6	.0535322	56	.02900673	106	.02001449	156
.39432323	7	.05263001	57	.02874636	107	.01989196	157
.34686677	8	.05175831	58	.0284907	108	.01977105	158
.30977112	9	.0509156	59	.02823965	109	.01965162	159
.27996269	10	.05010042	60	.02799308	110	.01953366	160
.2554763	11	.04931145	61	.02775086	111	.01941713	161
.23499697	12	.04854744	62	.02751287	112	.01930202	162
.21761079	13	.0478072	63	.02727902	113	.01918839	163
.20266244	14	.04708964	64	.02704929	114	.01907592	164
.18967042	15	.04639373	65	.02682328	115	.01896486	165
.17827218	16	.0457185	66	.02660129	116	.01885516	166
.16818991	17	.04506303	67	.02638282	117	.01874673	167
.15920688	18	.04442646	68	.02616807	118	.01863955	168
.15115167	19	.04380798	69	.02595687	119	.01853363	169
.14388689	20	.04320683	70	.02574911	120	.01842892	170
.13730072	21	.04262228	71	.02554472	121	.01832542	171
.13130205	22	.04205364	72	.02534362	122	.01822319	172
.12581511	23	.04150028	73	.02514572	123	.01812193	173
.1207767	24	.04096169	74	.02495096	124	.0180219	174
.11613379	25	.04043698	75	.02475924	125	.01792309	175
.11184102	26	.0399259	76	.02457051	126	.01782529	176
.10786025	27	.03942784	77	.02438479	127	.01772847	177
.10415837	28	.0389423	78	.02420172	128	.01763282	178
.1007069	29	.03846881	79	.02402153	129	.01753821	179
.09748111	30	.03800692	80	.02384406	130	.01744463	180
.09445944	31	.03755622	81	.02366924	131	.01735207	181
.09162309	32	.03711639	82	.02349702	132	.0172605	182
.08895515	33	.03668676	83	.02332735	133	.01716992	183
.08644121	34	.03626725	84	.02316015	134	.0170803	184
.08406815	35	.03585742	85	.02299538	135	.01699163	185
.08182438	36	.03545693	86	.02283298	136	.01690399	186
.07969955	37	.03506547	87	.02267291	137	.01681708	187
.07768441	38	.03468273	88	.02251511	138	.01673117	188
.07577069	39	.03430843	89	.02235954	139	.01664615	189
.07395062	40	.03394227	90	.02220615	140	.01656201	190
.07221771	41	.03358401	91	.02205499	141	.01647873	191
.07056571	42	.03323349	92	.02190572	142	.0163963	192
.06898907	43	.03289015	93	.02175869	143	.01631471	193
.06748279	44	.03255407	94	.02161347	144	.01623394	194
.06604198	45	.03222493	95	.02147031	145	.01615409	195
.06466268	46	.03190252	96	.02132907	146	.01607484	196
.06334093	47	.03158662	97	.02118972	147	.01599647	197
.06207329	48	.03127704	98	.02105221	148	.01591888	198
.06085629	49	.03097369	99	.02091651	149	.01584205	199
.05968691	50	.03067619	100	.02078269	150	.01576598	200
.05856261	51	.03038437	101	.0206504	151		

Table 30 - Vector Sum Monitored at an Angle to the Blast

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	.49418688	.06263641	51	.0416407	101	.03274623	151
.65629636	1	.06191388	52	.04139639	102	.03261734	152
.4337451	2	.06121322	53	.04115568	103	.03248989	153
.34042391	3	.06053336	54	.04091877	104	.03236357	154
.28666136	4	.05987332	55	.04068548	105	.03223865	155
.25087965	5	.05923217	56	.04045571	106	.03211501	156
.22498556	6	.05860907	57	.04022937	107	.03199263	157
.20518894	7	.05800318	58	.04000649	108	.03187159	158
.18945398	8	.05741376	59	.03978668	109	.03175157	159
.17657943	9	.05684008	60	.03957017	110	.03163285	160
.16580592	10	.05628147	61	.03935678	111	.03151531	161
.15662745	11	.05573731	62	.03914644	112	.03139893	162
.14869255	12	.05520709	63	.03893908	113	.03128379	163
.14174863	13	.05468995	64	.03873463	114	.03116957	164
.135609	14	.05418565	65	.03853302	115	.03105656	165
.13013242	15	.0536936	66	.0383342	116	.03094464	166
.1252098	16	.05321332	67	.03813819	117	.03083389	167
.12075547	17	.05274435	68	.03794465	118	.030724	168
.11670103	18	.05228627	69	.0377538	119	.03061524	169
.11299124	19	.05183868	70	.03756551	120	.03050751	170
.10958084	20	.05140129	71	.0373797	121	.03040089	171
.10643244	21	.05097343	72	.03719633	122	.03029506	172
.10351481	22	.05055506	73	.03701534	123	.0301903	173
.10080165	23	.05014574	74	.03683679	124	.03008651	174
.09827065	24	.04974517	75	.03666033	125	.02998367	175
.09590271	25	.04935304	76	.0364862	126	.02988176	176
.09368142	26	.04896907	77	.03631427	127	.02978078	177
.09159256	27	.04859298	78	.03614459	128	.0296807	178
.08962375	28	.04822451	79	.03597681	129	.02958151	179
.08776416	29	.04786342	80	.0358112	130	.02948321	180
.08600428	30	.04750948	81	.03564761	131	.02938577	181
.08433579	31	.04716244	82	.035486	132	.02928929	182
.08275094	32	.0468221	83	.03532634	133	.02919346	183
.08124337	33	.04648825	84	.03516869	134	.02909855	184
.07980707	34	.04616068	85	.0350127	135	.02900447	185
.07843671	35	.04583922	86	.03485865	136	.0289112	186
.0771275	36	.04552367	87	.03470649	137	.02881872	187
.07587514	37	.04521386	88	.03455591	138	.02872703	188
.0746757	38	.04490963	89	.03440715	139	.02863612	189
.07352566	39	.04461081	90	.03426019	140	.02854597	190
.07242178	40	.04431725	91	.03411471	141	.02845657	191
.07136113	41	.0440288	92	.03397095	142	.02836792	192
.070341	42	.04374531	93	.03382881	143	.02828001	193
.06935897	43	.04346665	94	.03368825	144	.02819282	194
.06841275	44	.04319268	95	.03354924	145	.02810634	195
.06750028	45	.04292339	96	.03341175	146	.02802058	196
.06661963	46	.04265834	97	.03327576	147	.0279355	197
.06576905	47	.04239772	98	.03314123	148	.02785112	198
.06494699	48	.04214131	99	.03300815	149	.02776741	199
.06415165	49	.041889	100	.0328765	150	.02768437	200
[illegible]	[illegible]						

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.40684519	[illegible]
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.32461207	8
.29594776	9
.27245827	10
.25281968	11
.23612971	12
.22175114	13
.20922044	14
.19819194	15
.18840231	16
.17964728	17
.17176577	18
.16462909	19
.15813266	20
.15219149	21
.14673456	22
.14170325	23
.13704784	24
.13272627	25
.12870263	26
.12494607	27
.12142991	28
.11813098	29
.11502905	30
.11210635	31
.10934723	32
.10673784	33
.10426588	34
.10192037	35
.09969151	36
.09757048	37
.09554938	38
.09362103	39
.09177896	40
.0900173	41
.08833079	42
.08671428	43
.0851636	44
.08367457	45
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.0612229	67
.0605151	68
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.05915389	70
.05849885	71
.05786017	72
.05723714	73
.05662915	74
.05603565	75
.05545611	76
.05489003	77
.05433691	78
.05379631	79
.05326789	80
.05275093	81
.05224534	82
.05175063	83
.05126644	84
.05079244	85
.05032839	86
.04987367	87
.04942828	88
.04899184	89
.04856407	90
.04814479	91
.04773346	92
.04733014	93
.04693447	94
.04654626	95
.04616526	96
.04579139	97
.04542413	98
.04506361	99
.04470952	100

.04119[illegible]	[illegible]
.04090428	112
.04061999	113
.04033995	114
.04006437	115
.03979302	116
.03952582	117
.03926267	118
.03900347	119
.03874812	120
.03849655	121
.03824866	122
.03800437	123
.03776369	124
.03752627	125
.0372923	126
.03706163	127
.03683417	128
.03660987	129
.03638864	130
.03617044	131
.03595529	132
.03574282	133
.03553339	134
.03532654	135
.03512259	136
.03492111	137
.03472234	138
.03452611	139
.0343324	140
.03414113	141
.03395228	142
.03376578	143
.03358169	144
.03339968	145
.03322009	146
.03304248	147
.03286711	148
.03269385	149
.03252266	150

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.03003566	166
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.02975464	168
.02961636	169
.02947954	170
.02934414	171
.02921015	172
.02907754	173
.02894639	174
.02881638	175
.02868789	176
.0285605	177
.02843448	178
.02830973	179
.02818621	180
.02806391	181
.0279428	182
.02782288	183
.02770413	184
.02758652	185
.02747004	186
.02735467	187
.0272404	188
.02712721	189
.02701508	190
.026904	191
.02679396	192
.02668493	193
.02657691	194
.02646987	195
.02636381	196
.02625872	197
.02615457	198
.02605135	199
.02594906	200

Table 32 - Vertical Trace Monitored Directly Beneath the Surface Blast

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	12.113301	.15513419	59	.07784229	106	.05053802	153
.92021371	13	.15209538	60	.07698663	107	.05015209	154
.84334897	14	.14916497	61	.07614831	108	.04977138	155
.77757201	15	.14633739	62	.07532672	109	.04939607	156
.7206938	16	.1436072	63	.07452138	110	.04902596	157
.67106046	17	.14096964	64	.07373181	111	.04866096	158
.62739967	18	.13842079	65	.07295758	112	.04830095	159
.58871765	19	.13595552	66	.07219826	113	.04794583	160
.55422705	20	.13357033	67	.07145342	114	.04759551	161
.5232966	21	.13125141	68	.07072267	115	.0472499	162
.49541428	22	.12902524	69	.07000564	116	.0469089	163
.47016075	23	.12685652	70	.06930192	117	.04657242	164
.44718928	24	.12475816	71	.06861129	118	.04624049	165
.42621098	25	.12272123	72	.06793307	119	.0459127	166
.40698315	26	.12074496	73	.06726726	120	.04558939	167
.38930043	27	.11882676	74	.06661341	121	.04527006	168
.37298813	28	.1169642	75	.06597122	122	.04495494	169
.35789661	29	.11515491	76	.06534049	123	.04464385	170
.34389695	30	.11339671	77	.06472063	124	.04433673	171
.33087756	31	.11168753	78	.06411165	125	.04403359	172
.31874141	32	.11002541	79	.06351329	126	.04373406	173
.30740372	33	.10840845	80	.06292498	127	.04343837	174
.29679006	34	.1068349	81	.06234676	128	.04314637	175
.28683485	35	.1053031	82	.0617783	129	.04285797	176
.27748018	36	.10381142	83	.06121935	130	.04257312	177
.26867469	37	.10235837	84	.06066968	131	.04229176	178
.26037228	38	.10094248	85	.06012908	132	.04201381	179
.25253233	39	.09956241	86	.05959731	133	.04173922	180
.24511812	40	.09821682	87	.05907418	134	.04146793	181
.23809673	41	.09690459	88	.05855948	135	.04119999	182
.2314385	42	.09562424	89	.05805301	136	.04093503	183
.22511668	43	.09437492	90	.05755469	137	.04067331	184
.21910709	44	.09315546	91	.05706402	138	.04041466	185
.21338747	45	.09196484	92	.05658113	139	.04015904	186
.2079381	46	.09080205	93	.05610575	140	.03990649	187
.20274065	47	.08966616	94	.0556377	141	.03965667	188
.1977785	48	.08855628	95	.05517682	142	.03940983	189
.19303641	49	.08747155	96	.05472295	143	.03916581	190
.18850042	50	.08641114	97	.05427594	144	.03892456	191
.18415773	51	.08537426	98	.05383564	145	.03868606	192
.17999651	52	.08436016	99	.0534019	146	.03845024	193
.17600594	53	.08336813	100	.05297469	147	.03821707	194
.17217609	54	.08239745	101	.05255354	148	.0379865	195
.16849749	55	.08144748	102	.05213865	149	.0377585	196
.16496155	56	.08051757	103	.05172978	150	.037533	197
.16156055	57	.0796071	104	.0513268	151	.03731009	198
.15828702	58	.0787155	105	.05092969	152	.03708942	199
						.03687124	200

Table 33 - Radial Trace Monitored Directly Beneath the Surface Blast

Particle Velocity	Scaled Distance
1	.58453393
.76895335	1
.54777981	2
.44920509	3
.39022227	4
.34985975	5
.32000045	6
.29675192	7
.27798299	8
.2624153	9
.24922982	10
.23787377	11
.22795894	12
.21920352	13
.21139736	14
.20438008	15
.19802686	16
.19223894	17
.18693696	18
.18205637	19
.17754401	20
.1733557	21
.1694543	22
.16580842	23
.16239126	24
.1591798	25
.15615416	26
.15329702	27
.15059328	28
.14802963	29
.14559437	30
.14327719	31
.14106852	32
.13896042	33
.13694536	34
.13501671	35
.1331684	36
.13139502	37
.12969162	38
.12805379	39
.12647715	40
.12495823	41
.12349351	42
.12207985	43
.12071427	44
.11939417	45
.11811706	46
.11688063	47
.11568277	48
.11452151	49
.11339502	50
.11230169	51
.11123964	52
.11020767	53
.1092043	54
.10822823	55
.10727824	56
.10635317	57
.10545197	58
.10457362	59
.10371716	60
.1028817	61
.10206649	62
.10127044	63
.10049308	64
.0997336	65
.09899133	66
.09826563	67
.09755587	68
.09686159	69
.09618194	70
.0955167	71
.09486527	72
.09422717	73
.09360196	74
.09298921	75
.0923885	76
.09179945	77
.09122179	78
.09065486	79
.09009861	80
.08955262	81
.08901658	82
.08849029	83
.08797316	84
.08746521	85
.08696619	86
.08647553	87
.0859933	88
.08551917	89
.08505291	90
.0845943	91
.08414313	92
.08369921	93
.08326233	94
.08283233	95
.08240901	96
.08199222	97
.08158177	98
.08117751	99
.08077939	100
.08038696	101
.08000036	102
.07961938	103
.07924386	104
.07887368	105
.07850871	106
.07814884	107
.07779394	108
.07744391	109
.07709862	110
.07675797	111
.07642187	112
.0760902	113
.07576288	114
.07543981	115
.07512099	116
.07480604	117
.07449518	118
.07418821	119
.07388506	120
.07358565	121
.0732899	122
.07299775	123
.0727091	124
.07242391	125
.07214219	126
.07186356	127
.07158832	128
.07131625	129
.07104739	130
.0707814	131
.07051852	132
.07025869	133
.07000155	134
.06974735	135
.06949594	136
.06924727	137
.06900139	138
.06875794	139
.0685172	140
.068279	141
.06804333	142
.06781005	143
.06757923	144
.06735078	145
.06712467	146
.06690085	147
.06667939	148
.06645995	149
.06624289	150
.06602777	151
.06581486	152
.06560403	153
.06539524	154
.06518846	155
.06498366	156
.0647808	157
.06457986	158
.06438081	159
.06418361	160
.06398823	161
.06379466	162
.06360286	163
.0634128	164
.06322446	165
.06303781	166
.06285284	167
.0626695	168
.06248777	169
.06230765	170
.06212919	171
.06195219	172
.06177661	173
.06160263	174
.06143014	175
.06125911	176
.06108952	177
.06092135	178
.06075458	179
.06058929	180
.06042517	181
.06026259	182
.06010114	183
.05994119	184
.05978234	185
.05962486	186
.05946863	187
.05931364	188
.05915988	189
.05900732	190
.05885595	191
.05870576	192
.05855673	193
.05840885	194
.0582621	195
.05811646	196
.05797192	197
.05782848	198
.05768611	199
.05754489	200

Table 34 - Vector Sum Monitored Directly
Beneath the Surface Blast

Particle Velocity	Scaled Distance
1	11.434208
.95064435	12
.87415287	13
.80883108	14
.75241318	15
.70320552	16
.65991738	17
.62154765	18
.58730847	19
.55657101	20
.52882772	21
.50366416	22
.4807389	23
.4597679	24
.44051317	25
.4227737	26
.40637858	27
.39118169	28
.37705693	29
.36389573	30
.35160333	31
.34009703	32
.32930431	33
.31916123	34
.30961123	35
.30060416	36
.29209533	37
.28404489	38
.27641673	39
.26917909	40
.26230258	41
.25576126	42
.24953134	43
.24359121	44
.23792139	45
.23250367	46
.227322	47
.2223613	48
.21760784	49
.21304909	50
.20867311	51
.20446959	52
.20042824	53
.19654029	54
.19279686	55
.18919035	56
.18571338	57
.18235912	58
.17912126	59
.17599386	60
.17297144	61
.17004889	62
.16722113	63
.1644839	64
.16183291	65
.15926414	66
.15677386	67
.15435855	68
.15201491	69
.14973982	70
.14753032	71
.14538365	72
.14329729	73
.14126845	74
.1392951	75
.1373749	76
.13550575	77
.13368568	78
.13191277	79
.13018524	80
.12850137	81
.12685954	82
.12525821	83
.12369592	84
.12217124	85
.12068299	86
.11922954	87
.11781001	88
.11642314	89
.11506782	90
.11374309	91
.11244766	92
.11118084	93
.1099416	94
.10872908	95
.10754242	96
.10638081	97
.10524346	98
.10412964	99
.10303862	100
.10196973	101
.10092239	102
.09989567	103
.09888926	104
.09790248	105
.09693476	106
.09598555	107
.09505434	108
.09414063	109
.09324392	110
.09236376	111
.09149967	112
.09065126	113
.08981808	114
.08899974	115
.08819584	116
.08740601	117
.08662988	118
.08586711	119
.08511735	120
.08438028	121
.08365569	122
.08294295	123
.08224219	124
.08155271	125
.08087452	126
.08020727	127
.0795507	128
.07890455	129
.07826857	130
.07764254	131
.07702622	132
.07641949	133
.07582183	134
.07523333	135
.07465379	136
.07408272	137
.07352022	138
.072966	139
.07241999	140
.07188172	141
.0713513	142
.07082847	143
.07031319	144
.06980498	145
.06930409	146
.06881009	147
.06832282	148
.06784235	149
.06736843	150
.06690094	151
.06643975	152
.06598473	153
.06553576	154
.06509272	155
.0646555	156
.06422398	157
.06379805	158
.06337761	159
.06296255	160
.06255277	161
.06214817	162
.06174865	163
.06135412	164
.06096448	165
.06057965	166
.06019955	167
.05982407	168
.05945314	169
.05908668	170
.05872461	171
.05836685	172
.05801332	173
.05766396	174
.05731868	175
.05697742	176
.05664011	177
.05630668	178
.05597706	179
.05565129	180
.05532901	181
.05501045	182
.05469547	183
.05438398	184
.05407594	185
.0537713	186
.05346998	187
.05317195	188
.05287716	189
.05258553	190
.05229704	191
.05201162	192
.05172922	193
.05144982	194
.05117335	195
.05089976	196
.05062901	197
.05036107	198
.05009588	199
.04983341	200

