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Lighten Up
Your Community Footprint…
Understanding Regulatory Limitations

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Common Blasting Issues

- Productivity
  - ✓ Minimizing drill/blast cost
  - ✓ Maximizing production
  - ✓ Reducing oversize/fines
  - ✓ Adjusting drill/blast program to optimize total productivity
- Community Impact
  - ✓ Reduce complaints
  - ✓ Minimize barriers to expansion/permit renewal
  - ✓ Reduce/eliminate litigation costs
- Community Impact may represent most serious challenge to an operations long term viability

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Minimizing Community Footprint

- Reduce community perception of blasting
  - ✓ Reduced overpressure
  - ✓ Reduced ground vibration amplitude
  - ✓ Improved frequency spectra
- Technology available to meet needs
- Can be impacted by regulatory barriers
- Can be negated by lack of understanding of process

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Improved Blasting Designs

- Electronic Initiation Systems
  - ✓ Precision
  - ✓ Programmability
  - ✓ Flexibility
- Vibration prediction processes
  - ✓ Active vibration cancellation
  - ✓ Real time analysis
  - ✓ Alternative timing sequences
- Impact can be negated or blocked by regulatory limits based on older technology

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Where It All Began…..

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VIBRATIONS FROM INSTANTANEOUS AND MILLISECOND-DELAYED QUARRY BLASTS

By Wilbur I. Duvall, Charles F. Johnson, Alfred V. C. Meyer, and James F. Devine

* * * * * * * * * * * report of investigations 6151

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UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L. Udall, Secretary

BUREAU OF MINES
Marling J. Ankeny, Director

USBM RI - 6151

- Published in 1963
- Measured vibration from single row shots at a single location in Iowa
  - ✓ **3 hole shots**
  - ✓ **7 hole shots**
  - ✓ **15 hole shots**
- Holes detonated with Det Cord (no down hole dets)
- Holes delayed using 9ms and 17ms surface delays
- Delayed shots shows significant vibration reduction
- Scatter for electric seismic caps used was +/- 1 ms
- 8ms was listed as minimum delay

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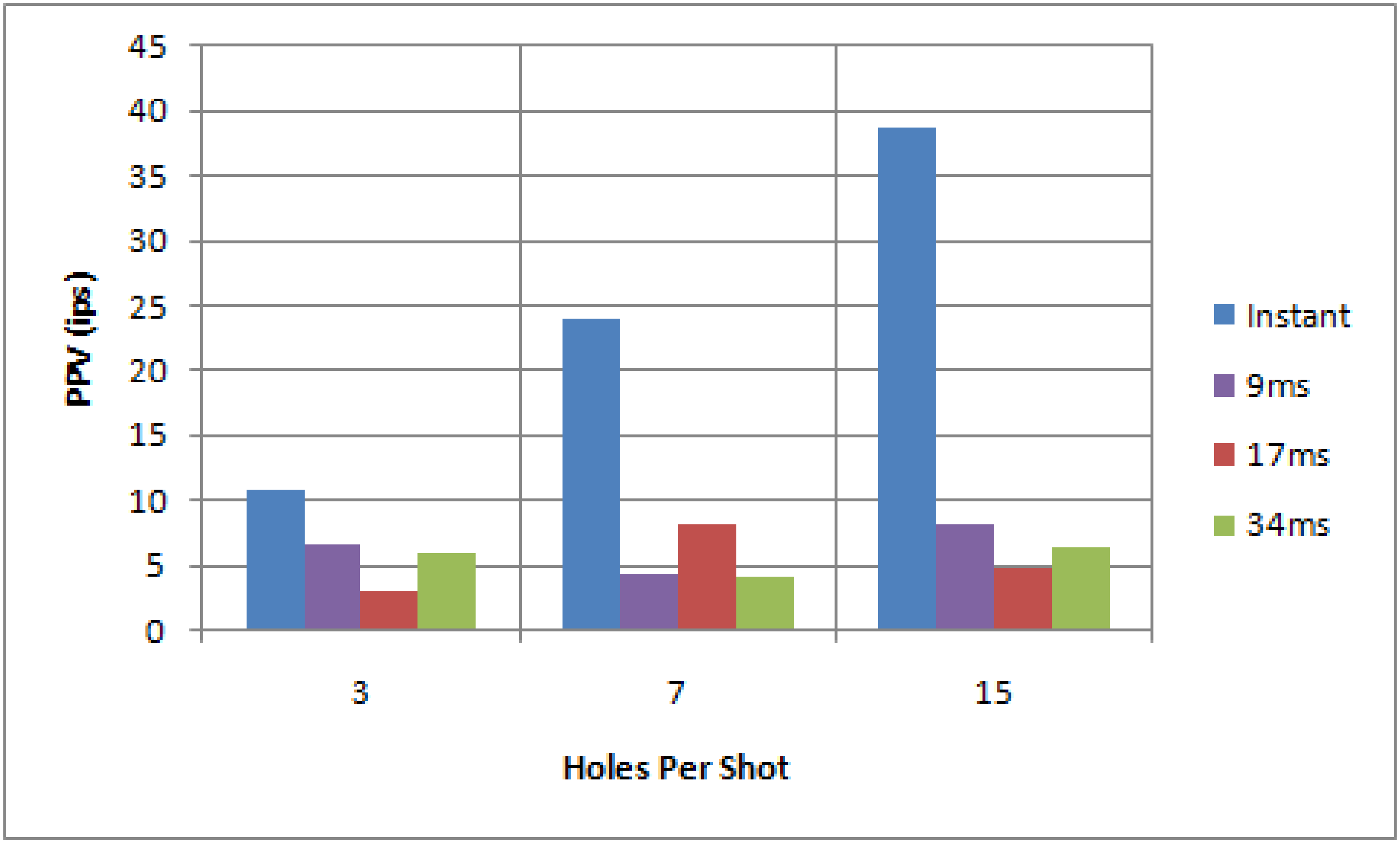
Shot	Number of holes	Delay interval, milliseconds	Charge/delay, pounds	Particle-velocity intercepts		
				Radial in/sec	Vertical in/sec	Transverse in/sec
14......	1	0	100	-	2.15	-
4......	1	0	200	4.03	2.88	0.94
9......	1	0	200	3.62	3.70	.98
18......	1	0	200	5.24	3.48	2.39
10......	1	0	200	4.24	3.44	1.12
2......	3	0	600	10.8	7.76	2.28
8......	7	0	1,400	23.9	17.9	3.74
12......	15	0	3,000	38.6	22.1	8.99
19......	3	9	200	6.66	3.72	1.93
20......	7	9	200	4.53	4.35	2.35
21......	15	9	200	8.24	6.33	3.60
3......	3	17	200	2.99	3.16	2.65
5......	7	17	200	8.10	7.04	2.42
11......	15	17	200	4.83	4.61	2.14
6......	3	34	200	5.81	3.90	1.45
7......	7	34	200	4.14	3.06	1.30
13......	15	34	200	6.41	4.71	1.61
27......	13	17	800	14.4	12.3	3.79
32......	21	17	1,218	18.2	12.7	4.83



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So what did this tell us???

- 0 delay does not work !!!!
- 9ms was never the lowest ppv
- 17ms was not lowest ppv in all cases
- 34ms was not lowest ppv in all cases
- 0 delay ppv did not increase proportionally to charge weight increases.

Bulletin 656

BLASTING VIBRATIONS AND THEIR EFFECTS ON STRUCTURES

By Harry R. Nicholls, Charles F. Johnson, and Wilbur I. Duvall

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USBM Bulletin 656

- Published in 1971
- Not so much a research report but a summary of previous work
- Single row shots and simple multi row shots
- 0ms, 9ms, 17ms and 34ms delays
- Set vibration limit of 2.00 ips
- Used Scaled Distance to maintain safe blasting limits
- 8 ms criterion again implied based on previous research

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Scaled Distance

$$SD = d/(wt)^{1/2}$$

Where:
d = distance to dwelling
Wt = max charge per 8ms delay

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What else does it say ????