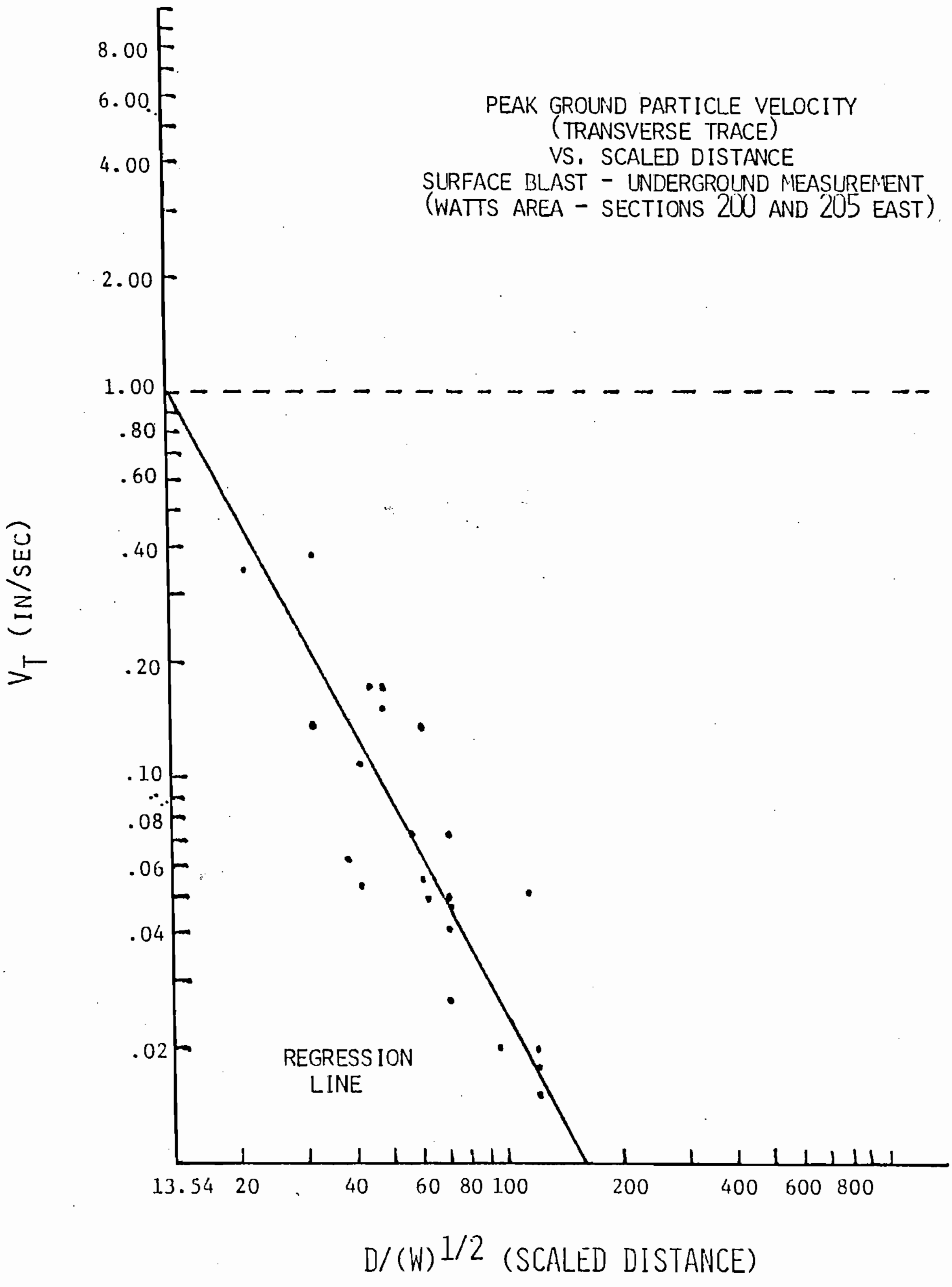


Figure 25 - Transverse Peak Particle Velocity Composite Plot for Direct and Angle Shots

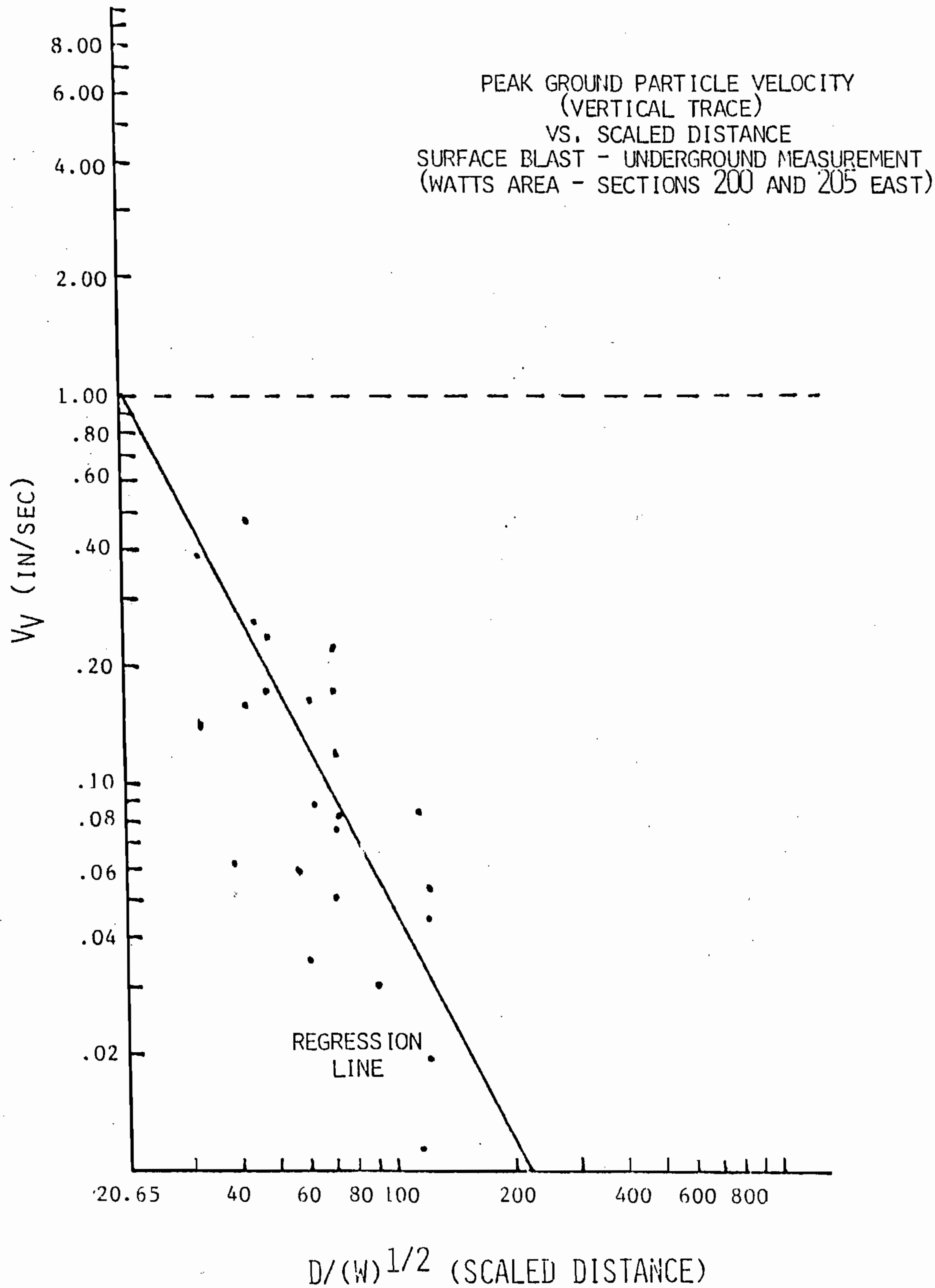


Figure 26 - Vertical Peak Particle Velocity Composite Plot for Direct and Angle Shots

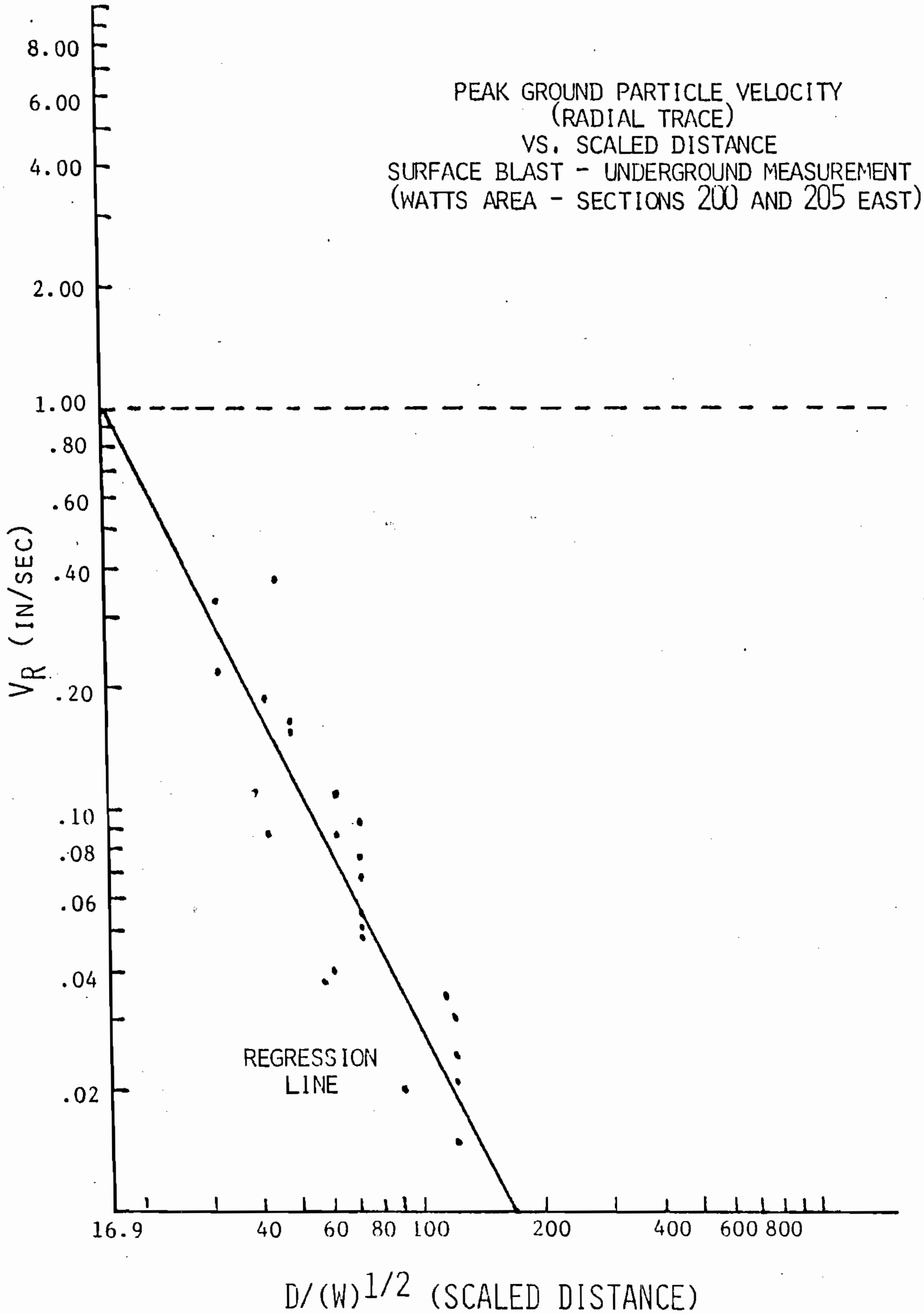


Figure 27 - Radial Peak Particle Velocity
Composite Plot for Direct and Angle Shots

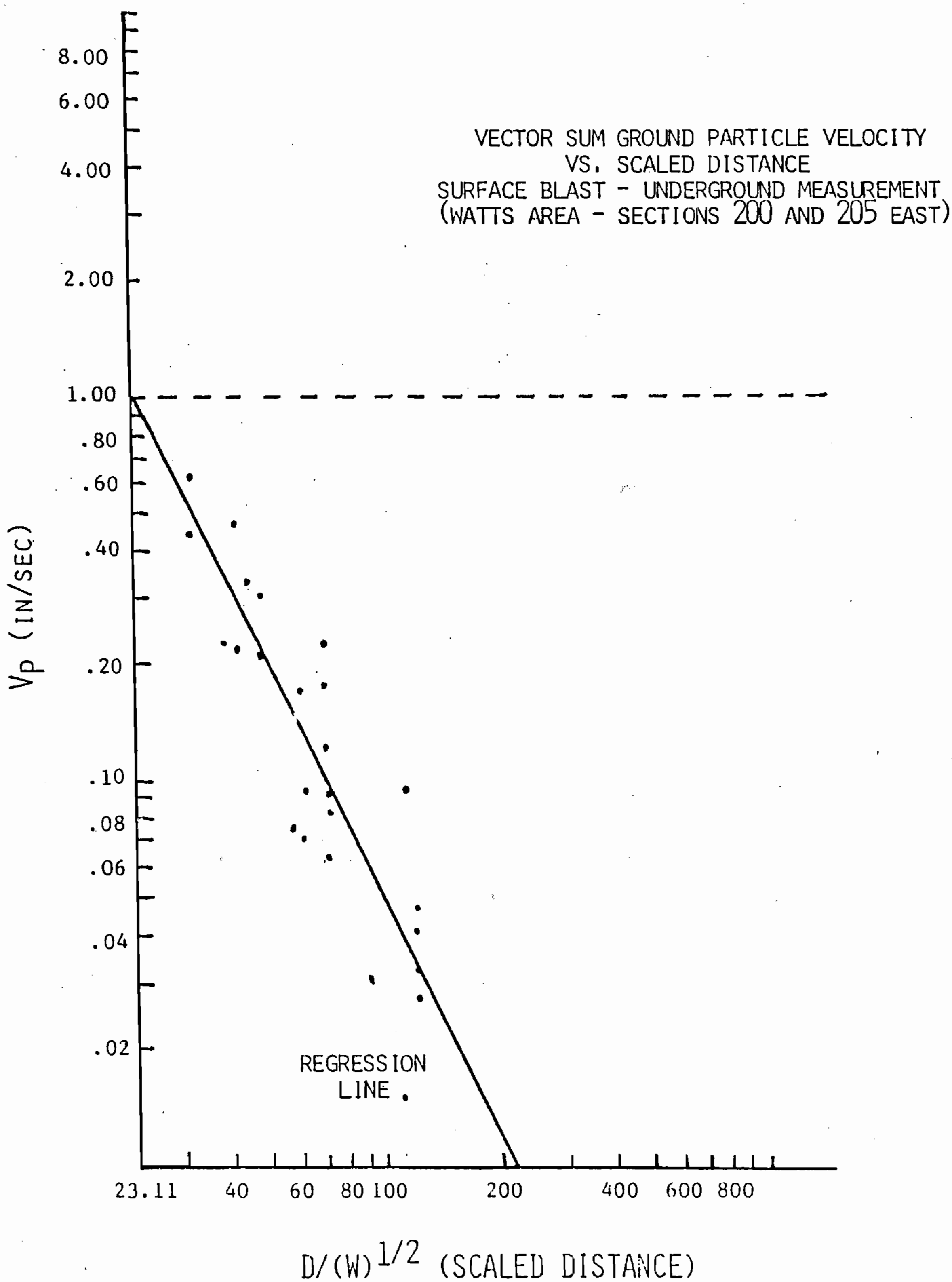


Figure 28- Vector Sum Ground Particle Velocity Composite Plot for Direct and Angle Shots

4) How does the average ground particle velocity measured at the surface correlate with the direction of major and minor principal stresses? Figures 29 - 32 show that blasts monitored along the N40 to 50W axis, the minor principal stress as opposed to N50 to 40E, the major principal stress, result in a higher transverse particle velocity, lower vertical ground particle velocity up to about 200 scaled distance, higher radial particle velocity up to 50 scaled distance, and lower vector sum ground particle velocity up to about 25 scaled distance. These results, on the average, should provide some idea about where and at which direction on the surface a higher or lower ground particle velocity could be expected.

Tables 35 - 42 give the approximate ground particle velocity with the equivalent scaled distance for blasts monitored along NW and NE directions, respectively.

Appendixes F and G show the results of statistical analysis for two models. The correlations with scaled distance model appear to be fair enough, for all practical purposes, in both directions.

5) How does the composite ground particle velocity measured at surface along NW (minor) and NE (major) principal stress axes correlate with the scaled distance law? Although answering this particular question was not a part of the main objectives, it was decided to shed some light on this matter for the

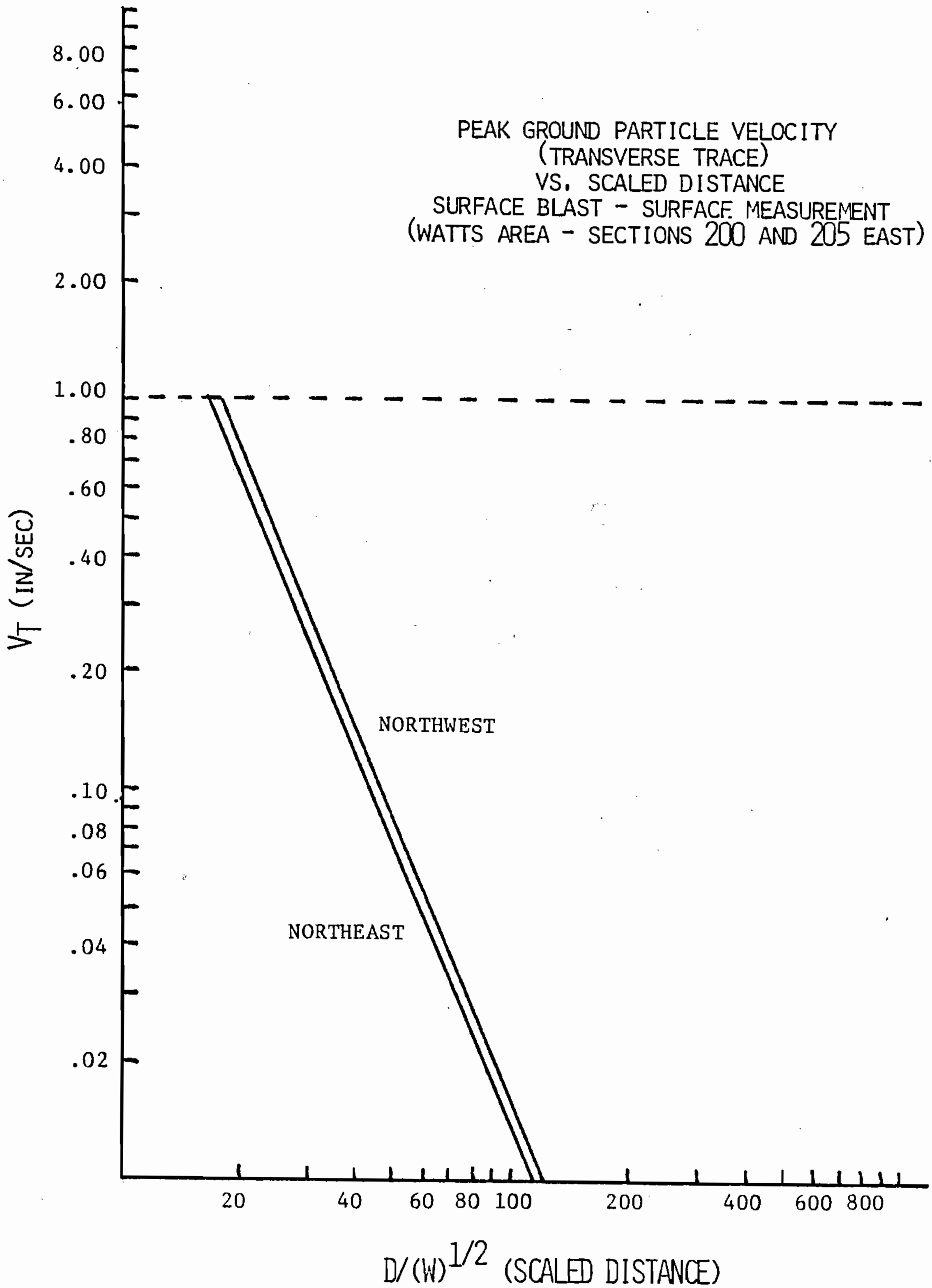


Figure 29 - Comparison of Transverse Trace Measured Along NW (Minor) and NE (Major) Axes

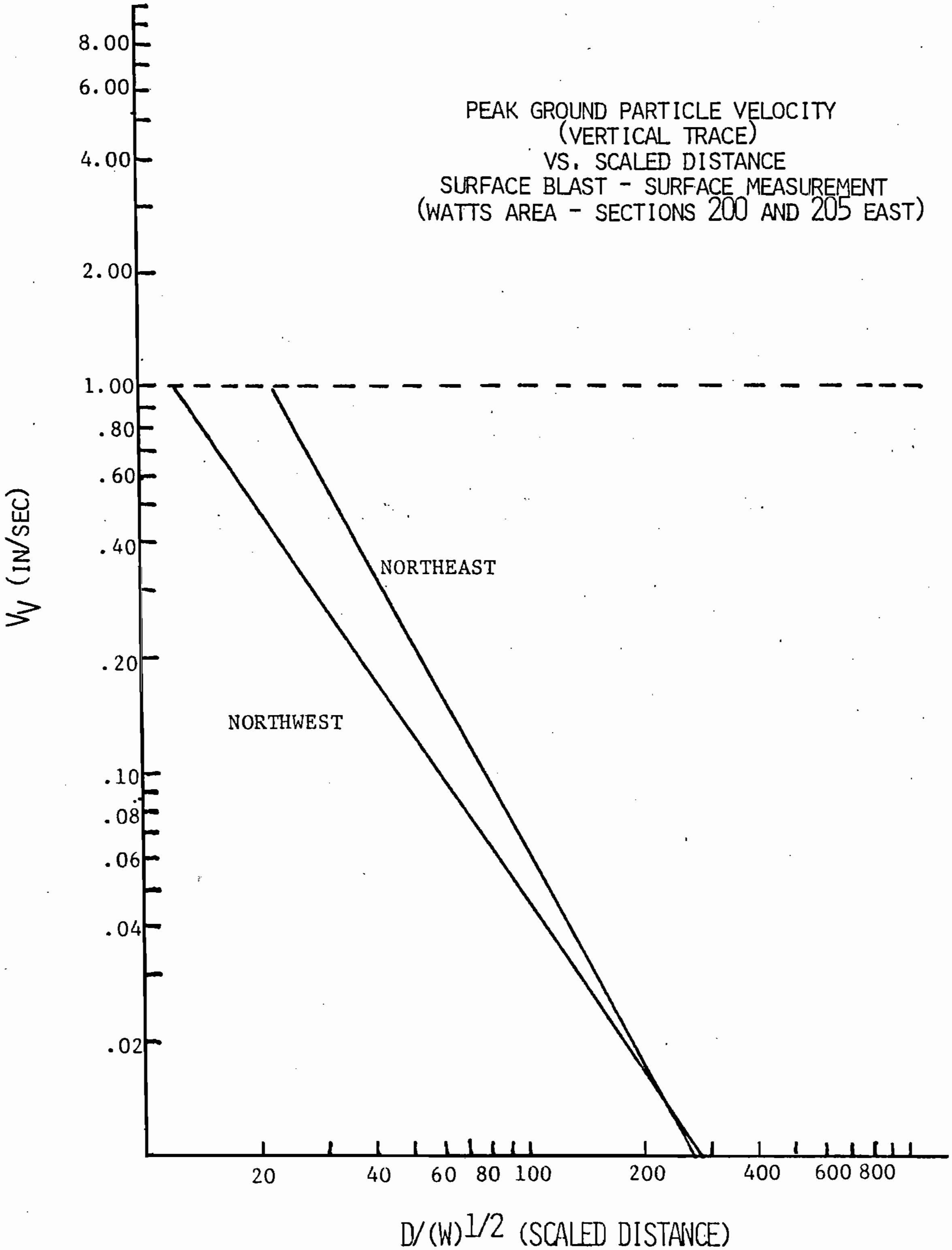


Figure 30 - Comparison of Vertical Trace Measured Along NW (Minor) and NE (Major) Axes

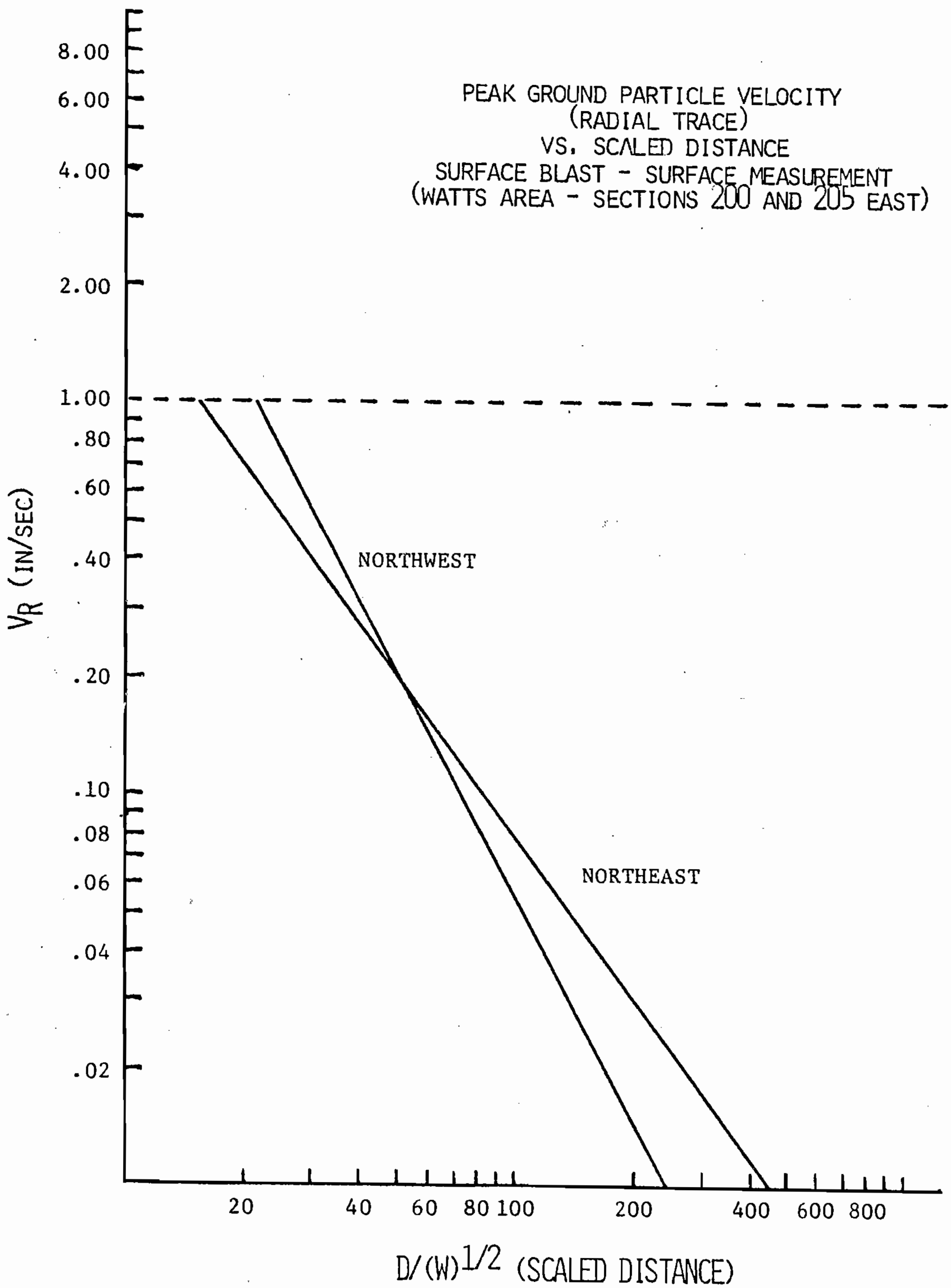


Figure 31 - Comparison of Radial Trace Measured Along NW (Minor) and NE (Major) Axes

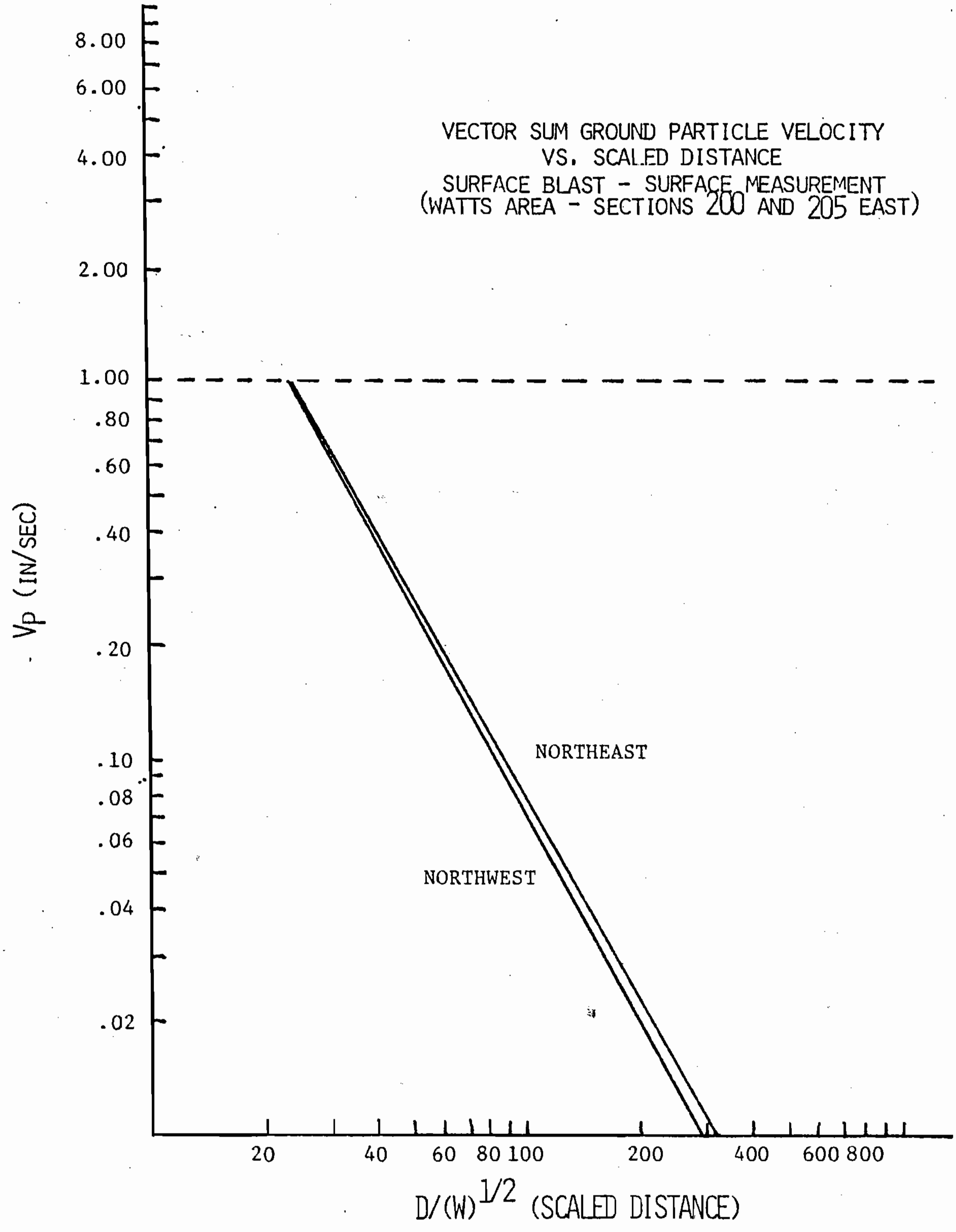


Figure 32 - Comparison of Vector Sum
Measured Along NW (Minor)
and NE (Major) Axes

Table 35 - Transverse Particle Velocity Along NW Axis

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	18.173307	.11822758	64	.04718436	110	.0260892	156
.92732923	19	.1151593	65	.04646568	111	.02580809	157
.85006707	20	.11221579	66	.04576425	112	.02553158	158
.78255726	21	.1093899	67	.04507959	113	.02525984	159
.72318793	22	.10667556	68	.04441099	114	.02499267	160
.67067129	23	.10406676	69	.04375791	115	.02472996	161
.62396723	24	.10155792	70	.04312006	116	.02447162	162
.58222895	25	.09914588	71	.04249686	117	.02421753	163
.54476005	26	.09681989	72	.04188786	118	.02396762	164
.51098377	27	.09458113	73	.04129262	119	.02372178	165
.48041884	28	.09242363	74	.04071071	120	.02347993	166
.45266097	29	.09034335	75	.04014173	121	.02324197	167
.42736842	30	.08833651	76	.03958539	122	.02300782	168
.40425055	31	.08639961	77	.03904101	123	.0227774	169
.38305909	32	.08452937	78	.03850853	124	.02255063	170
.36358035	33	.08272267	79	.0379875	125	.02232743	171
.34563032	34	.08097658	80	.03747769	126	.02210771	172
.32904905	35	.07928837	81	.03697847	127	.02189142	173
.31369745	36	.07765542	82	.03648984	128	.02167846	174
.29945387	37	.07607539	83	.03601149	129	.02146889	175
.28621151	38	.07454567	84	.03554284	130	.02126232	176
.27387632	39	.07306435	85	.03508391	131	.02105898	177
.26236524	40	.0716293	86	.03463432	132	.02085872	178
.25160465	41	.07023853	87	.03419383	133	.02066148	179
.24152909	42	.06889029	88	.03376217	134	.02046718	180
.23207992	43	.06758256	89	.03333911	135	.02027576	181
.2232052	44	.06631393	90	.03292442	136	.02008718	182
.21485805	45	.06508275	91	.03251786	137	.01990137	183
.2069964	46	.06388751	92	.03211923	138	.01971828	184
.19958233	47	.06272678	93	.03172831	139	.01953785	185
.19258166	48	.06159922	94	.0313449	140	.01936004	186
.18596341	49	.06050355	95	.03096881	141	.01918478	187
.17969953	50	.05943853	96	.03059983	142	.01901202	188
.17376459	51	.05840301	97	.0302378	143	.01884173	189
.16813519	52	.05739587	98	.02988252	144	.01867385	190
.16279017	53	.05641606	99	.02953384	145	.01850834	191
.15771037	54	.05546258	100	.02919158	146	.01834515	192
.15287798	55	.05453447	101	.02885569	147	.01818423	193
.14827678	56	.05363089	102	.02852579	148	.01802554	194
.14389199	57	.05275079	103	.02820176	149	.01786905	195
.13970958	58	.05189333	104	.02788363	150	.0177147	196
.13571725	59	.05105791	105	.02757117	151	.01756246	197
.13190327	60	.05024367	106	.02726424	152	.01741239	198
.12825688	61	.04944988	107	.0269627	153	.01726415	199
.12476816	62	.04867583	108	.02666643	154	.01711801	200
.1214279	63	.04792087	109	.02637531	155		

Table 36 - Vertical Particle Velocity Along NW Axis

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	12.45197	.09832404	59	.04104583	106	.0237479	153
.93780057	13	.09589071	60	.04047529	107	.02351834	154
.839698	14	.09355635	61	.03991767	108	.02329247	155
.75761398	15	.0913154	62	.03937288	109	.02307029	156
.68810882	16	.08916271	63	.03884049	110	.02285144	157
.6286381	17	.08709359	64	.03831982	111	.02263614	158
.57728293	18	.08510326	65	.03781081	112	.0224242	159
.53257211	19	.08318788	66	.037313	113	.02221555	160
.49336043	20	.08134344	67	.03682603	114	.02201013	161
.45874471	21	.07956631	68	.03634969	115	.02180787	162
.42800397	22	.07785313	69	.03588337	116	.02160868	163
.40055653	23	.07620079	70	.03542704	117	.02141253	164
.37592832	24	.07460601	71	.03498034	118	.02121932	165
.35372967	25	.07306633	72	.03454296	119	.02102901	166
.33363744	26	.071579	73	.03411464	120	.02084154	167
.31538183	27	.07014158	74	.03369512	121	.02065684	168
.29873599	28	.06875174	75	.03328416	122	.02047486	169
.28350753	29	.06740731	76	.03288159	123	.02029554	170
.26953318	30	.06610622	77	.0324869	124	.02011884	171
.25667274	31	.06484657	78	.03210016	125	.01994468	172
.24480562	32	.0636265	79	.03172105	126	.01977303	173
.23382758	33	.06244431	80	.03134936	127	.01960384	174
.22364797	34	.06129836	81	.03098499	128	.01943705	175
.21418772	35	.06018712	82	.03062745	129	.01927261	176
.20537756	36	.05910914	83	.03027684	130	.01911059	177
.19715657	37	.05806302	84	.02993288	131	.01895064	178
.18947098	38	.05704747	85	.02959541	132	.018793	179
.18227315	39	.05606126	86	.02926424	133	.01863755	180
.1755208	40	.0551032	87	.02893922	134	.01848423	181
.16917622	41	.05417229	88	.02862018	135	.018333	182
.1632057	42	.05326716	89	.02830698	136	.01818384	183
.15757908	43	.05238711	90	.02799946	137	.01803668	184
.1522692	44	.05153119	91	.02769759	138	.01789151	185
.14725164	45	.05069829	92	.02740091	139	.01774828	186
.14250435	46	.04988753	93	.0271096	140	.01760695	187
.13800732	47	.04909839	94	.02682344	141	.0174675	188
.13374247	48	.0483297	95	.02654227	142	.01732988	189
.12969334	49	.04758101	96	.026266	143	.01719406	190
.12584494	50	.04685159	97	.02599451	144	.01706001	191
.12218369	51	.04614046	98	.02572766	145	.0169277	192
.1186968	52	.04544739	99	.02546537	146	.01679719	193
.11537314	53	.04477133	100	.02520751	147	.01666816	194
.11220219	54	.04411202	101	.02495398	148	.01654088	195
.10917402	55	.04346875	102	.02470479	149	.0164152	196
.10628003	56	.04284101	103	.02445952	150	.01629112	197
.10351198	57	.04222828	104	.0242184	151	.01616869	198
.10086231	58	.04163004	105	.02398122	152		

Table 37 - Radial Particle Velocity
Along NW Axis

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	21.900179	.12013139	66	.04425217	111	.02301483	156
.99130214	22	.11671062	67	.04349639	112	.02273405	157
.91016655	23	.11343587	68	.04275987	113	.02245845	158
.8387146	24	.11029884	69	.04204224	114	.0221879	159
.7754562	25	.10729184	70	.04134276	115	.02192227	160
.71917772	26	.10440775	71	.04066083	116	.02166145	161
.66888314	27	.10163991	72	.03999586	117	.02140532	162
.62374838	28	.09898213	73	.03934728	118	.02115376	163
.58308712	29	.0964286	74	.03871456	119	.02090668	164
.54632376	30	.09397393	75	.03809718	120	.02066396	165
.51297265	31	.09161301	76	.03749465	121	.02042559	166
.48262175	32	.08934111	77	.0369065	122	.02019118	167
.45491968	33	.0871538	78	.03633226	123	.01996094	168
.42956515	34	.08504688	79	.03577159	124	.01973466	169
.40629857	35	.08301645	80	.03522378	125	.01951226	170
.38489554	36	.08105883	81	.03468872	126	.01929366	171
.3651611	37	.07917054	82	.03416592	127	.01907875	172
.34692513	38	.07734835	83	.03365501	128	.01886746	173
.33003876	39	.07558917	84	.03315563	129	.01865971	174
.31437122	40	.0738901	85	.03266742	130	.01845542	175
.29980734	41	.07224845	86	.03219007	131	.01825451	176
.28624515	42	.07066161	87	.03172324	132	.01805691	177
.27359436	43	.06912717	88	.03126663	133	.01786254	178
.26177455	44	.06764283	89	.03081994	134	.01767134	179
.25071411	45	.06620643	90	.03038288	135	.01748323	180
.24034896	46	.06481599	91	.02995517	136	.01729815	181
.23062162	47	.06346939	92	.02953656	137	.01711603	182
.22148055	48	.06216477	93	.02912677	138	.01693681	183
.21287926	49	.06090058	94	.02872557	139	.01676043	184
.2047758	50	.05967508	95	.02833271	140	.01658682	185
.19713226	51	.05848679	96	.02794796	141	.01641594	186
.18991426	52	.05733391	97	.0275711	142	.01624772	187
.18309061	53	.05621533	98	.02720192	143	.0160821	188
.17663291	54	.0551296	99	.0268402	144	.01591904	189
.17051539	55	.05407543	100	.02648574	145	.01575848	190
.16471411	56	.05305163	101	.02613835	146	.01560037	191
.15920784	57	.052057	102	.02579785	147	.01544466	192
.15397664	58	.05109045	103	.02546404	148	.0152913	193
.14900242	59	.05015093	104	.02513676	149	.01514025	194
.14426859	60	.04923743	105	.02481583	150	.01499145	195
.13975953	61	.048349	106	.02450119	151	.01484486	196
.13546141	62	.04748471	107	.02419238	152	.01470044	197
.13136112	63	.0466437	108	.02388954	153	.01455815	198
.1274466	64	.04582514	109	.02359243	154	.01441794	199
.12370677	65	.04502821	110	.02330091	155	.01427978	200

Table 38 - Vector Sum Particle Velocity Along NW Axis

Particle Velocity	Scaled Distance						
1	23.279706	.14168906	68	.05613556	113	.0304683	158
.94596476	24	.13796793	69	.05524113	114	.03011987	159
.87812313	25	.134396	70	.05436857	115	.02977758	160
.81752986	26	.13096526	71	.05351718	116	.02944127	161
.7631746	27	.12766825	72	.05268625	117	.02911081	162
.71421628	28	.12449803	73	.05187513	118	.02878605	163
.66995941	29	.12144807	74	.05108318	119	.02846687	164
.62980776	30	.1185123	75	.05030981	120	.02815314	165
.59326357	31	.11568496	76	.04955441	121	.02784473	166
.5599015	32	.11296073	77	.04881644	122	.02754152	167
.52935757	33	.11033458	78	.04809535	123	.0272434	168
.50131883	34	.10780177	79	.04739061	124	.02695024	169
.47551474	35	.10535788	80	.04670175	125	.02666194	170
.45171088	36	.10299874	81	.04602826	126	.02637838	171
.4297029	37	.10072049	82	.0453697	127	.02609947	172
.4093121	38	.09851916	83	.04472561	128	.0258251	173
.39038155	39	.09639155	84	.04409558	129	.02555517	174
.37277321	40	.09433424	85	.04347918	130	.02528969	175
.35636505	41	.09234416	86	.04287602	131	.02502825	176
.34104885	42	.09041832	87	.04228573	132	.02477107	177
.32672854	43	.08855409	88	.04170793	133	.02451796	178
.31331833	44	.08674852	89	.04114225	134	.02426884	179
.30074179	45	.08499942	90	.04058838	135	.02402361	180
.28892993	46	.08330434	91	.04004596	136	.0237822	181
.27782138	47	.08166103	92	.03951468	137	.02354452	182
.26736051	48	.08006749	93	.03899425	138	.02331051	183
.25749725	49	.07852149	94	.03848434	139	.02308007	184
.24818626	50	.07702114	95	.0379847	140	.02285314	185
.23938647	51	.07556481	96	.03749503	141	.02262966	186
.23106062	52	.07415079	97	.03701506	142	.02240953	187
.2231748	53	.07277713	98	.03654454	143	.02219271	188
.21569806	54	.07144257	99	.03608322	144	.02197911	189
.2086022	55	.07014554	100	.03563085	145	.02176879	190
.20186149	56	.06888462	101	.03518721	146	.02156136	191
.19545204	57	.06765844	102	.03475206	147	.02135708	192
.1893524	58	.06646573	103	.03432529	148	.02115578	193
.1835426	59	.06530539	104	.03390649	149	.02095741	194
.17800424	60	.0641759	105	.03349544	150	.0207619	195
.17272046	61	.06307648	106	.03309216	151	.02056929	196
.16767566	62	.06200597	107	.03269635	152	.02037925	197
.16285543	63	.06096331	108	.03230782	153	.020192	198
.15824644	64	.05994757	109	.03192649	154	.02000741	199
.15383637	65	.05895789	110	.03155199	155	.01982542	200
.14961374	66	.0579931	111	.03118415	156		
.14556793	67	.05705263	112	.030823	157		