- Electric Caps reduce vibration more compared to cord
- Geology, rock type and orientation effects vibration within Scaled Distance limits
- Seismographs, not scaled distance is recommended to insure safe blasting limits are maintained

Summary of Early Research

- Mostly simple, single row shots
- Simple delay timing achieved with surface delays
- 8 ms criterion simply because 9ms caps available
- No consideration of frequencies
- Based on two assumptions
  - ✓ As distance increases, vibration decreases
  - ✓ As charge weight decreases, vibration decreases
- Neither assumption is always true
  - ✓ Undershooting
  - ✓ waveguides

QUARRY ACADEMY

Scaled Distance

$$SD = D / W^{1/2}$$

Where

SD = Scaled Distance
D = Distance from the blast to structure (ft.)
W = Maximum pounds per delay of detonated explosives

SMCRA 38CSR2-6.5.i. and West Virginia 199CSR1-3.6.h. stipulate minimum scaled distance factors or maximum allowable PPV to be used for the protection of structures. These requirements are:

Distance from blast to structure (ft.)	Scaled Distance factor	Maximum PPV allowed (ips)
0 - 300	50	1.25
301 – 5,000	55	1.00
5,000+	65	0.75

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Report of Investigations 8507

Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting

By D. E. Siskind, M. S. Stagg, J. W. Kopp, and C. H. Dowding

UNITED STATES DEPARTMENT
Cecil D. Andrus, Secretary

BUREAU OF MINES
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RI - 8507

- **Documented importance of frequency in structure response to blasting**
- **Created frequency based safe blasting limits**
- **Used regression to develop vibration prediction formulas**
- **Still promoted scaled distance concept**

APPENDIX B.—ALTERNATIVE BLASTING LEVEL CRITERIA

Safe blasting vibration criteria were developed for residential structures, having two frequency ranges and a sharp discontinuity at 40 Hz (table 13). There are blasts that represent an intermediate frequency case, being higher than the structure resonances (4 to 12 Hz) and lower than 40 Hz. The criteria of table 13 apply equally to a 35-Hz and a 10-Hz ground vibration, although the responses and damage potentials are very much different.

Using both the measured structure amplifications (fig. 39) and damage summaries (figs. 52 and 54), a smoother set of criteria was developed. These criteria have more severe measuring requirements, involving both displacement and velocity (fig. B–1).

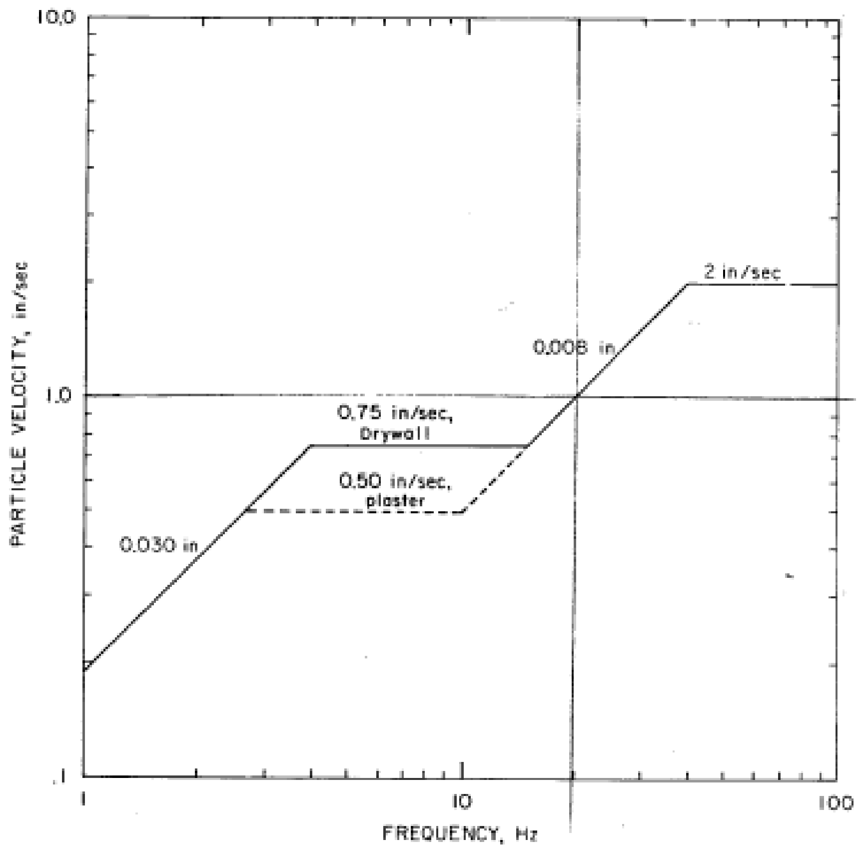

Figure B–1.—Safe levels of blasting vibration for houses using a combination of velocity and displacement.