Table 39 - Transverse Particle Velocity Along NE Axis

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	16.668516	.10321119	63	.03983835	110	.02169729	157
.9669261	17	.1004719	64	.0392273	111	.02146316	158
.87698991	18	.09784621	65	.03863097	112	.02123312	159
.79962971	19	.09532768	66	.0380489	113	.02100696	160
.73255596	20	.0929104	67	.0374806	114	.02078469	161
.67398385	21	.09058887	68	.03692565	115	.02056593	162
.62250392	22	.08835809	69	.03638361	116	.0203509	163
.57699081	23	.08621297	70	.03585408	117	.02013941	164
.53653646	24	.08414935	71	.03533667	118	.01993149	165
.5004013A	25	.08216297	72	.03483109	119	.01972675	166
.46797813	26	.08024991	73	.0343367	120	.01952542	167
.43876376	27	.07840653	74	.03385343	121	.01932733	168
.4123387	28	.0766294	75	.03338086	122	.01913241	169
.38835084	29	.07491528	76	.03291866	123	.01894058	170
.36650251	30	.07326118	77	.03246653	124	.01875189	171
.34654072	31	.07166424	78	.03202416	125	.01856596	172
.32824933	32	.07012189	79	.03159127	126	.01838304	173
.31144275	33	.06863132	80	.0311676	127	.01820296	174
.2959607	34	.06719047	81	.03075285	128	.01802566	175
.28166439	35	.06579709	82	.03034689	129	.01785108	176
.26843265	36	.06444878	83	.02994917	130	.01767916	177
.2561601	37	.06314385	84	.02955974	131	.01750986	178
.24475392	38	.06188031	85	.02917839	132	.01734311	179
.23413251	39	.06065641	86	.02880458	133	.01717887	180
.22422373	40	.05947044	87	.02843849	134	.01701708	181
.21496376	41	.05832082	88	.02807954	135	.01685779	182
.20629574	42	.05720604	89	.02772781	136	.01670066	183
.1981691	43	.05612467	90	.02738302	137	.01654593	184
.19053855	44	.05507536	91	.02704498	138	.01639346	185
.18336357	45	.05405682	92	.0267135	139	.01624321	186
.17660771	46	.05306781	93	.02638842	140	.01609513	187
.17023815	47	.05210729	94	.02606957	141	.01594918	188
.16422528	48	.05117386	95	.02575678	142	.01580532	189
.15854239	49	.05026675	96	.0254499	143	.0156635	190
.1531649	50	.04938487	97	.02514878	144	.01552379	191
.14807106	51	.04852728	98	.02485327	145	.01538585	192
.14324065	52	.04769305	99	.02456322	146	.01524994	193
.13865543	53	.04688134	100	.02427851	147	.01511592	194
.13429861	54	.04609132	101	.02399909	148	.01498377	195
.13015492	55	.0453222	102	.02372455	149	.01485343	196
.12621032	56	.04457323	103	.02345504	150	.01472488	197
.12245198	57	.04384379	104	.02319036	151	.01459819	198
.11886803	58	.04313291	105	.02293038	152	.01447302	199
.11544758	59	.04244022	106	.02267509	153	.01434963	200
.11218069	60	.04176501	107	.02242408	154		
.1090578	61	.04110667	108	.02217755	155		
.10607061	62	.04046463	109	.02193528	156		

Table 40 - Vertical Particle Velocity Along NE Axis

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	22.287448	.12965976	67	.04996333	112	.02669389	157
.94326384	23	.12614311	68	.04914581	113	.02638107	158
.87162157	24	.1227711	69	.04834868	114	.02607396	159
.80802235	25	.11953582	70	.04757128	115	.02577231	160
.75129325	26	.1164299	71	.04681295	116	.025476	161
.70046895	27	.11344645	72	.04607306	117	.0251849	162
.65474883	28	.11057904	73	.04535102	118	.02489888	163
.61346437	29	.10782164	74	.04464624	119	.02461784	164
.57605373	30	.10516867	75	.04395817	120	.02434164	165
.54204176	31	.10261481	76	.04328639	121	.02407029	166
.51102441	32	.10015514	77	.04263019	122	.02380336	167
.48265659	33	.09778505	78	.04198906	123	.02354106	168
.45664128	34	.09550017	79	.04136275	124	.02328318	169
.43272275	35	.09329643	80	.0407507	125	.02302962	170
.41067906	36	.09116998	81	.04015248	126	.02278039	171
.39031713	37	.0891172	82	.03956766	127	.02253519	172
.37146825	38	.0871347	83	.03899585	128	.02229392	173
.35398441	39	.08521925	84	.03843665	129	.0220567	174
.33773559	40	.08336783	85	.0378897	130	.02182335	175
.32260658	41	.0815776	86	.03735464	131	.02159377	176
.30849586	42	.07984584	87	.03683111	132	.02136799	177
.29531301	43	.07817001	88	.0363188	133	.02114563	178
.28297747	44	.07654771	89	.03581736	134	.0209269	179
.27141734	45	.07497664	90	.0353265	135	.02071163	180
.26056826	46	.07345464	91	.03484591	136	.02049975	181
.25037237	47	.07197967	92	.03437531	137	.02029129	182
.24077772	48	.07054989	93	.03391443	138	.02008588	183
.23173749	49	.06916315	94	.03346298	139	.01988375	184
.223209	50	.06781801	95	.03302071	140	.01968472	185
.21515418	51	.06651271	96	.03258738	141	.01948875	186
.20753819	52	.06524567	97	.03216273	142	.01929577	187
.20032919	53	.0640154	98	.03174654	143	.01910571	188
.19349833	54	.06282046	99	.03133857	144	.01891851	189
.18701951	55	.0616595	100	.03093862	145	.01873412	190
.18086855	56	.06053124	101	.03054648	146	.01855248	191
.17502348	57	.05943444	102	.03016193	147	.01837354	192
.1694641	58	.05836791	103	.02978477	148	.01819725	193
.16417186	59	.05733056	104	.02941483	149	.01802354	194
.15912973	60	.05632131	105	.02905191	150	.01785237	195
.15432202	61	.05533914	106	.02869583	151	.01768379	196
.14973422	62	.05438308	107	.02834643	152	.01751744	197
.14535309	63	.05345229	108	.02800353	153	.0173536	198
.14116596	64	.05254561	109	.02766697	154	.01719219	199
.13716179	65	.05166248	110	.02733669	155	.01703299	200
.13332958	66	.05080198	111	.02701225	156		

Table 41 - Radial Particle Velocity Along NE Axis

Particle Velocity	Scaled Distance						
1	15.506398	.1497695	62	.06913942	109	.04230779	156
.95797818	16	.1465222	63	.06827977	110	.04193894	157
.88162725	17	.1433948	64	.06743845	111	.04157572	158
.81522359	18	.14038112	65	.06661499	112	.04121791	159
.75702041	19	.13747535	66	.06580869	113	.04086549	160
.70564932	20	.13467207	67	.06501901	114	.04051805	161
.66002376	21	.13196623	68	.06424579	115	.0401758	162
.61927127	22	.12935308	69	.06348814	116	.0398385	163
.5826837	23	.12682816	70	.06274591	117	.03950608	164
.54968084	24	.12438731	71	.06201856	118	.03917843	165
.51978316	25	.12202669	72	.06130568	119	.03885545	166
.49259106	26	.11974232	73	.06060685	120	.03853705	167
.46776925	27	.11753103	74	.05992179	121	.03822314	168
.44503433	28	.11538945	75	.05924983	122	.03791362	169
.42414549	29	.11331448	76	.05859088	123	.03760841	170
.4048964	30	.11130322	77	.05794451	124	.03730743	171
.38711008	31	.10935292	78	.05731049	125	.03701069	172
.37063336	32	.10746101	79	.05668816	126	.03671782	173
.35533339	33	.105625	80	.05607754	127	.03642902	174
.34109386	34	.1038426	81	.0554782	128	.03614414	175
.32781347	35	.10211169	82	.05488986	129	.03586308	176
.31540282	36	.1004299	83	.05431223	130	.03558589	177
.30378312	37	.09879556	84	.05374503	131	.03531229	178
.29288457	38	.09720667	85	.05318801	132	.0350422	179
.28264512	39	.09566159	86	.0526409	133	.03477576	180
.27300953	40	.0941583	87	.05210345	134	.03451281	181
.26392841	41	.09269551	88	.05157542	135	.03425328	182
.25535742	42	.09127161	89	.05105658	136	.03399711	183
.2472568	43	.08988511	90	.05054671	137	.03374424	184
.23959062	44	.08853466	91	.05004558	138	.03349469	185
.23232655	45	.08721892	92	.04955298	139	.03324814	186
.22543522	46	.08593665	93	.04906871	140	.03300489	187
.21889001	47	.08468663	94	.04859257	141	.03276452	188
.21266671	48	.08346775	95	.04812436	142	.03252725	189
.20674327	49	.08227899	96	.04766391	143	.03229294	190
.20109955	50	.08111903	97	.04721102	144	.03206153	191
.19571714	51	.07998716	98	.04676553	145	.03183298	192
.19057916	52	.07888234	99	.04632726	146	.03160723	193
.18567014	53	.07780366	100	.04589605	147	.03138424	194
.18097583	54	.07675024	101	.04547173	148	.03116396	195
.17648311	55	.07572125	102	.04505415	149	.03094634	196
.17217999	56	.0747159	103	.04464317	150	.03073133	197
.16805501	57	.07373342	104	.04423862	151	.03051899	198
.16409814	58	.07277307	105	.04384038	152	.03030898	199
.16029973	59	.07183416	106	.0434483	153	.03010155	200
.15665087	60	.070916	107	.04306224	154		
.15314336	61	.07001796	108	.04268208	155		

Table 42 - Vector Sum Particle Velocity Along NE Axis

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	23.492623	.15047666	68	.06087154	113	.03349601	158
.96263939	24	.14661259	69	.05992328	114	.03312153	159
.89509868	25	.14290102	70	.05899799	115	.03275354	160
.83467522	26	.13933417	71	.05809462	116	.03239199	161
.78038662	27	.1359044	72	.05721275	117	.03203644	162
.73141592	28	.13260462	73	.05635161	118	.03168704	163
.68707916	29	.12942825	74	.05551052	119	.03134356	164
.6467999	30	.1263691	75	.05468888	120	.03100585	165
.61008949	31	.12342133	76	.05388606	121	.03067389	166
.5765311	32	.12057951	77	.05310151	122	.03034725	167
.5457681	33	.11783857	78	.05233463	123	.0300261	168
.51749313	34	.11519365	79	.0515849	124	.02971022	169
.49144027	35	.11264027	80	.05085181	125	.02939951	170
.46737873	36	.11017416	81	.05013485	126	.02909384	171
.44510711	37	.10779131	82	.04943355	127	.0287931	172
.42444916	38	.10548795	83	.04874745	128	.02849718	173
.40524999	39	.10326053	84	.04807619	129	.02820598	174
.38737281	40	.10110566	85	.04741906	130	.02791941	175
.37069711	41	.0990202	86	.04677595	131	.02763735	176
.35511561	42	.09700111	87	.04614634	132	.02735972	177
.34053303	43	.09504557	88	.04552987	133	.02708642	178
.32686429	44	.09315099	89	.04492616	134	.02681735	179
.31403301	45	.09131453	90	.04433485	135	.02655244	180
.30197123	46	.08953406	91	.04375561	136	.02629169	181
.29061741	47	.0878072	92	.04318819	137	.02603471	182
.27991626	48	.08613178	93	.04263198	138	.02578174	183
.2698178	49	.08450573	94	.04208697	139	.02553258	184
.2602768	50	.08292712	95	.04155276	140	.02528716	185
.25125224	51	.08139406	96	.04102906	141	.0250454	186
.24270685	52	.07990478	97	.04051569	142	.02480723	187
.2346067	53	.07845763	98	.04001219	143	.02457258	188
.22692083	54	.07705097	99	.03951828	144	.02434137	189
.21962093	55	.07568339	100	.03903393	145	.02411355	190
.21268113	56	.07435315	101	.03855877	146	.02388903	191
.20607773	57	.07305913	102	.0380926	147	.02366777	192
.1997889	58	.07179994	103	.03763515	148	.02344968	193
.19379463	59	.07057431	104	.03718623	149	.02323471	194
.18807648	60	.06938102	105	.03674561	150	.02302281	195
.18261746	61	.06821894	106	.03631308	151	.02281391	196
.1774018	62	.06708697	107	.03588846	152	.02260795	197
.17241504	63	.06598404	108	.03547153	153	.02240488	198
.16764372	64	.06490916	109	.03506211	154	.02220464	199
.16307549	65	.06386138	110	.03466003	155	.02200729	200
.15869847	66	.06283976	111	.0342651	156		
.15450223	67	.06184343	112	.03387715	157		

purpose of designing scaled distances which were corrected for the directional effects of field stresses at the surface. The previous study[1] during the surface blast - surface measurement experiments did not correct for the effect of principal stresses, therefore it was deemed necessary by the principal investigator to provide a better guideline for designing scaled distance to be used in surface mining operations.

Figures 33 - 36 show the composite plot of ground particle velocity vs. scaled distance and accompanying Tables 43 - 46 provide approximations of magnitude of ground particle velocity for equivalent scaled distance corrected for the total effect of field principal stresses.

Appendix H gives the results of statistical analysis for two models attempted. The analysis points out to a fair correlation of data with square root scaled distance law as was expected.

(It should be noted that in all statistical analyses, if the number of observations (measurements) is less than 20, the results should be considered amendable. However, it should be remembered that the data fewer than 20 or 30, in any case, points out to the direction of what might be expected.)

6) Since it is known that the amount of strain is the critical factor in breaking a certain kind of rock and not the ground particle velocity, then what is the equivalent elastic strain for a given magnitude of ground particle velocity? The first

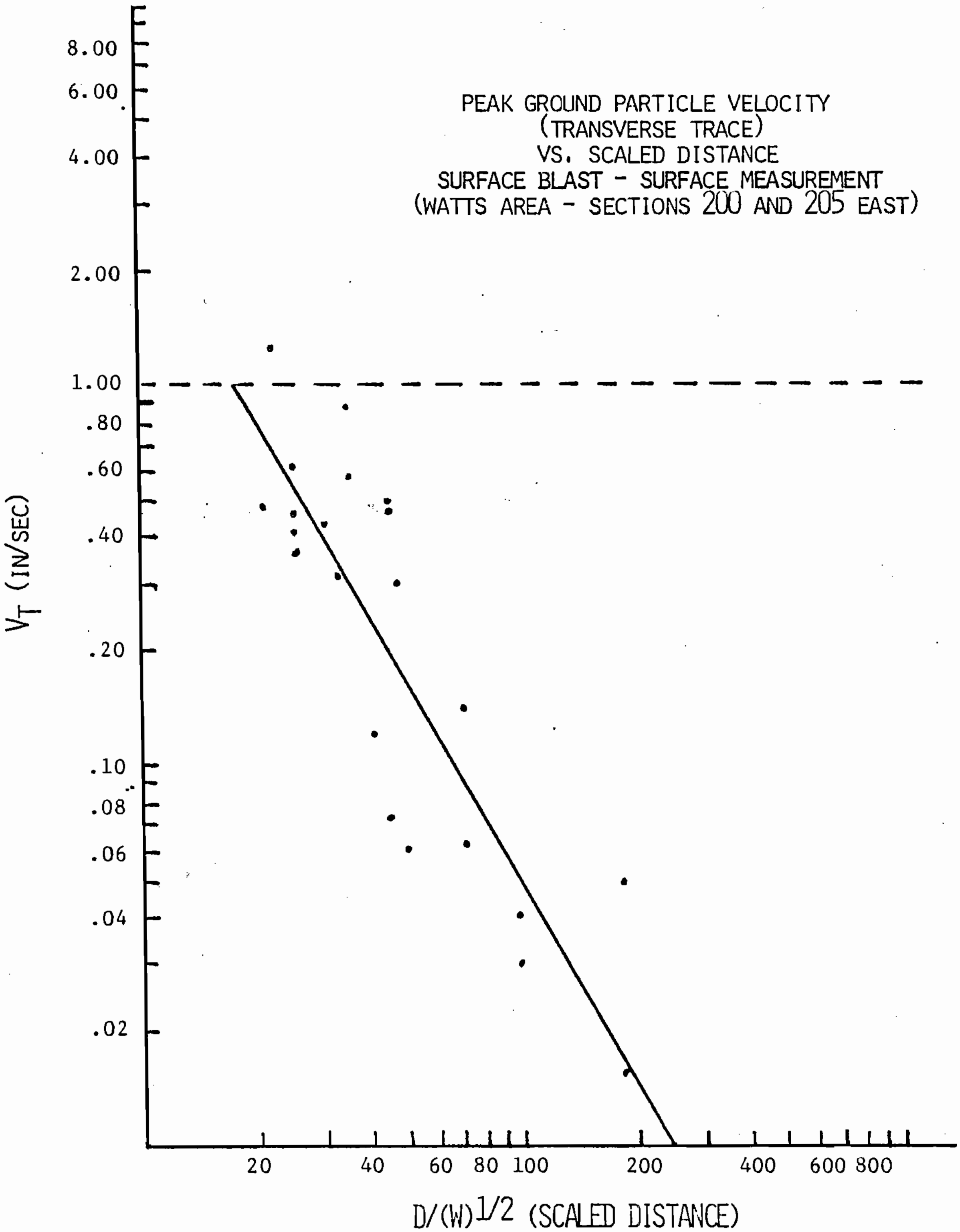


Figure 33 - Composite Plot of NW and NE Transverse Ground Particle Velocity for S_B - S_M

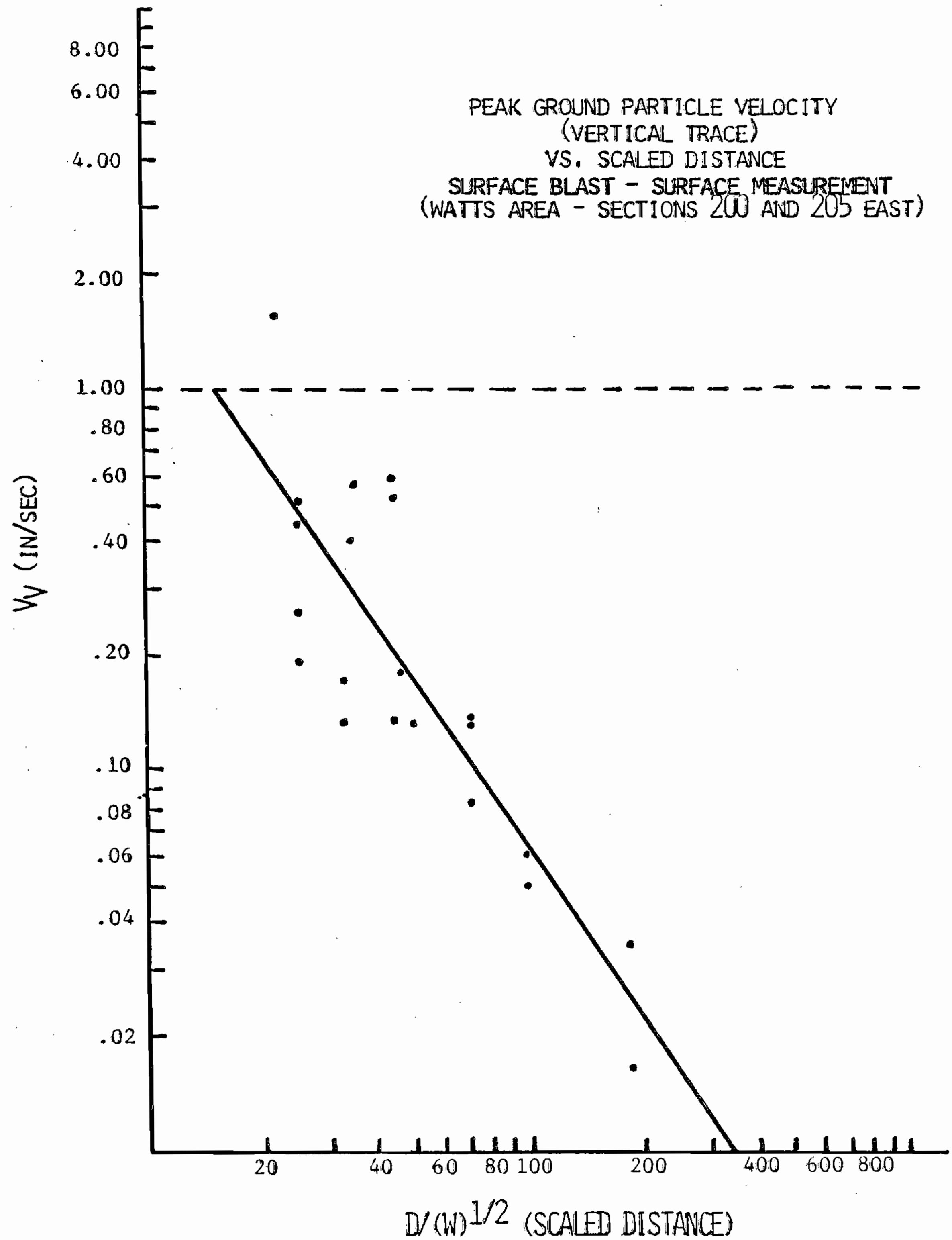


Figure 34 - Composite Plot of NW & NE Vertical Ground Particle Velocity for S_B - S_M