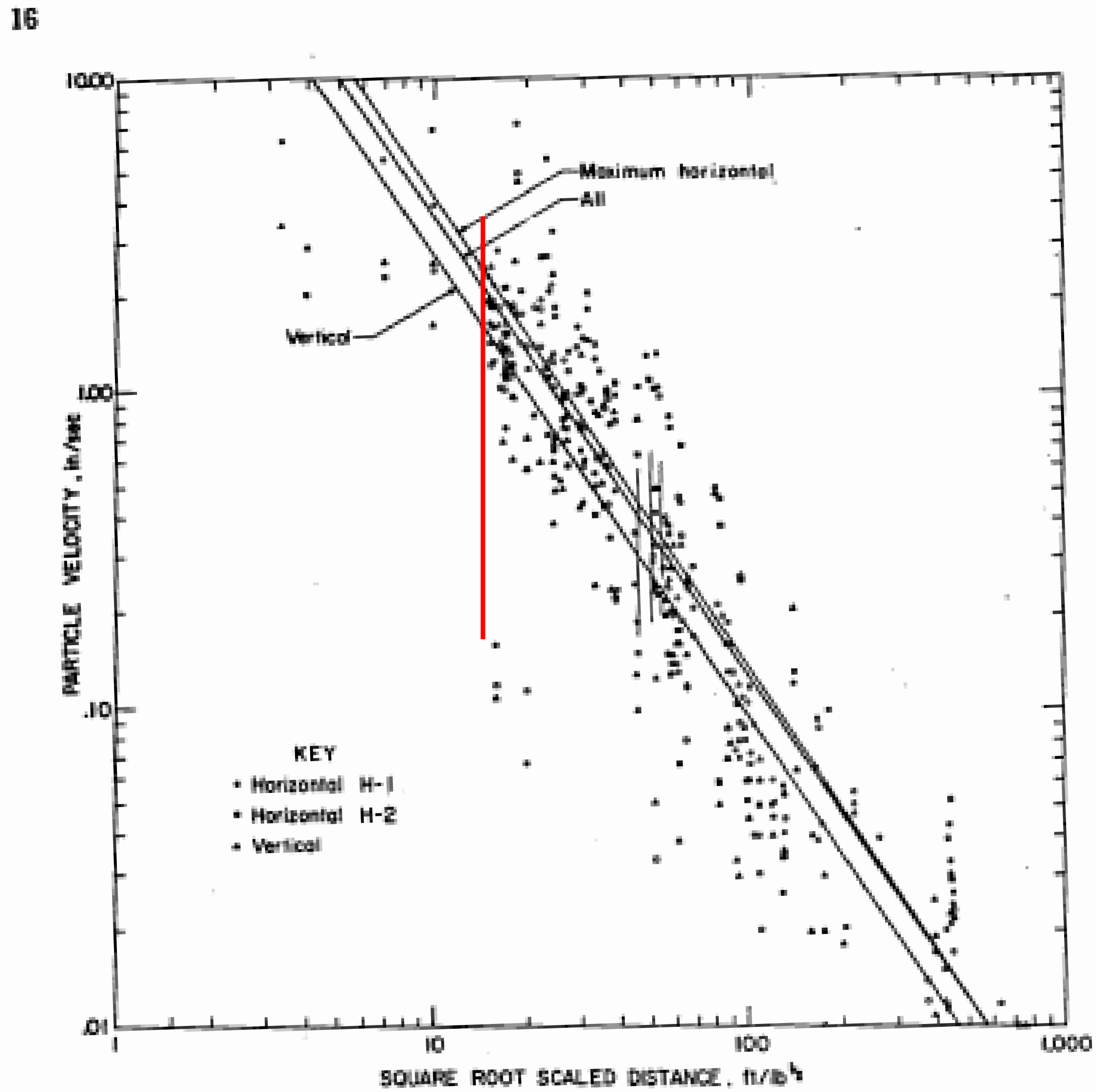

Figure 10.—Summary of ground vibrations from all surface coal mines. The component H-1 approximates "radial" and H-2 "transverse".

SD approx = 18
PPVmin = 0.10ips
PPVmax = 2.90ips

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Scale Distance and 8ms

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Vibration Prediction Formula

$$PPV = 160(SD)^{-1.6}$$

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Lets Start With the Basics

Charge weight = 750 lbs
Distance = 1000 ft

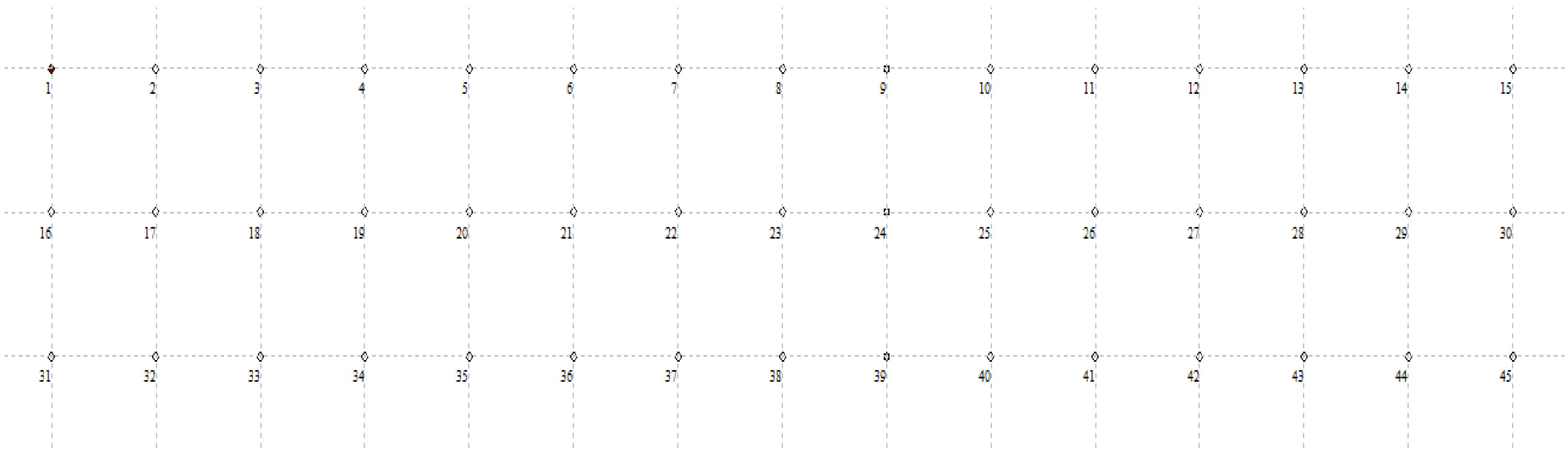
$PPV = 160\,(1000/\sqrt{750})^{-1.6}$

$PPV = 160\,(36.59)^{-1.6}$

$PPV = 160\,(0.00315)$

$PPV = 0.504$

Here is our pattern



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How do we time it ???

Hole	Row	Charges
17	75	2
17	76	2
17	77	2
17	78	3
17	79	3
17	80	3
17	81	2
17	82	3
17	83	3
17	84	3
17	85	3
17	86	3
17	87	3
17	88	3
17	89	2
17	90	3
17	91	3
17	92	3
17	93	2
17	94	2
17	95	3
17	96	3
17	97	3
17	98	2
17	99	3
17	100	3

Hole	Row	Charges
17	101	3
17	102	3
17	103	3
17	104	3
17	105	3
17	106	2
17	107	3
17	108	3
17	109	3
17	110	2
17	111	2
17	112	3
17	113	3
17	114	3
17	115	2
17	116	3
17	117	3
17	118	3
17	119	3
17	120	3
17	121	3
17	122	3
17	123	2
17	124	2
17	125	2

Predicted PPV

Hole Delay	Row Delay	Charges 8ms	Weight 8ms	PPV in/sec
17	75	3	2250	1.22
17	77	2	1500	0.88
17	85	3	2250	1.22
17	93	2	1500	0.88
17	94	2	1500	0.88
17	100	3	2250	1.22
17	101	3	2250	1.22
17	102	3	2250	1.22
17	109	3	2250	1.22
17	118	3	2250	1.22
17	118	3	2250	1.22

How about 25ms???