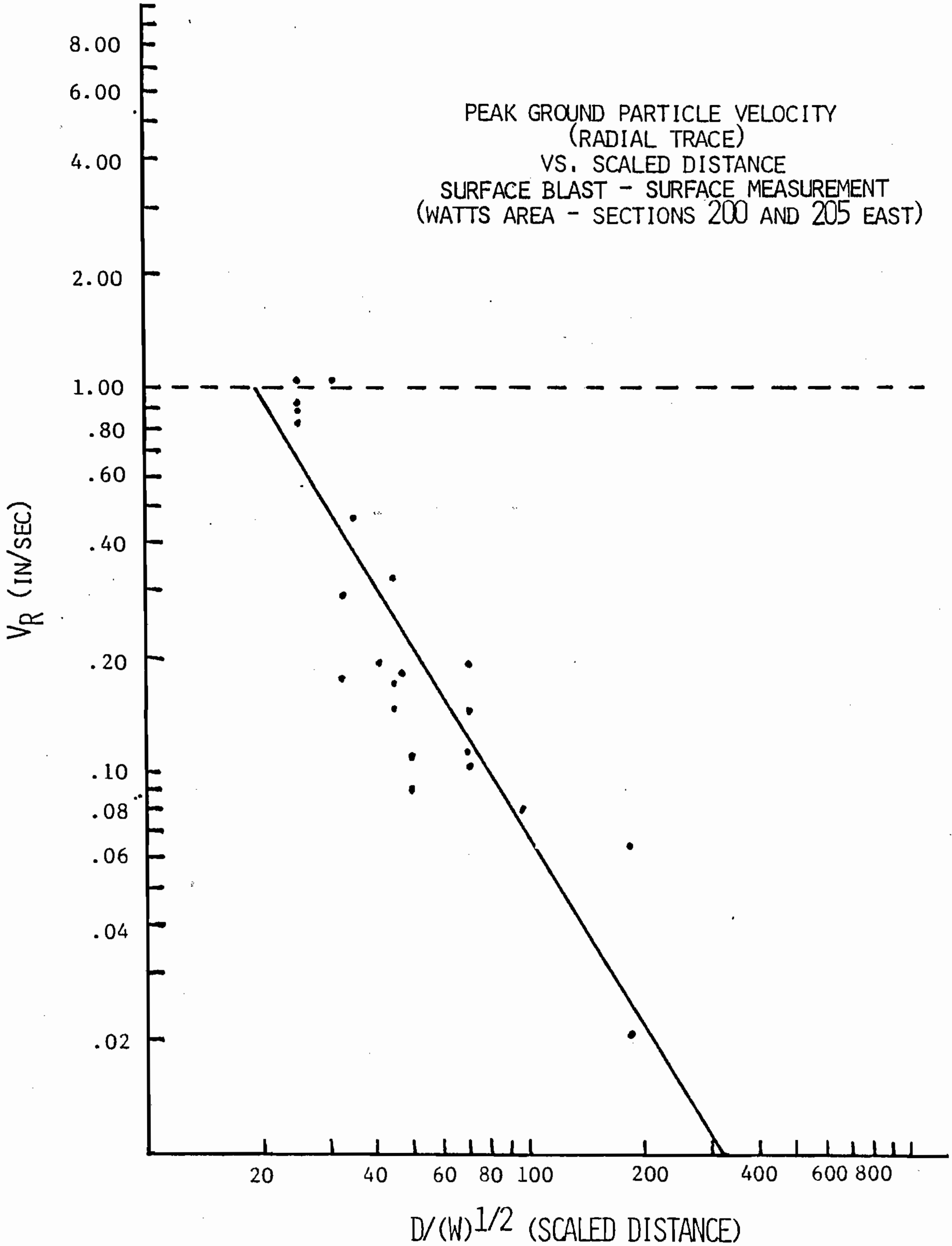


Figure 35 - Composite Plot of NW and NE Radial Ground Particle Velocity for S_B - S_M

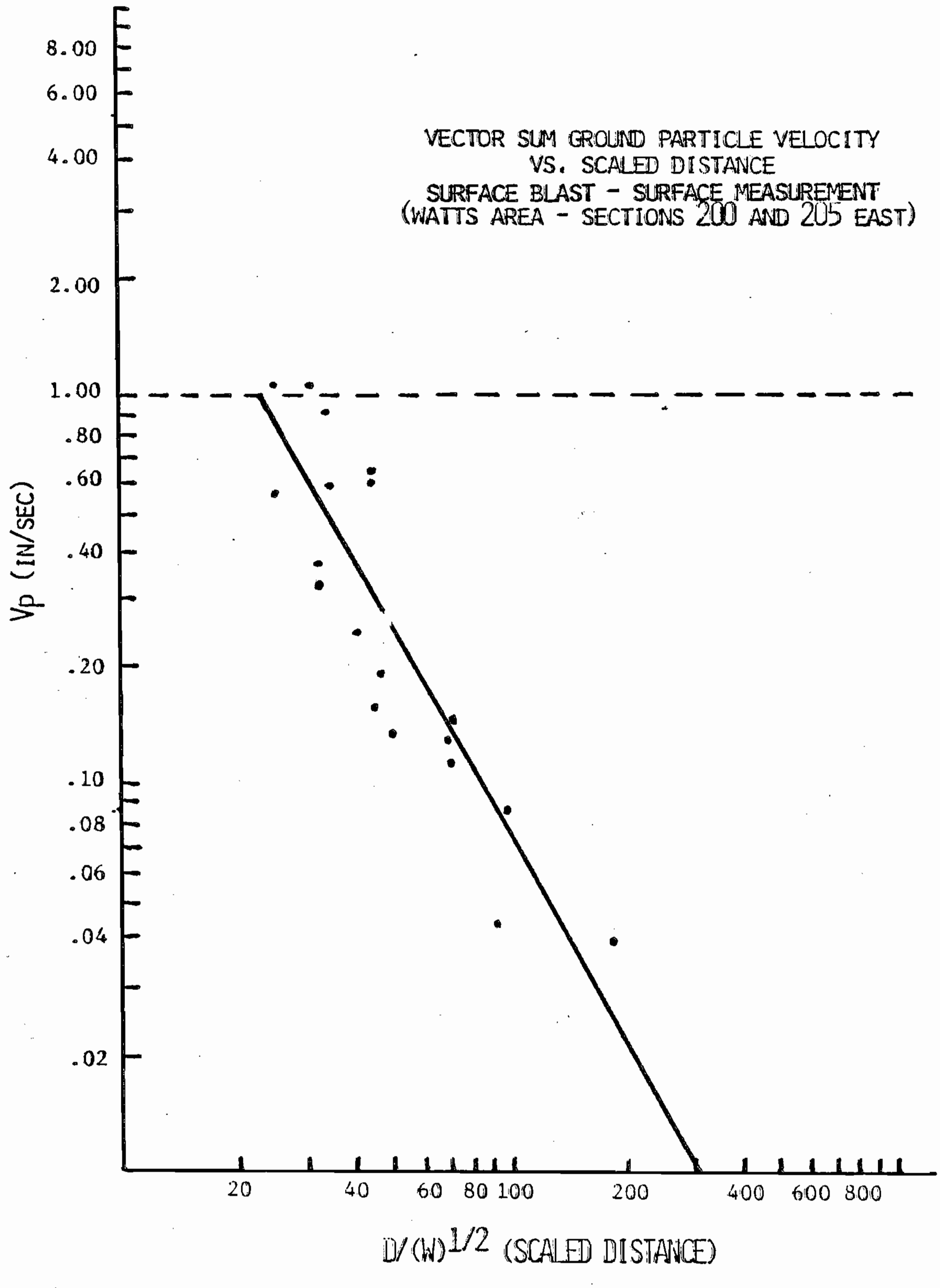


Figure 36 - Composite Plot of NW and NE Vector Sum Ground Particle Velocity for S_B - S_M

Table 43 - Composite NE & NW Approximate Transverse Ground Particle Velocity and Equivalent Scaled Distance for S_B - S_M

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	17.806127	.10873217	63	.04152219	109	.02237575	155
.98116384	18	.10576646	64	.04086152	110	.02212459	156
.89229558	19	.10292578	65	.0402173	111	.02187763	157
.81543881	20	.10020305	66	.03958888	112	.02163507	158
.74848477	21	.09759166	67	.03897574	113	.0213967	159
.68977249	22	.09508553	68	.03837737	114	.02116242	160
.63797838	23	.09267894	69	.03779339	115	.02093215	161
.59203732	24	.09036669	70	.03722304	116	.02070589	162
.55108359	25	.08814352	71	.03666618	117	.02048324	163
.51440696	26	.0860051	72	.03612239	118	.02026443	164
.48142127	27	.08394698	73	.03559095	119	.02004926	165
.45163808	28	.08196513	74	.03507178	120	.01983765	166
.42464808	29	.08005575	75	.03456449	121	.01962954	167
.40010608	30	.07821525	76	.03406844	122	.01942482	168
.37771907	31	.07644039	77	.03358356	123	.01922344	169
.35723729	32	.07472776	78	.03310942	124	.01902531	170
.33844615	33	.07307468	79	.03264571	125	.01883037	171
.3211612	34	.07147827	80	.03219211	126	.01863855	172
.3052225	35	.06993593	81	.03174832	127	.01844978	173
.29049119	36	.06844529	82	.03131406	128	.01826409	174
.2768457	37	.06700373	83	.03088905	129	.01808112	175
.26418008	38	.06560934	84	.03047302	130	.0179011	176
.25240073	39	.06425995	85	.03006572	131	.01772399	177
.24142525	40	.06295364	86	.02966691	132	.01754941	178
.23118073	41	.06168851	87	.02927633	133	.01737761	179
.22160231	42	.06046283	88	.02889376	134	.01720844	180
.2126324	43	.05927495	89	.02851898	135	.01704184	181
.20421946	44	.05812339	90	.02815178	136	.01687776	182
.19631744	45	.05700637	91	.02779193	137	.01671614	183
.18888493	46	.05592277	92	.02743926	138	.01655694	184
.18188471	47	.05487115	93	.02709356	139	.0164001	185
.17528326	48	.05385023	94	.02675465	140	.01624569	186
.16905021	49	.05285881	95	.02642235	141	.01609334	187
.16315813	50	.05189575	96	.02609647	142	.01594332	188
.15758207	51	.05095994	97	.02577686	143	.01579559	189
.15229949	52	.05005035	98	.02546335	144	.0156498	190
.14728944	53	.04916598	99	.02515578	145	.0155062	191
.14253349	54	.04830599	100	.02485401	146	.01536467	192
.13801402	55	.04746929	101	.02455788	147	.01522514	193
.13371554	56	.046655	102	.02426724	148	.0150876	194
.12962353	57	.04586252	103	.02398198	149	.014952	195
.12572468	58	.04509097	104	.02370194	150	.0148183	196
.12200677	59	.04433969	105	.02342709	151	.01468647	197
.11845857	60	.04360768	106	.02315702	152	.01455647	198
.11506968	61	.04289456	107	.02289191	153	.01442826	199
.1118305	62	.04219956	108	.02263152	154	.01430182	200

Table 44 - Composite NE & NW Approximate Vertical Ground Particle Velocity and Equivalent Scaled Distance for S_B-S_M

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	15.13656	.12548721	62	.05469004	109	.03226418	156
.921585	16	.12256621	63	.05395976	110	.03196213	157
.84290615	17	.1197576	64	.05324571	111	.0316648	158
.77488793	18	.11705543	65	.05254738	112	.03137219	159
.71560726	19	.1144541	66	.05186431	113	.0310839	160
.66356561	20	.11194641	67	.05119601	114	.03080011	161
.61758	21	.10953359	68	.05054204	115	.03052066	162
.57670514	22	.10720478	69	.04990209	116	.03024544	163
.54017779	23	.10495804	70	.04927543	117	.02997436	164
.50737509	24	.10278926	71	.04866198	118	.02970733	165
.4777848	25	.10069479	72	.04806123	119	.02944428	166
.45098204	26	.09867083	73	.04747284	120	.02918512	167
.42661151	27	.09671435	74	.04689645	121	.02892976	168
.40437415	28	.09482217	75	.04633172	122	.02867813	169
.38401675	29	.09299132	76	.0457783	123	.02843015	170
.36532343	30	.09121907	77	.04523591	124	.02818576	171
.3481093	31	.08950283	78	.04470422	125	.02794488	172
.33221509	32	.08784013	79	.04418294	126	.02770743	173
.31750275	33	.08622865	80	.04367189	127	.02747334	174
.30385267	34	.0846662	81	.04317059	128	.02724257	175
.29116008	35	.08315073	82	.04267878	129	.02701502	176
.2793333	36	.08168026	83	.0421964	130	.02679066	177
.2682916	37	.08025294	84	.04172311	131	.0265694	178
.25796368	38	.07886701	85	.04125867	132	.0263512	179
.2482864	39	.07752082	86	.04080285	133	.02613609	180
.23920361	40	.07621276	87	.04035541	134	.02592371	181
.23066526	41	.07494135	88	.03991616	135	.02571431	182
.22262661	42	.07370516	89	.03948488	136	.02550774	183
.21504753	43	.07250284	90	.03906136	137	.02530394	184
.20789194	44	.0713331	91	.03864542	138	.02510286	185
.20112749	45	.07019471	92	.03823686	139	.02490445	186
.19472445	46	.06908659	93	.03783551	140	.02470866	187
.18865658	47	.06800734	94	.03744118	141	.02451544	188
.18289966	48	.06695621	95	.0370537	142	.02432474	189
.17743177	49	.06593208	96	.03667291	143	.02413652	190
.17223292	50	.06493398	97	.03629865	144	.02395074	191
.16728499	51	.063961	98	.03593075	145	.02376734	192
.162571	52	.06301225	99	.03556908	146	.02358639	193
.15807601	53	.06208691	100	.03521348	147	.02340755	194
.15378586	54	.06118416	101	.0348638	148	.02323106	195
.14968771	55	.06030323	102	.03451993	149	.02305681	196
.14576979	56	.0594434	103	.0341817	150	.02288473	197
.14202099	57	.05860396	104	.03384901	151	.0227148	198
.13843121	58	.05778424	105	.03352172	152	.02254698	199
.13499133	59	.05698369	106	.03319971	153	.02238123	200
.13169261	60	.0562014	107	.03288285	154		
.12852705	61	.05543706	108	.03257105	155		

Table 45 - Composite NE & NW Approximate Radial Ground Particle Velocity and Equivalent Scaled Distance for $S_B - S_M$

Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance	Particle Velocity	Scaled Distance
1	19.764858	.13925651	65	.0574044	111	.03232865	157
.98060557	20	.13577984	66	.05655812	112	.03199071	158
.90449228	21	.13244031	67	.05573168	113	.03165822	159
.83742912	22	.12923058	68	.05492444	114	.03133122	160
.77799848	23	.12614382	69	.05413578	115	.03100962	161
.72505377	24	.12317362	70	.05336514	116	.03069327	162
.67765927	25	.120314	71	.05261193	117	.03038207	163
.63504452	26	.11755942	72	.05187564	118	.0300759	164
.59657033	27	.11490469	73	.05115573	119	.02977465	165
.56170245	28	.11234462	74	.05045171	120	.02947821	166
.52999154	29	.10987493	75	.0497631	121	.02918647	167
.50105713	30	.10749116	76	.04908945	122	.02889934	168
.47457521	31	.10518925	77	.0484303	123	.02861671	169
.45026669	32	.10296542	78	.04778524	124	.02833859	170
.42789865	33	.10081603	79	.04715385	125	.02806458	171
.40725923	34	.0987377	80	.04653572	126	.02779499	172
.38817121	35	.09672725	81	.04593059	127	.02752933	173
.37047856	36	.09478166	82	.04533789	128	.02726782	174
.35404469	37	.09289808	83	.04475726	129	.02701028	175
.3387493	38	.09107382	84	.04418856	130	.02675661	176
.32448682	39	.08930634	85	.04363136	131	.02650674	177
.31116352	40	.08759325	86	.04308535	132	.02626069	178
.29869649	41	.08593224	87	.04255022	133	.02601819	179
.28701144	42	.08432129	88	.04202566	134	.02577916	180
.27604271	43	.08275804	89	.0415114	135	.02554373	181
.2657311	44	.08124084	90	.04100716	136	.02531173	182
.25602366	45	.07976778	91	.04051266	137	.02508319	183
.2468727	46	.07833719	92	.04002767	138	.02485775	184
.23823522	47	.07694711	93	.03955192	139	.02463563	185
.23007241	48	.07559626	94	.03908517	140	.02441668	186
.22234907	49	.07428305	95	.0386272	141	.02420083	187
.21503339	50	.07300606	96	.03817777	142	.02398803	188
.20809603	51	.0717639	97	.03773667	143	.02377822	189
.20151086	52	.0705553	98	.03730379	144	.02357133	190
.19525367	53	.[illegible]6937902	99	.03687862	145	.02336731	191
.18930233	54	.06823387	100	.03646126	146	.02316611	192
.18363668	55	.06711875	101	.03605143	147	.02296768	193
.17823814	56	.06603257	102	.03564894	148	.02277196	194
.17308973	57	.064[illegible]43	103	.03525361	149	.0225789	195
.16817572	58	.06394297	104	.03486526	150	.02238845	196
.16348179	59	.06293766	105	.03448373	151	.02220056	197
.1589943	60	.06195745	106	.03410885	152	.02201529	198
.15470126	61	.0610015	107	.03374046	153	.02183239	199
.15059113	62	.06006898	108	.03337841	154	.02165182	200
.14665349	63	.05915913	109	.03302256	155		
.1428782	64	.05827118	110	.03267275	156		

Table 46 - Composite NE & NW Approximate Vector Sum Ground Particle Velocity and Equivalent Scaled Distance for $S_B - S_M$