Hole	Row	Charges
25	75	3
25	76	3
25	77	3
25	78	3
25	79	2
25	80	2
25	81	2
25	82	2
25	83	1
25	84	2
25	85	2
25	86	2
25	87	2
25	88	2
25	89	2
25	90	2
25	91	2
25	92	1
25	93	2
25	94	2
25	95	2
25	96	2
25	97	3
25	98	3
25	99	3
25	100	3

Hole	Row	Charges
25	101	3
25	102	3
25	103	3
25	104	2
25	105	2
25	106	2
25	107	2
25	108	1
25	109	2
25	110	2
25	111	2
25	112	2
25	113	2
25	114	2
25	115	2
25	116	2
25	117	1
25	118	2
25	119	2
25	120	2
25	121	2
25	122	3
25	123	3
25	124	3
25	125	3

QUARRY ACADEMY

Predicted PPV

Hole Delay	Row Delay	Charges 8ms	Weight 8ms	PPV in/sec
25	84	2	1500	0.88
25	92	1	750	0.51
25	100	3	2250	1.22
25	108	1	750	0.51
25	109	2	1500	0.88
25	117	1	750	0.51
25	125	3	2250	1.22

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So What do we have ???

- Depending on timing, we can have 1, 2 or 3 holes per 8ms delay interval
  - ✓ 750 lbs/delay
  - ✓ 1500 lbs/delay
  - ✓ 2250 lbs/delay
- Using our formula, we would predict vibration values of ….
  - ✓ 750 lbs = 0.50 ips
  - ✓ 1500 lbs = 0.88 ips
  - ✓ 2250 lbs = 1.22 ips
- Is that what really happens when we blast??

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Lets change directions……

- **Seismic Wave Interaction**
  - ✓ **Acts as sound waves in the ground**
    - Compression waves
    - Lower frequency with distance
    - Waves can be influenced by other waves
  - ✓ **To understand seismic wave interaction, we can look at simple sound wave interaction**

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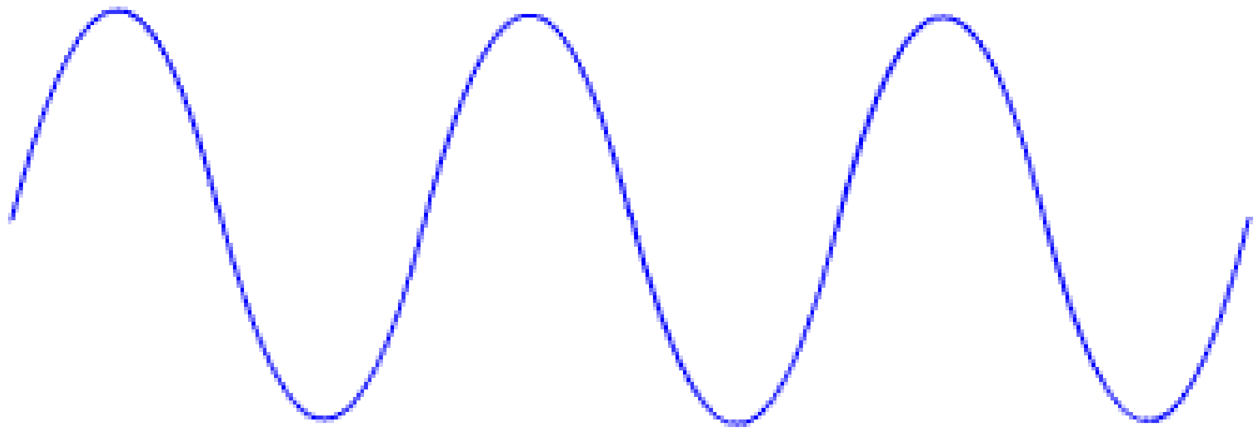
Sound can be represented by waves



Simple sine wave for single sound frequency

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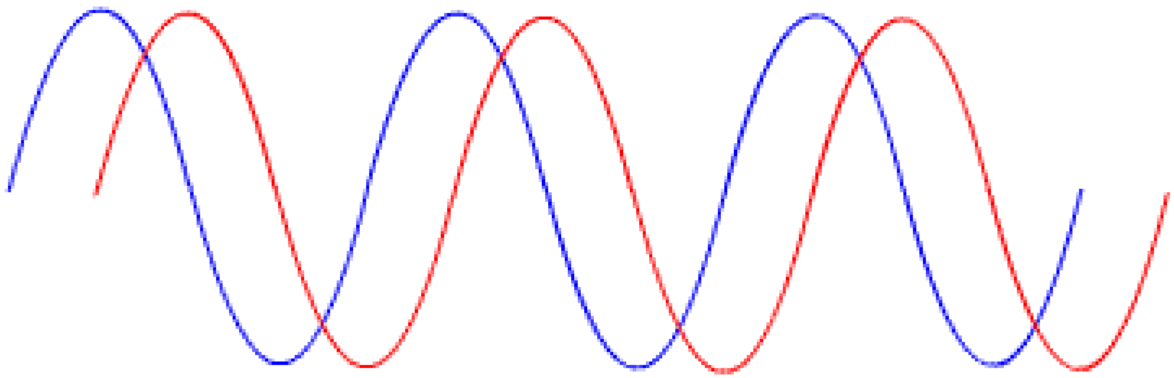
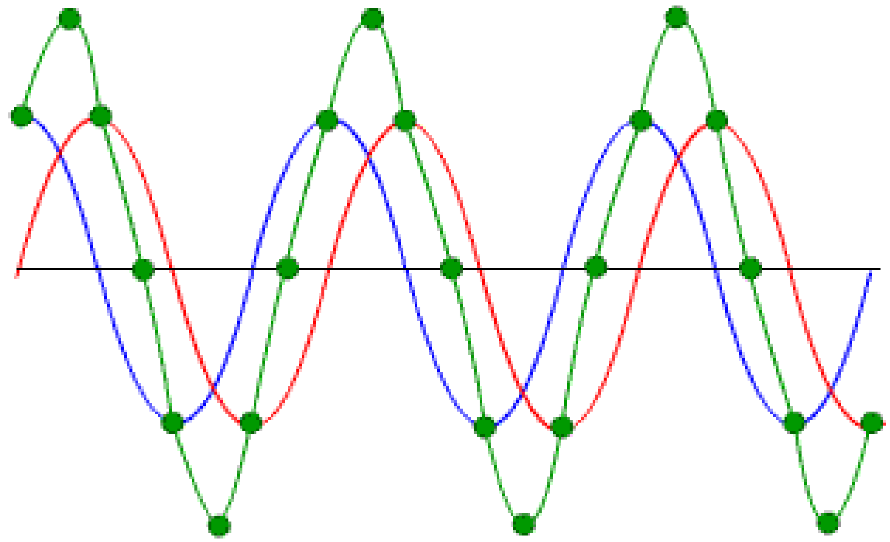
When two similar sounds are combined that are only slightly out of phase…



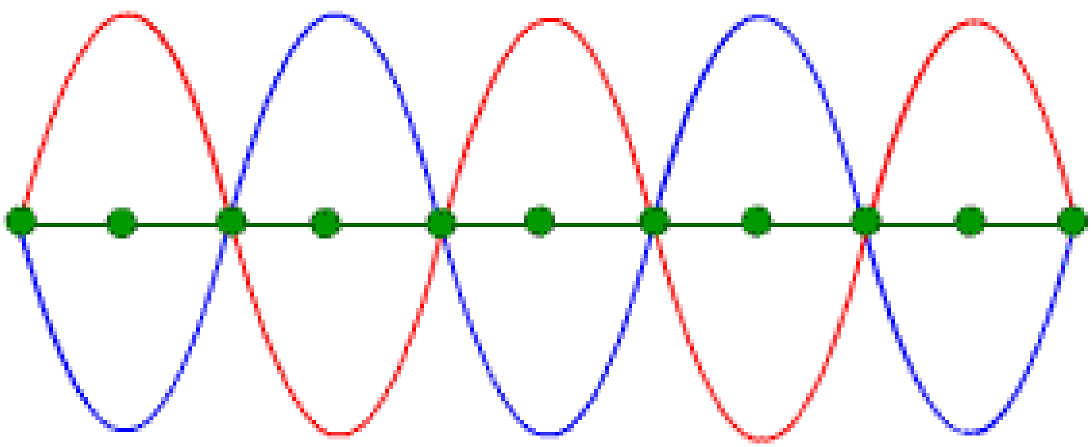
One pure sound a fraction of a second after the next