Particle Velocity	Scaled Distance						
1	23.33506	.14773184	68	.05957936	113	.03271919	158
.951004	24	.14392555	69	.05864813	114	.03235207	159
.8840632	25	.14027009	70	.05773941	115	.03199142	160
.82419067	26	.13675717	71	.05685245	116	.03163701	161
.77040952	27	.13337963	72	.05598656	117	.03128868	162
.72190735	28	.1301304	73	.05514105	118	.03094639	163
.67800422	29	.12700292	74	.05431539	119	.03060971	164
.6381272	30	.12399111	75	.05350865	120	.03027881	165
.60179053	31	.12108929	76	.05272053	121	.02995345	166
.56858036	32	.1182918	77	.05195038	122	.02963351	167
.53814226	33	.1155939	78	.05119762	123	.02931886	168
.51017098	34	.11299074	79	.05046172	124	.02900949	169
.48440247	35	.11047783	80	.0497422	125	.02870509	170
.46060766	36	.10805102	81	.04903854	126	.02840554	171
.43858657	37	.10570631	82	.04835028	127	.02811093	172
.41816433	38	.10343998	83	.04767697	128	.02782106	173
.39918713	39	.10124853	84	.04701817	129	.02753582	174
.38151953	40	.0991286	85	.04637344	130	.02725511	175
.36504174	41	.09707711	86	.0457424	131	.02697885	176
.3496474	42	.09509104	87	.04512465	132	.02670692	177
.33524204	43	.09316762	88	.04451982	133	.02643925	178
.32174117	44	.09130429	89	.04392752	134	.02617573	179
.30906944	45	.08949823	90	.04334743	135	.02591639	180
.29715911	46	.08774736	91	.04277929	136	.02566083	181
.28594933	47	.08604932	92	.04222248	137	.02540928	182
.27538526	48	.08440197	93	.04167709	138	.02516156	183
.26541744	49	.08280326	94	.0411424	139	.02491758	184
.25600101	50	.08125139	95	.04061843	140	.02467726	185
.24709534	51	.0797442	96	.0401048	141	.02444055	186
.23866352	52	.07828025	97	.03960121	142	.02420735	187
.23067195	53	.07685778	98	.03910742	143	.02397761	188
.22308996	54	.07547521	99	.03862317	144	.02375124	189
.21588953	55	.07413103	100	.0381482	145	.02352829	190
.20904503	56	.07282382	101	.03768228	146	.02330849	191
.20253301	57	.07155229	102	.03722517	147	.02309178	192
.19633187	58	.07031486	103	.03677664	148	.02287839	193
.1904218	59	.06911057	104	.03633659	149	.02266786	194
.18478454	60	.06793813	105	.0359045	150	.02246044	195
.17940326	61	.06679642	106	.03548046	151	.02225595	196
.1742624	62	.06568435	107	.03506429	152	.02205436	197
.16934764	63	.06460087	108	.03465547	153	.0218556	198
.16464564	64	.06354502	109	.03425413	154	.02165962	199
.1601441	65	.06251582	110	.03386	155	.02146636	200
.15583169	66	.06151249	111	.03347299	156		
.15169747	67	.06053384	112	.03309264	157		

step taken toward answering this question was to utilize the dynamic physical properties of rock measured in the rock mechanics laboratory (Table 3), particularly the V_P; compare the V_P measured in the laboratory with the V_P measured at the mine roof in order to provide a reasonable range of strains and stresses that could be expected as an equivalent ground particle velocity. A reasonable V_P measured in the laboratory was 17,756 ft/sec and an average V_P measured at the mine roof was about 12,000 ft/sec, Poisson's ratio = 0.329, shear wave velocity = 8,710 ft/sec, Young's modulus = 7.039 x 10^6, and shear modulus - 2.525 x 10^6 psi. The strains and stresses were computed as follows,[3] with units corrected to read in micro-inches per inch and psi, respectively:

$$\epsilon = \frac{-\dot{A}}{C_P} \qquad \text{and} \qquad \gamma = \frac{-\dot{A}}{C_S}$$

where:

ϵ = normal strain

$\dot{A}$ = ground particle velocity (inch/sec)

C_P = compressional wave velocity (ft/sec)

γ = shear strain (micro-inches/inch)

C_S = shear wave velocity (ft/sec)

and

$$\sigma = \frac{\dot{A}E(1-\nu)}{(1+\nu)(1-2\nu)C_P} \qquad \text{and} \qquad \tau = \frac{-\dot{A}G}{C_S}$$

where

σ = normal stress (psi)

E = Young's modulus (psi)

ν = Poisson's ratio

G = shear modulus (psi)

τ = shear stress (psi)

Note that in all of the computations, we assumed, for the sake of simplicity, that a) roof rock is elastic, b) waves follow simple harmonic motion, and c) the roof rock is allowed to move only in one direction. It is also important to note that strains equivalent to V_{MAX} (maximum peak particle velocities of three traces added together), V_{YT}, V_{YV}, V_{YR} (components of the motion vector in transverse, vertical, and radial traces at the same phase), and V_P (the vector sum of V_{YT}, V_{YV}, AND V_{YR}) are only shown here as a matter of curiosity because the assumption of unidirectional wave propagation does justify the calculation of equivalent strain and stress by the equations given previously. In short, the strain and stress as a result of vertical ground particle velocity measured at the mine roof is most valid; the rest provide only an order of magnitude figure.

If in the above equations an average V_P of 12,000 ft/sec is measured at the mine roof, the normal strain and stress is almost doubled. However, as seen in Appendixes I - K, the highest amount of strain associated with the peak vertical ground particle velocity with V_p taken as 17,756 ft/sec or 12,000 ft/sec ranges from 4 to 8 micro-inches per inch with an equivalent stress of 41 to 82 psi. If these numbers are compared with the typical strength characteristic of rock (Tables 1 and 2) or just read on the stress-strain curves for the rock,[1,2] it is noticed that they are far below the failure range of rock strength, either in tension or compression for the dry rock.

In order to carry the precautions to a practical limit, the scaled distance should be kept above 48 during the summer months when high mine roof condensation and adsorption of water at high stress concentrations with a great deal of clay content occurs. In designing scaled distance as such, the peak particle velocity at the mine roof would be most likely in order of 2/10 to 3/10 or less with an equivalent strain of fractions of micro-inches per inch to 2 micro-inches per inch.

Although all theories used in calculations of strains and stresses appear to be sound, the principal investigator was not quite convinced that the surface blasting, as carried out by surface miners, had a very minimal effect on the underground mine roof. So, for many times, the principal investigator and his assistants stayed in the underground mine under the blasts of surface mines to see for themselves the theory results. Prior to the blasts, many markers were set at the mine roof and general observations were made to see if any unexpected or unusual mine behavior could be noticed. All the visual observation pointed to was the fact that was predicted by theory; a few micro strains could not destabilize the mine roof.

Again the visual observations and theoretical computations were not quite convincing. This led to further work involving further instrumentation and data collection on the behavior of underground mine at a designated area. This particular phase of work is referred to hereafter as pre- and post-blast survey of the underground mine.

Pre- and Post-Blast Survey

It is often necessary to establish a history of roof rock behavior before any drastic action such as heavy surface blasting takes place. This is because one wishes to know or have some idea about two important factors that affect the behavior of roof rock. One is the effect of time (in a domain of steady increase of time or in a cyclic domain like day and night or yearly or seasonal changes) on the roof and floor convergence, roof strata separation, load change on the roof bolt, pillar dilation, and pillar shortening. We shall refer to the plot of these parameters vs. time as the natural behavior of the mine because it is only affected by the underground mining procedures, plans, orientation, geology, mineralogy, methods of roof support, field stresses, moisture, coal and rock mechanics properties, bulk material handling, production rate, mine design, rock stand-up time, government regulations, mine worker, mine supervisor, and the like. The other is the cumulative effect of external causes such as surface mine blasting on top of the underground mine on the natural behavior of the roof rock as was mentioned above. For the sake of brevity we refer to the time plots of convergence, roof bolt load, strata separations, pillar shortening, and pillar dilation prior to the heaviest blast of scaled distance 25 on April 11, 1979, and after as pre- and post-blast survey. Moreover, the survey is strengthened by measuring of mine roof ground particle velocity at several stations directly under the blast, remotely monitoring of roof bolt load changes at least at one station directly below the surface mine blast in the underground mine and continuously by monitoring of roof and floor convergence at least at two stations directly under the blast during the blast. In order to have the least interference with both underground and surface mine coal production, the principal investigator waited until Section 205E of Mary Lee No. 2 and a section of Watts area Cobb Mine had a period of two weeks unscheduled work. The instruments were quickly installed, experimental blast holes drilled, and pre-blast survey was conducted for about a week. The blast was set off and monitored by the principal investigator and post-blast survey was conducted for about one week. The time duration for the experiment was considered adequate in view of past mining experience in the area.

The pre- and post-blast survey results are as follows:

1) Figures 37 - 40 show the results of tape extensometers installed according to the plan presented in Figure 2 measuring H_1, the roof and floor convergence. The graphs show that neither the slope of the line intersecting the dashed line referred to as blast event line, nor the general behavior prior and after the blast has changed.

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET $\#T_1H_1$
FROM APRIL 6 THROUGH APRIL 18, 1979

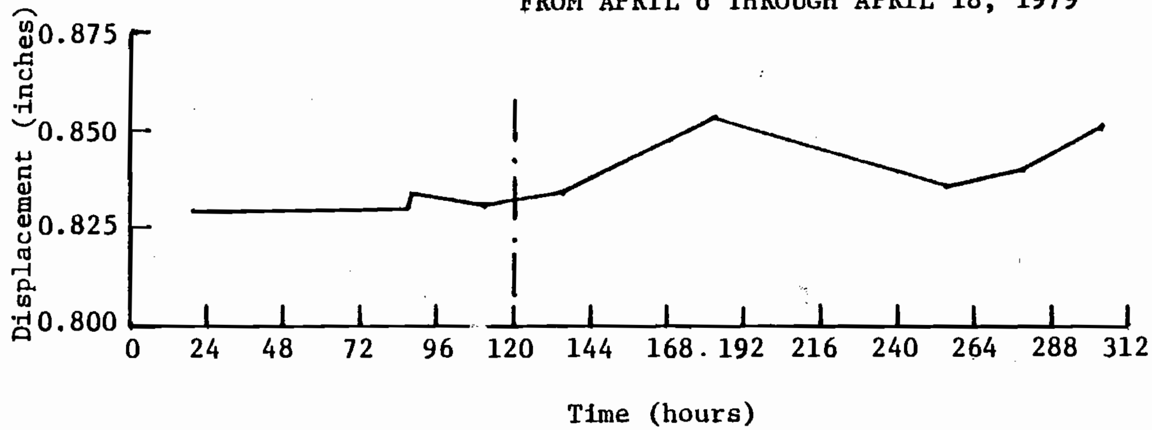


Figure 37

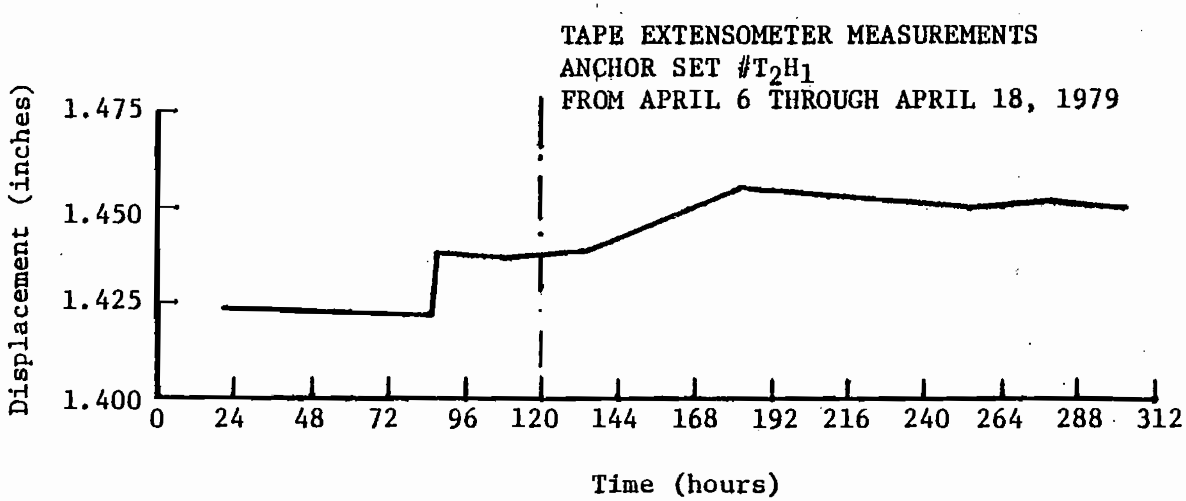

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET #T_2H_1
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.475
1.450
1.425
1.400
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (hours)

Figure 38

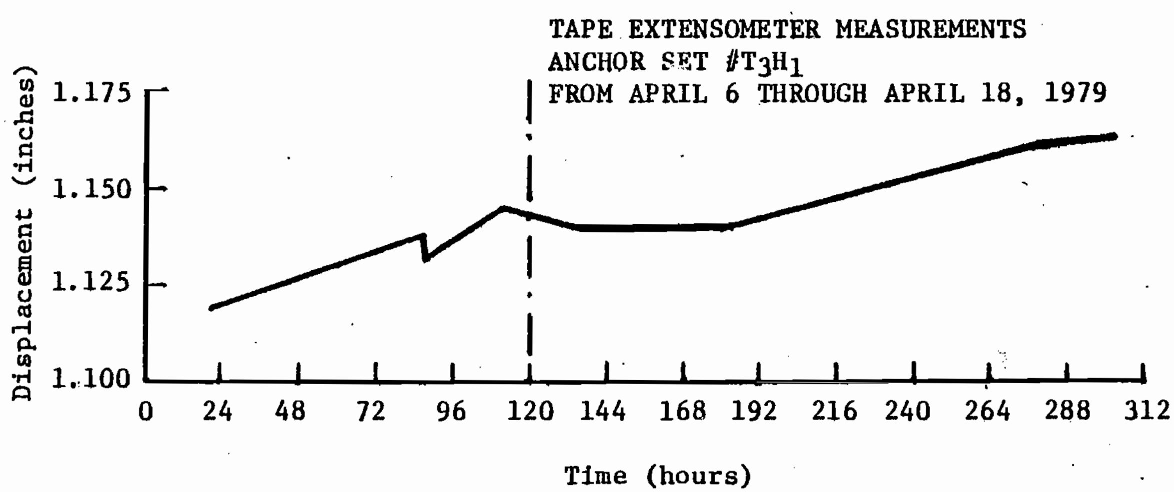
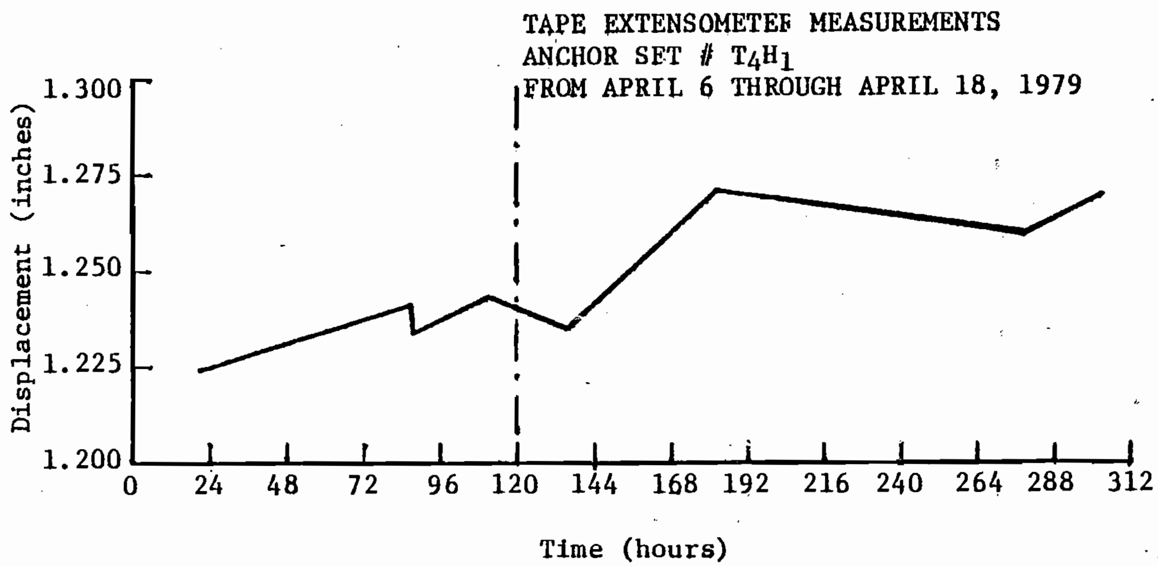

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET #T_3H_1
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.175
1.150
1.125
1.100
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (hours)

Figure 39



TAPE EXTENSOMETEF MEASUREMENTS
ANCHOR SET # T_4H_1
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.300
1.275
1.250
1.225
1.200
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (hours)

Figure 40

2) Figures 41 and 42 show the same trend recorded by the convergence meters.

3) Figures 43 - 46 show the results of H_2, the pillar dilation. The slope of the line intersecting the blast event line, the pre- and post-blast survey do not indicate an unusual change.

4) Figures 47 - 50 show the results of H_3 parameter, the pillar shortening. As is evidenced here, neither the slope of the line intersecting the blast event line nor the pre- and post-blast survey have been changed.

5) Figures 51 - 57 indicate that strata separation did not take place prior, during, or after the blast at 5 feet or 2 feet adjacent to single point rod extensometers.

6) Roof bolt load cell data only indicate usual trend of anchor loosening prior, during, and after the blast. These are shown in Figures 58 - 62.

In short, the pre- and post-blast survey of underground mine reveals that the surface blast did not affect the stability of mine roof and, above all, the magnitude of changes documented are negligible. In fact, the actual measurements had to be exaggerated scale-wise so that we could produce a graph for the purpose of demonstration.

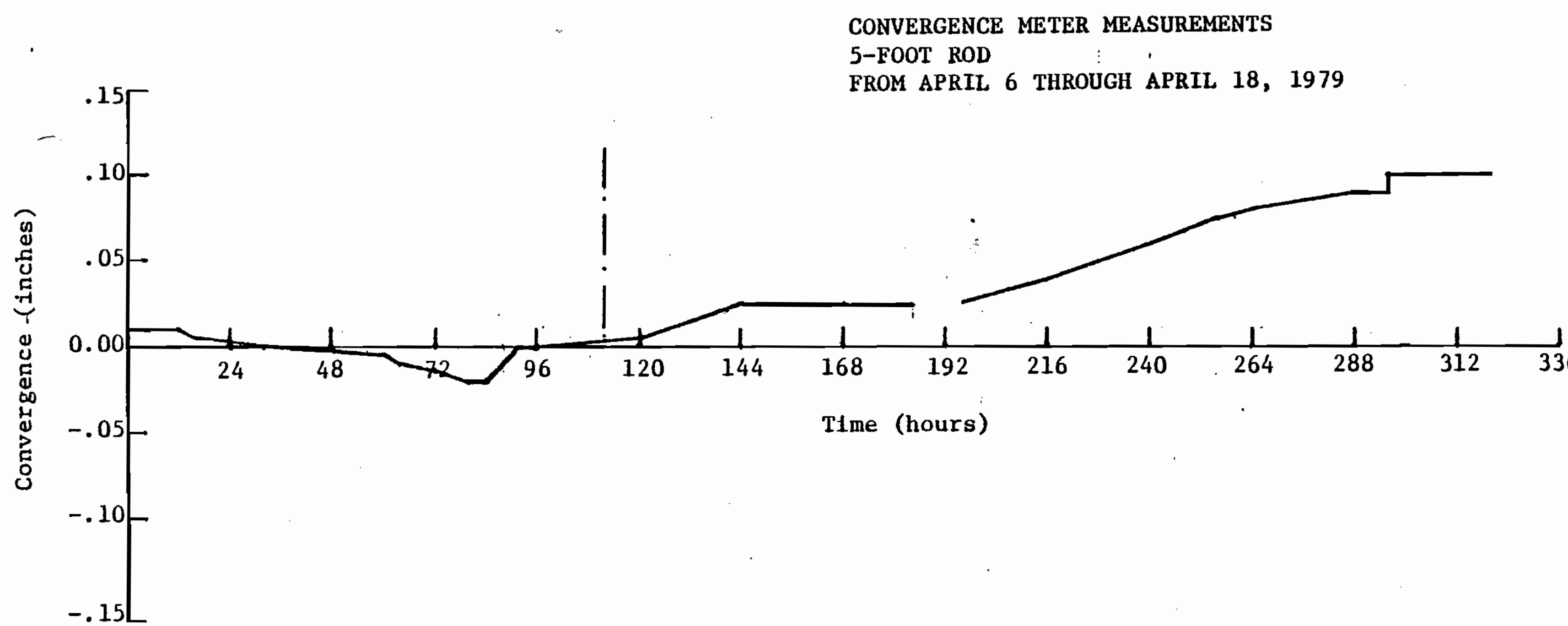

CONVERGENCE METER MEASUREMENTS
5-FOOT ROD
FROM APRIL 6 THROUGH APRIL 18, 1979
.15
.10
.05
0.00
-.05
-.10
-.15
Convergence -(inches)
24
48
72
96
120
144
168
192
216
240
264
288
312
336
Time (hours)

Figure 41

CONVERGENCE METER MEASUREMENTS
10 FOOT ROD
FROM APRIL 6 THROUGH APRIL 18, 1979

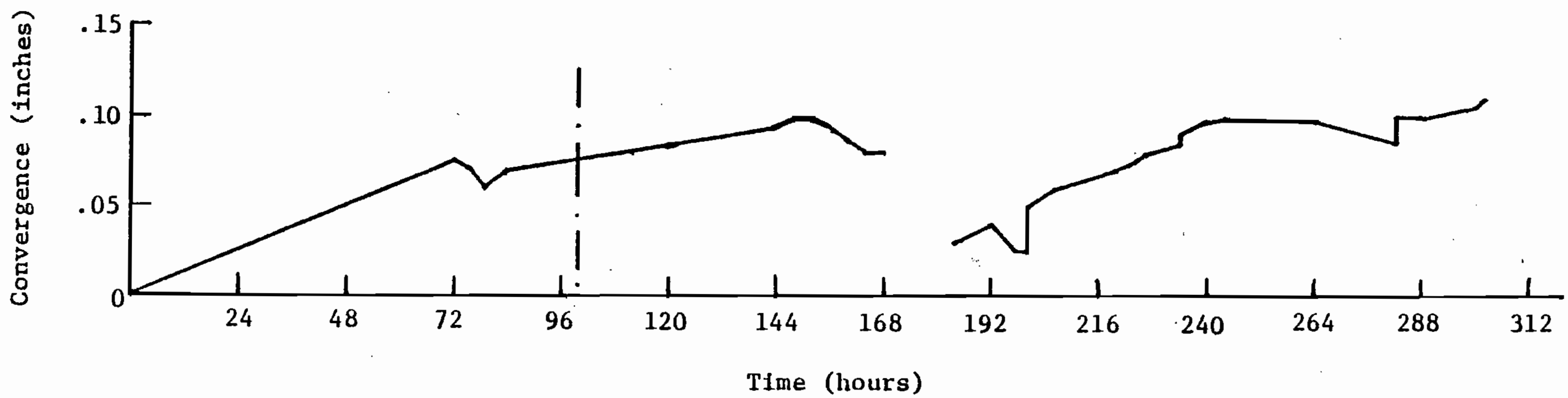


Figure 42

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET T_1H_2
FROM APRIL 6 THROUGH APRIL 18, 1979

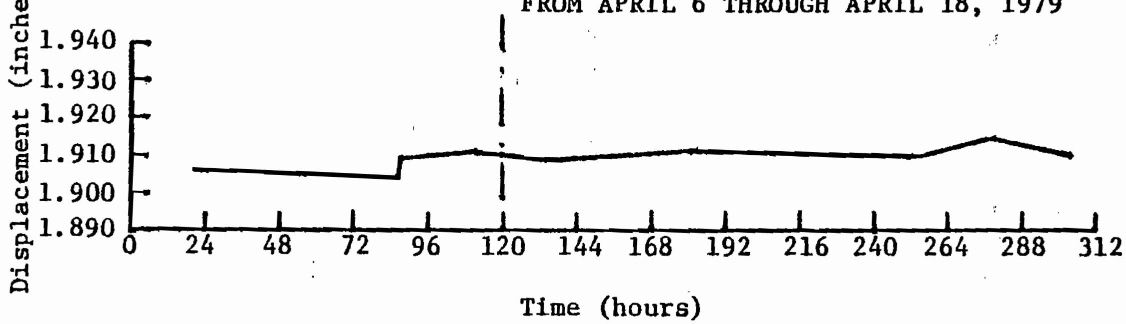


Figure 43

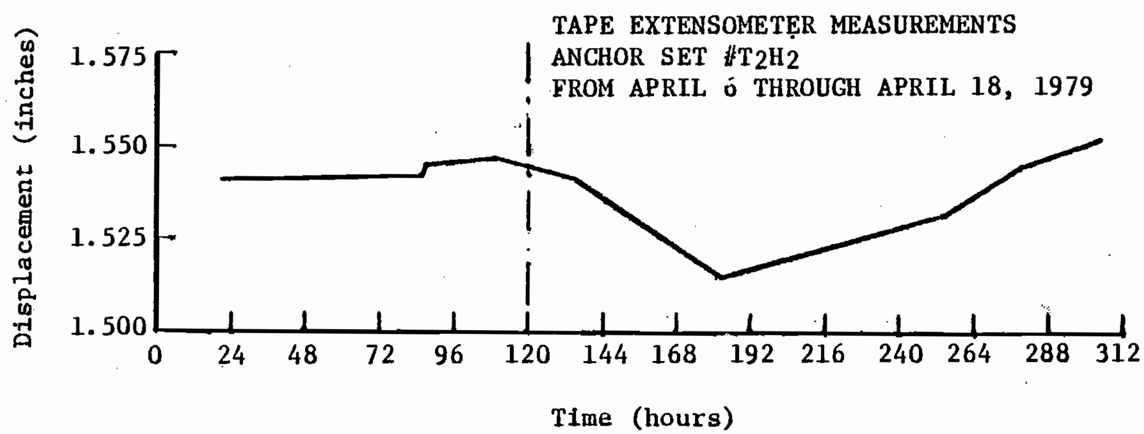

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET #T2H2
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.575
1.550
1.525
1.500
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (hours)

Figure 44

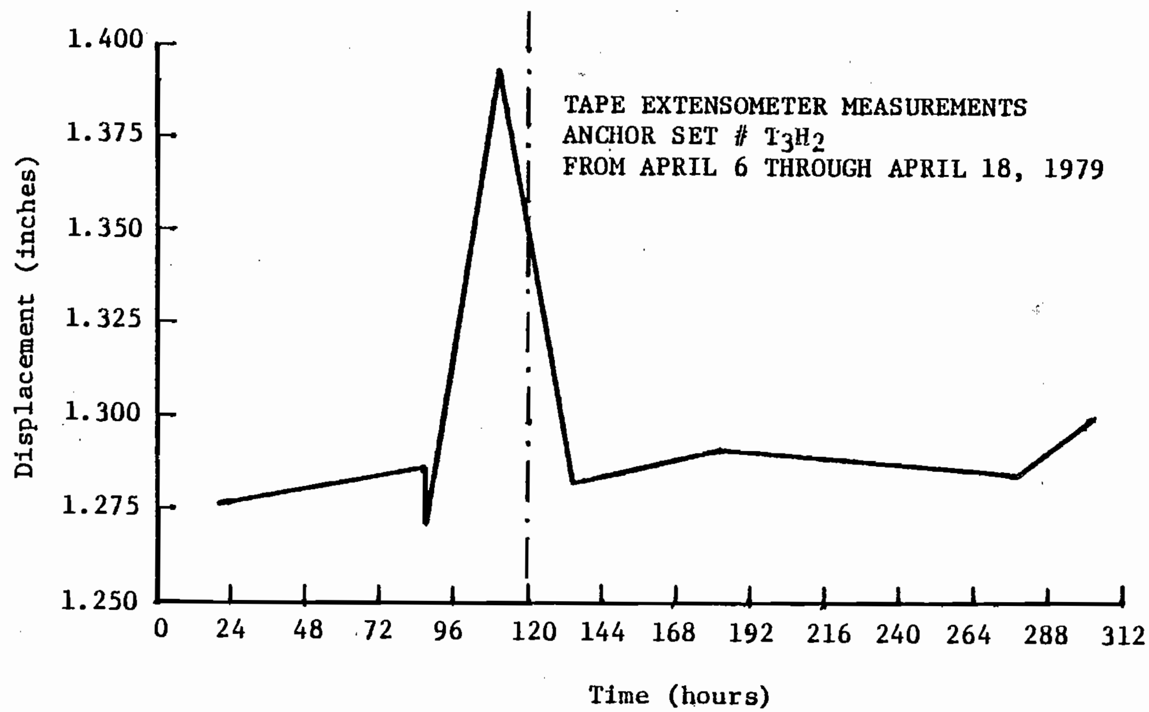

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET # T_3H_2
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.400
1.375
1.350
1.325
1.300
1.275
1.250
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (hours)

Figure 45

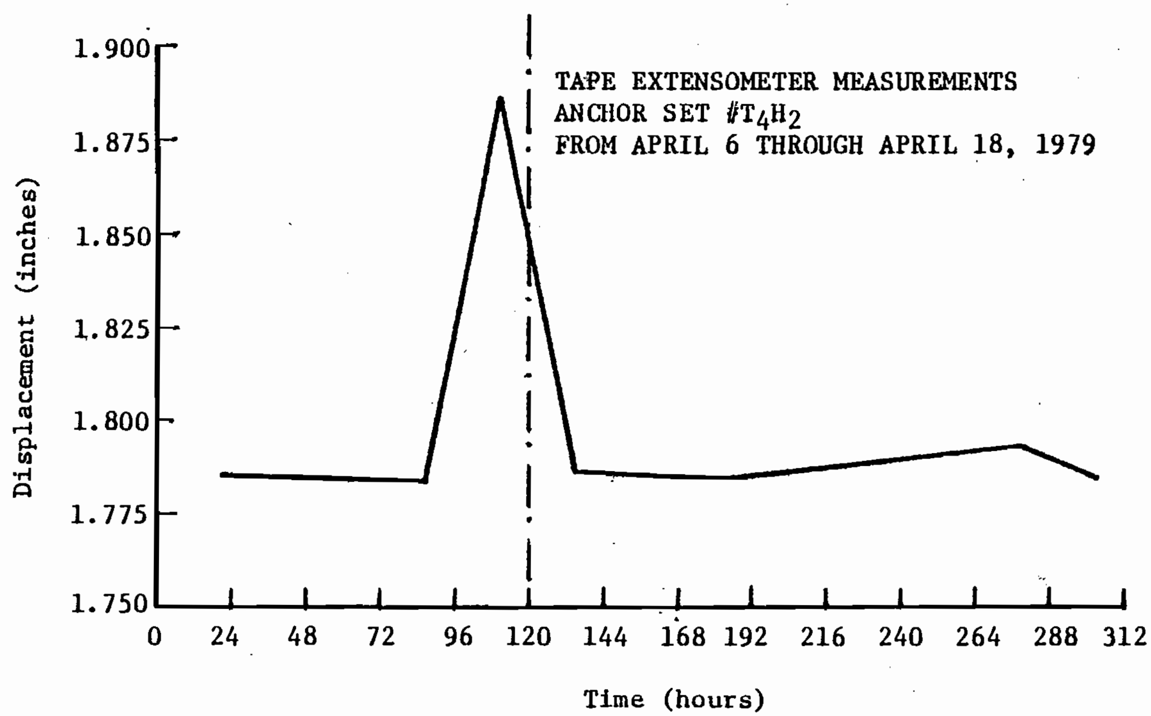

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET #T_4H_2
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.900
1.875
1.850
1.825
1.800
1.775
1.750
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (hours)

Figure 46

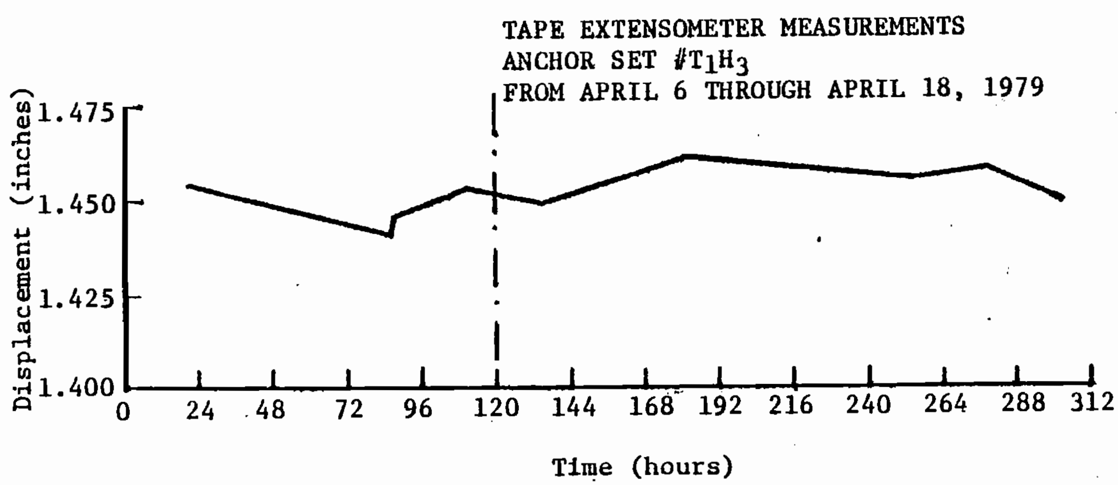

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET #T1H3
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.475
1.450
1.425
1.400
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (hours)

Figure 47

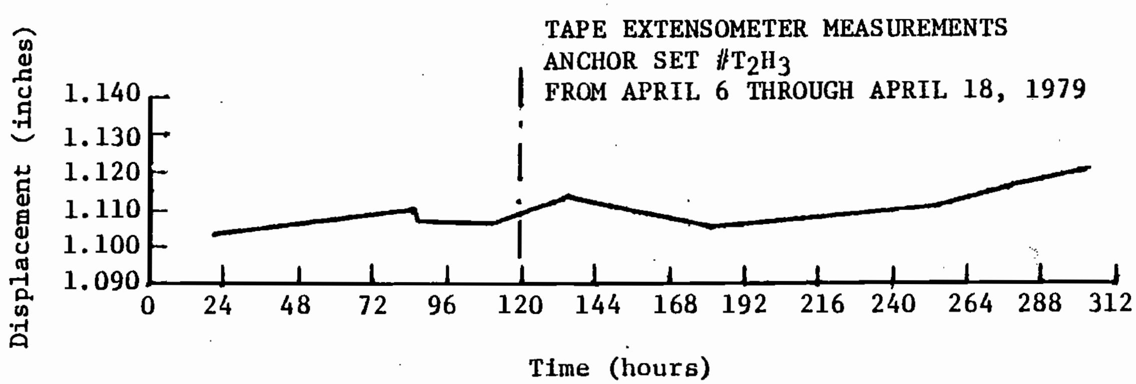

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET #T2H3
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.140
1.130
1.120
1.110
1.100
1.090
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (hours)

Figure 48

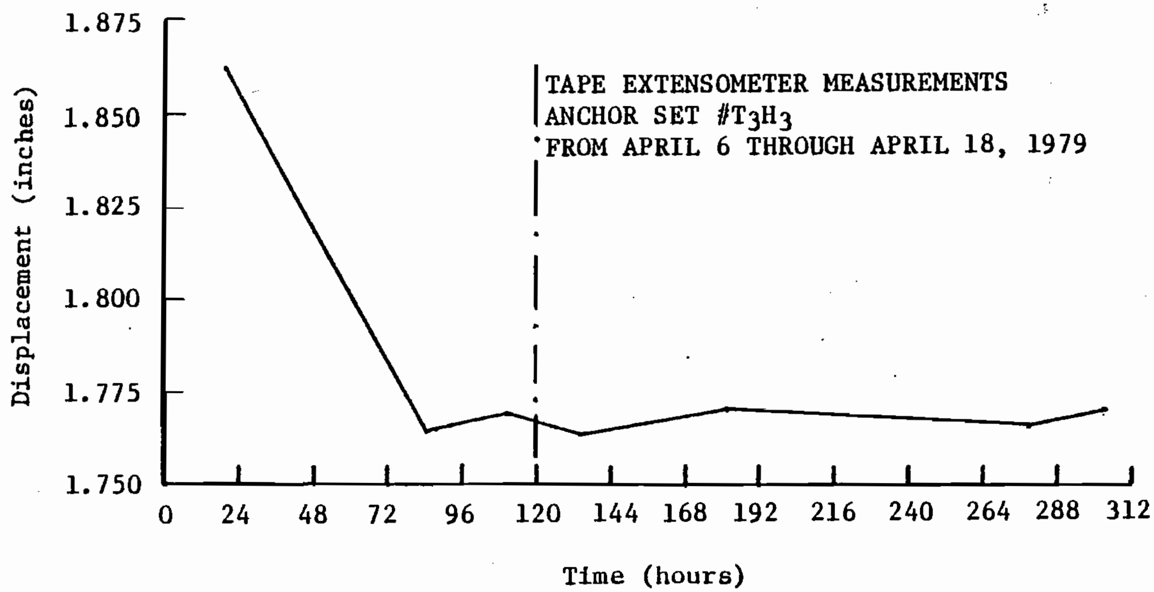

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET #T3H3
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.875
1.850
1.825
1.800
1.775
1.750
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (hours)

Figure 49

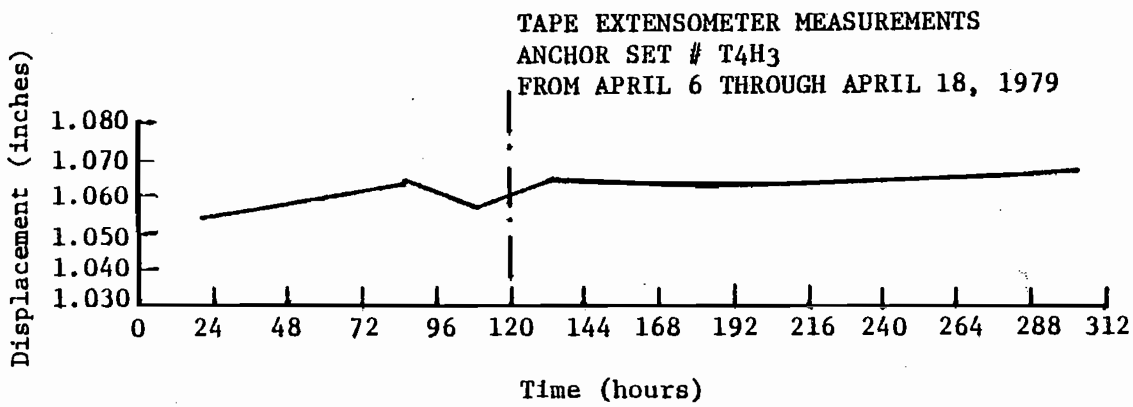

TAPE EXTENSOMETER MEASUREMENTS
ANCHOR SET # T4H3
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.080
1.070
1.060
1.050
1.040
1.030
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Time (hours)

Figure 50

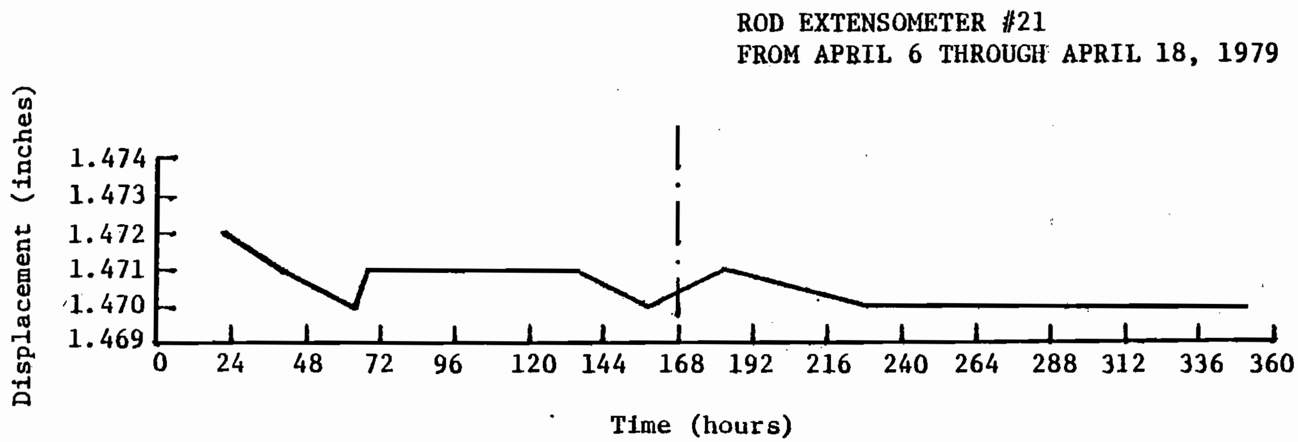

ROD EXTENSOMETER #21
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.474
1.473
1.472
1.471
1.470
1.469
0
24
48
72
96
120
144
168
192
216
240
264
288
312
336
360
Time (hours)

Figure 51

ROD EXTENSOMETER #22
FROM APRIL 6 THROUGH APRIL 18, 1979

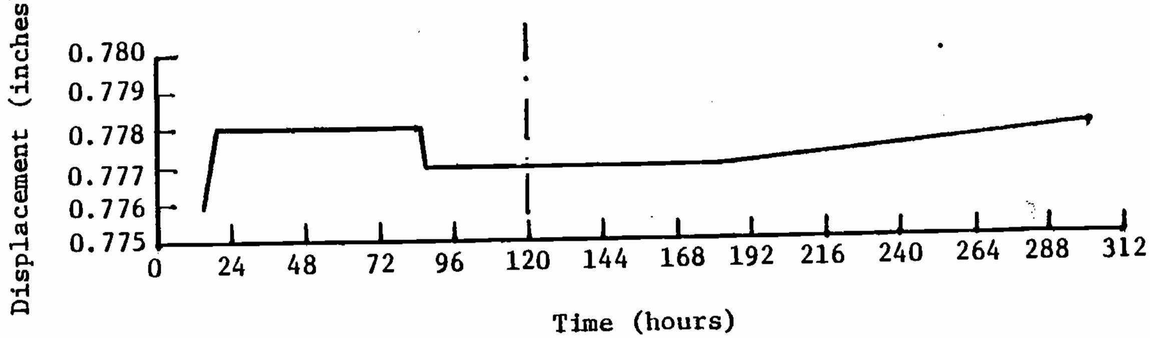


Figure 52

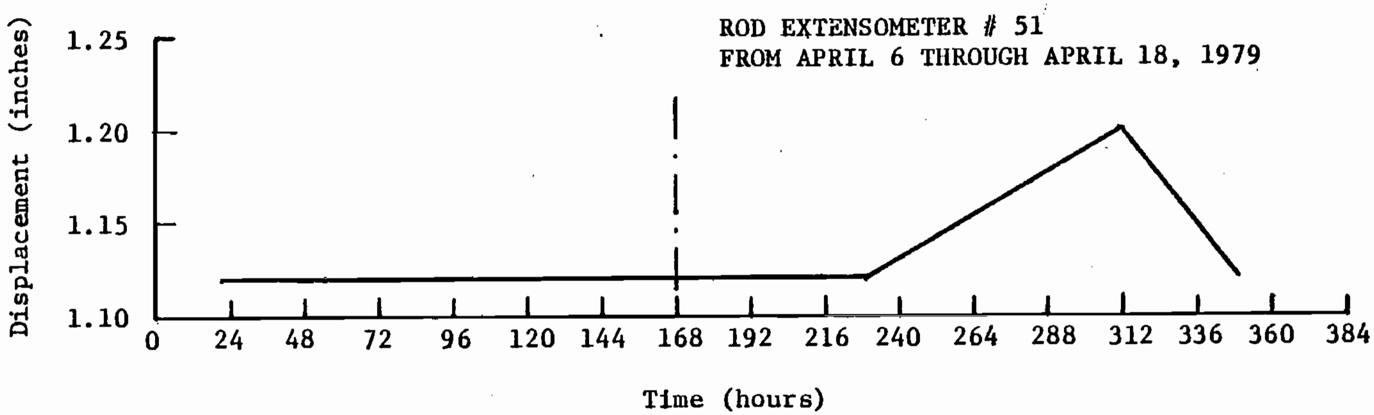

ROD EXTENSOMETER # 51
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.25
1.20
1.15
1.10
0
24
48
72
96
120
144
168
192
216
240
264
288
312
336
360
384
Time (hours)

Figure 53

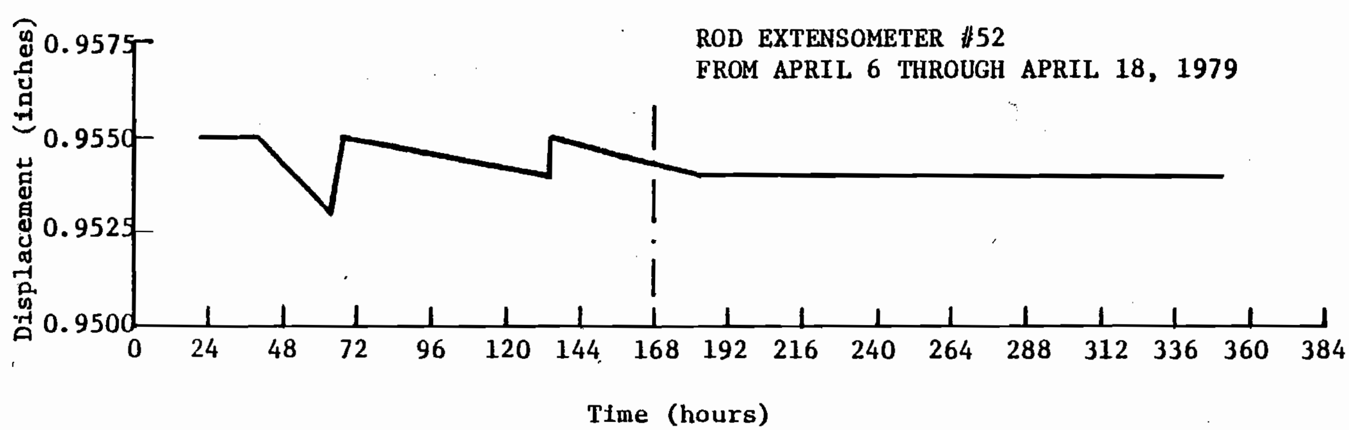

ROD EXTENSOMETER #52
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
0.9575
0.9550
0.9525
0.9500
0
24
48
72
96
120
144
168
192
216
240
264
288
312
336
360
384
Time (hours)

Figure 54

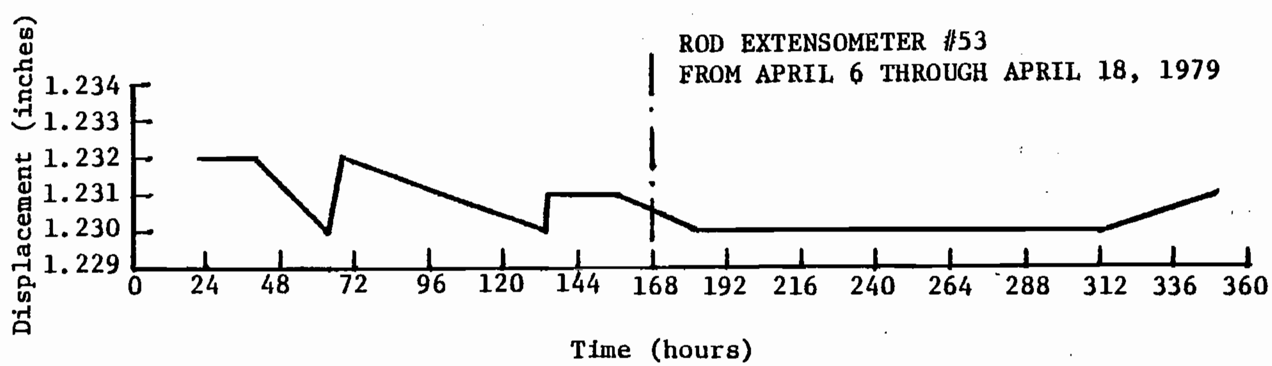

ROD EXTENSOMETER #53
FROM APRIL 6 THROUGH APRIL 18, 1979
Displacement (inches)
1.234
1.233
1.232
1.231
1.230
1.229
0
24
48
72
96
120
144
168
192
216
240
264
288
312
336
360
Time (hours)

Figure 55

ROD EXTENSOMETER #54
FROM APRIL 6 THROUGH APRIL 18, 1979

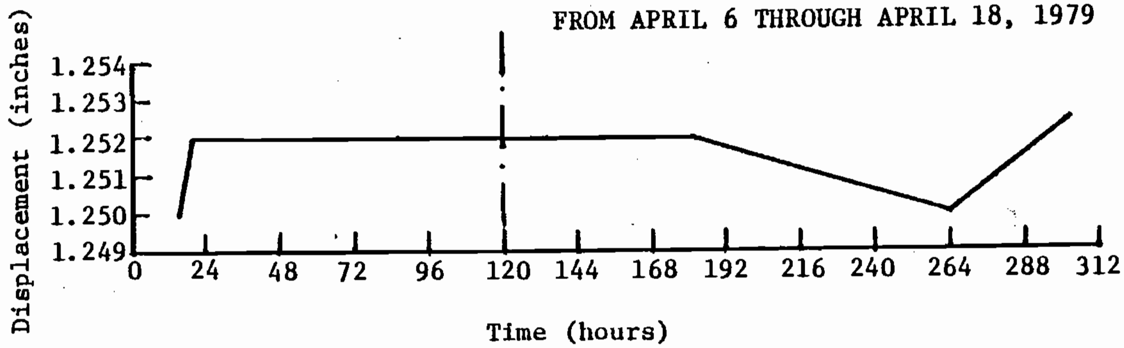


Figure 56

ROD EXTENSOMETER #55
FROM APRIL 6 THROUGH APRIL 18, 1979

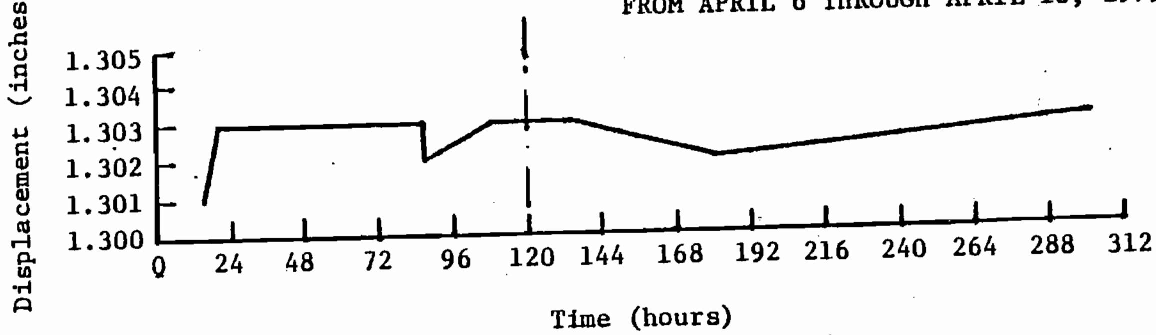


Figure 57

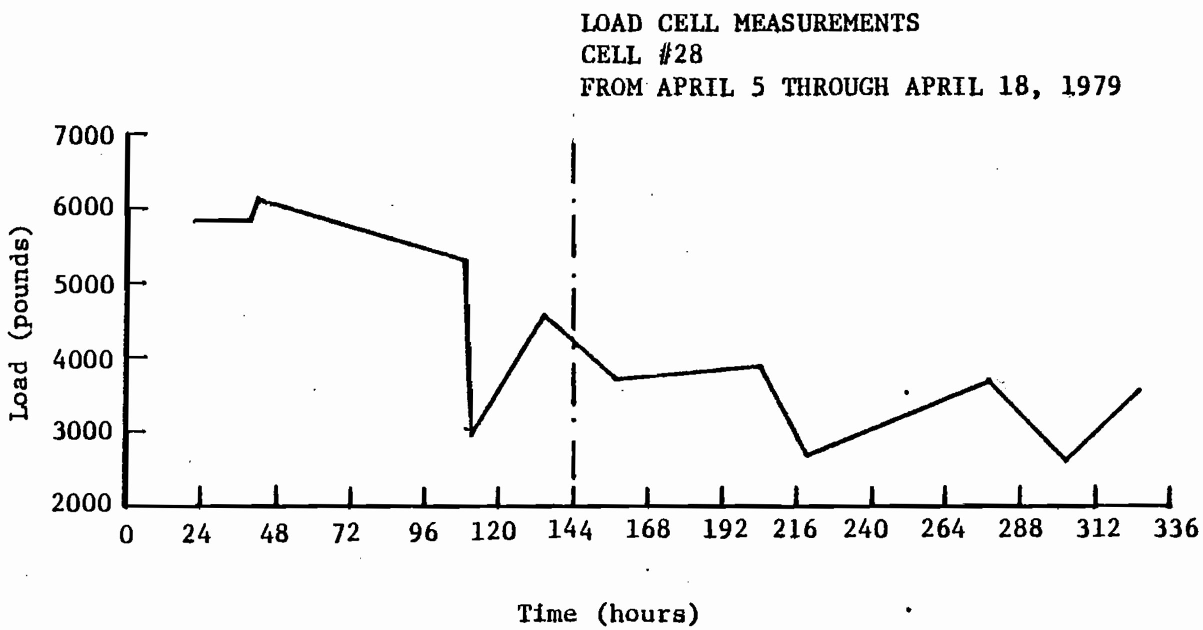

LOAD CELL MEASUREMENTS
CELL #28
FROM APRIL 5 THROUGH APRIL 18, 1979
Load (pounds)
7000
6000
5000
4000
3000
2000
0
24
48
72
96
120
144
168
192
216
240
264
288
312
336
Time (hours)

Figure 58

LOAD CELL MEASUREMENTS
CELL #29
FROM APRIL 4 THROUGH APRIL 18, 1979

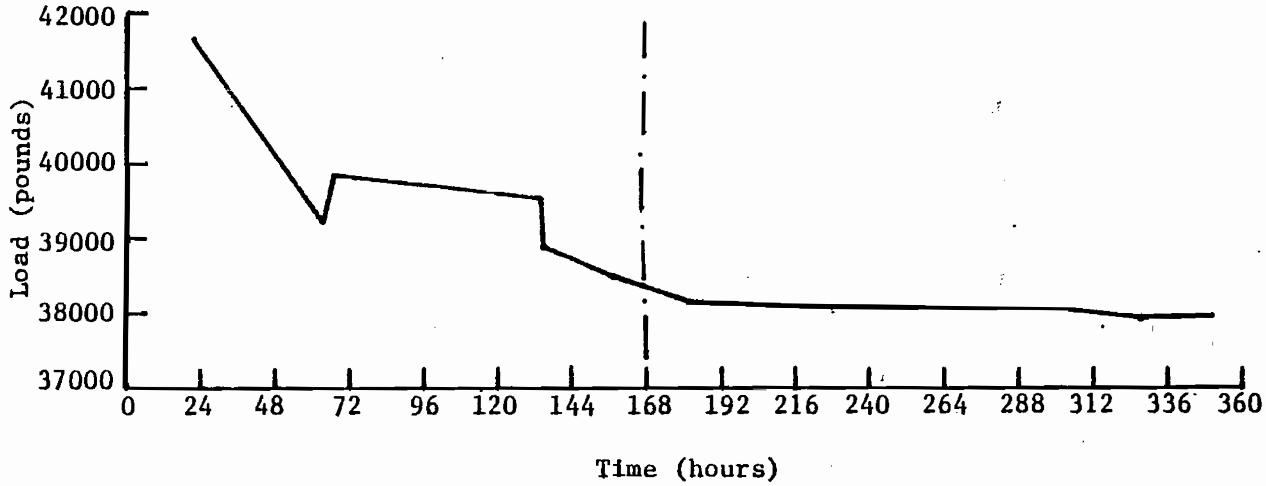


Figure 59

LOAD CELL MEASUREMENTS
CELL #30
FROM APRIL 6 THROUGH APRIL 18, 1979

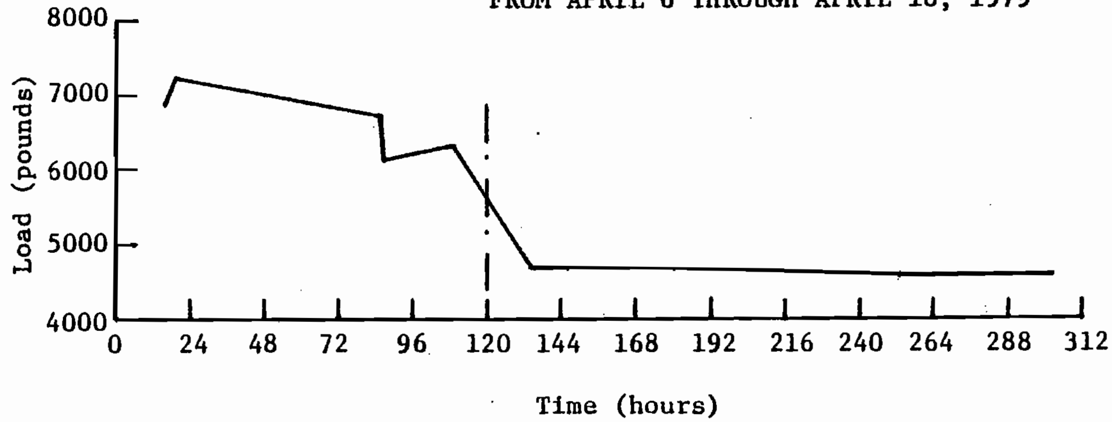


Figure 60

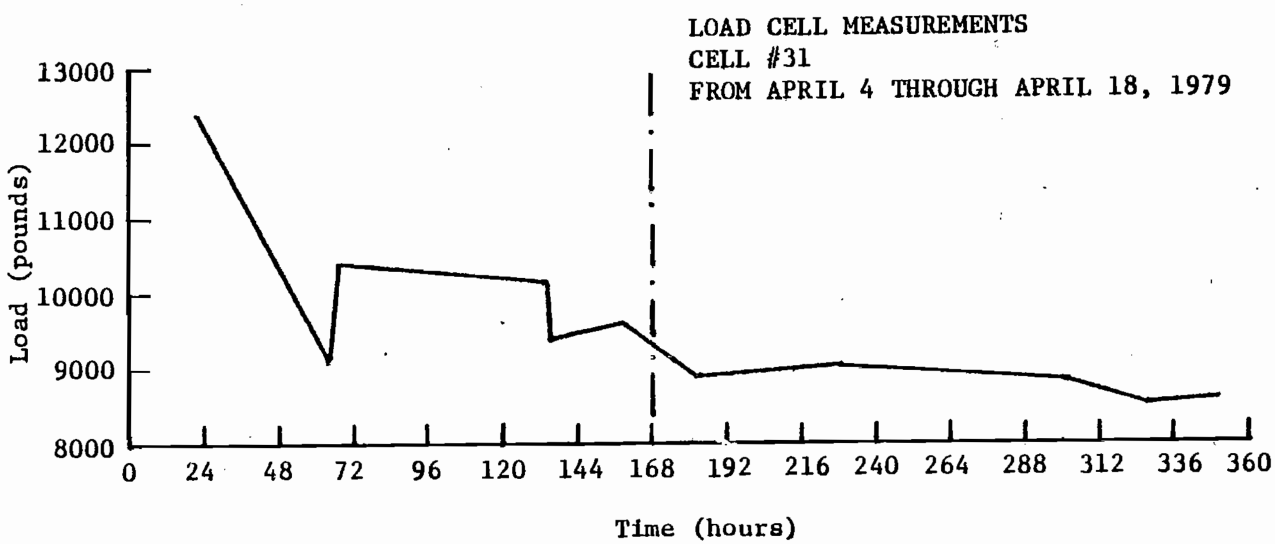

LOAD CELL MEASUREMENTS
CELL #31
FROM APRIL 4 THROUGH APRIL 18, 1979
13000
12000
11000
10000
9000
8000
Load (pounds)
0
24
48
72
96
120
144
168
192
216
240
264
288
312
336
360
Time (hours)

Figure 61

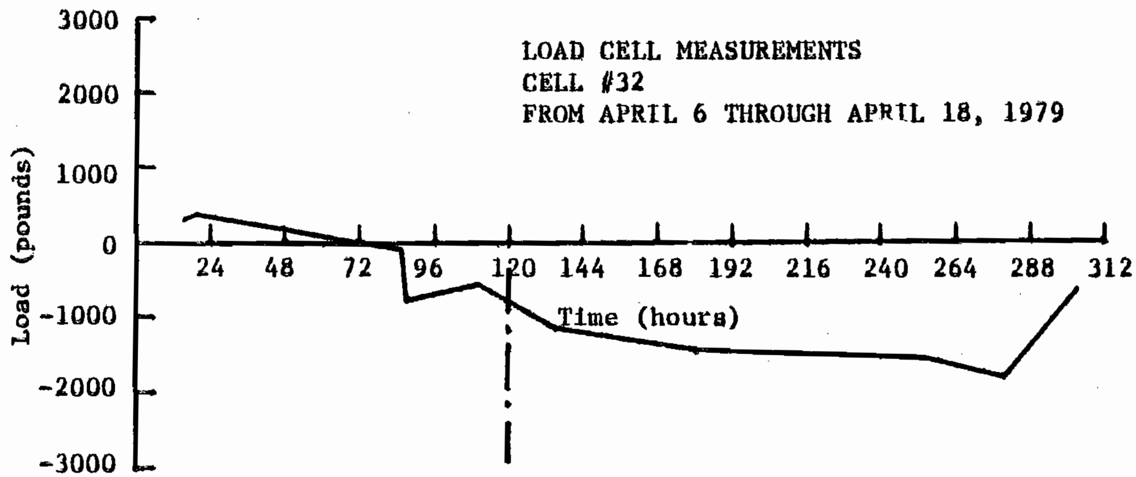

LOAD CELL MEASUREMENTS
CELL #32
FROM APRIL 6 THROUGH APRIL 18, 1979
Load (pounds)
3000
2000
1000
0
-1000
-2000
-3000
24 48 72 96 120 144 168 192 216 240 264 288 312
Time (hours)

Figure 62

CONCLUSIONS

On the basis of our laboratory and field research work and the limited data, the following may be concluded:

1) Surface blasts monitored at surface usually give higher ground particle velocity up to a certain scaled distance when compared with the mine roof ground particle velocity for the same blast.

2) The instruments bolted to the roof usually give a higher ground particle velocity than those held to the roof by epoxy.

3) Rocks are strong enough to take the surface blast dynamic loads.

4) The amplitude of ground particle velocity at the mine roof is usually lower than that of the surface but the frequencies in underground mine roof are much higher.

5) Major and minor principal stresses affect the magnitude of ground particle velocity to some extent.

6) The surface blasts monitored directly above the underground mine give a higher ground particle velocity up to some scaled distance than the blasts monitored at underground mine roof at some angle.

7) The magnitude of equivalent strain for any given ground particle velocity measured at underground mine roof is quite small.

8) Pre- and post-blast survey indicate the surface mine blast does not affect the stability of supported mine roof.

9) The magnitude of parameters measured prior to, during, and after the blast are quite small and does not point to any changes as a result of surface mine blast.

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