We get a single sound almost twice as loud



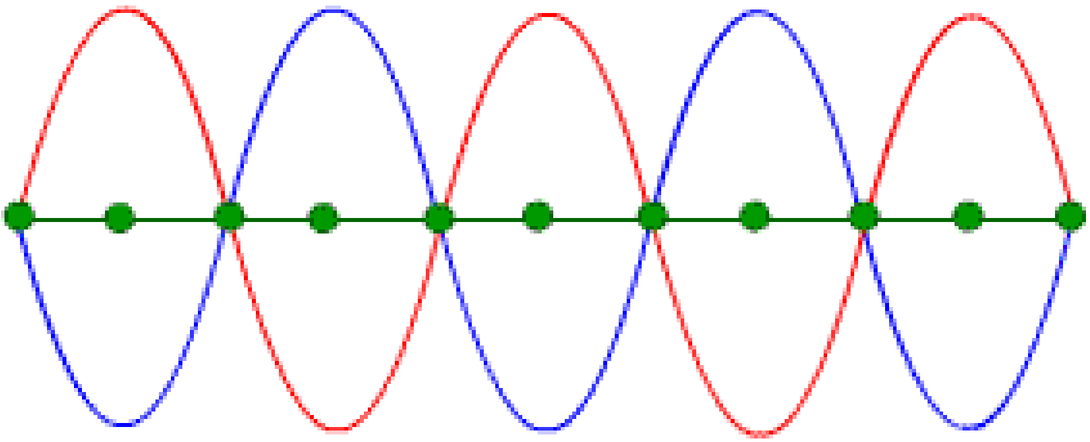
Sum of two waves slightly out of phase

If the two sounds are perfectly out of phase….



Sum of waves equals zero sound

If the two sounds are perfectly out of phase….there would be no sound



Sum of waves equals zero sound

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Critical Factors

- Determine phase delay to perfectly cancel waves
- The shape of the wave (wave period) determines delay that provides optimum cancellation

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This concept has led to the development of active noise cancellation applications

- Headphones
- Automobiles
- Electronics cabinets

NEW QuietComfort® 15 Acoustic Noise Cancelling® headphones

360° Photos Videos

Headphones

Noise cancelling headphones

- QuietComfort® 15 headphones
- QuietComfort® 3 headphones
- QuietComfort accessories
- Compare QuietComfort headphones

Audio headphones

Aviation headsets

Mobile solutions

Compare headphones

Factory-renewed products

Overview | In the box | Details/manuals | Accessories

NEW QuietComfort® 15 Acoustic Noise Cancelling® headphones

- **Our best headphones reduce more noise across a wider range of frequencies**
- **Enjoy your music and movies even more, with clear and lifelike sound**
- **Comfortable, around-the-ear fit**
- **AAA battery: 35 hours average life**
- **Ideal for frequent flyers**

The headphones that pioneered an industry are now even better.

QuietComfort 15 headphones feature exclusive Bose® advancements in noise reduction technology. You hear less noise than ever before, and even more of your music and movies. With the quality sound you expect from Bose. And a lightweight fit that stays comfortable for hours. It's a combination of benefits unmatched in the industry.

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Toyota develops noise-cancelling system for cars

Toyota develops noise-cancelling system for cars

Expanding on the same concept used in noise-cancelling headphones, Toyota has developed a noise cancelling system for its Japanese-market Crown Hybrid that nearly eliminates engine sound within the passenger compartment. The system uses a complex system of microphones, speakers and sensors located around the cabin.

The same technology has been transferred to ground vibration control

- Record “background” vibration
- Impact target with similar amplitude vibration out of phase
- Up to ten times more effective than traditional isolation systems

Semiconductor Manufacture

Electro-Damp® Active Vibration Isolation Systems

Electro-Damp® II
Active Pneumatic Vibration
Damping System

PEPS® II
Digital Precision Electronic
Positioning System

AccuDock™
Precision Kinematic
Docking System

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Quiet Island®

Sub-Floor Platforms and Supports

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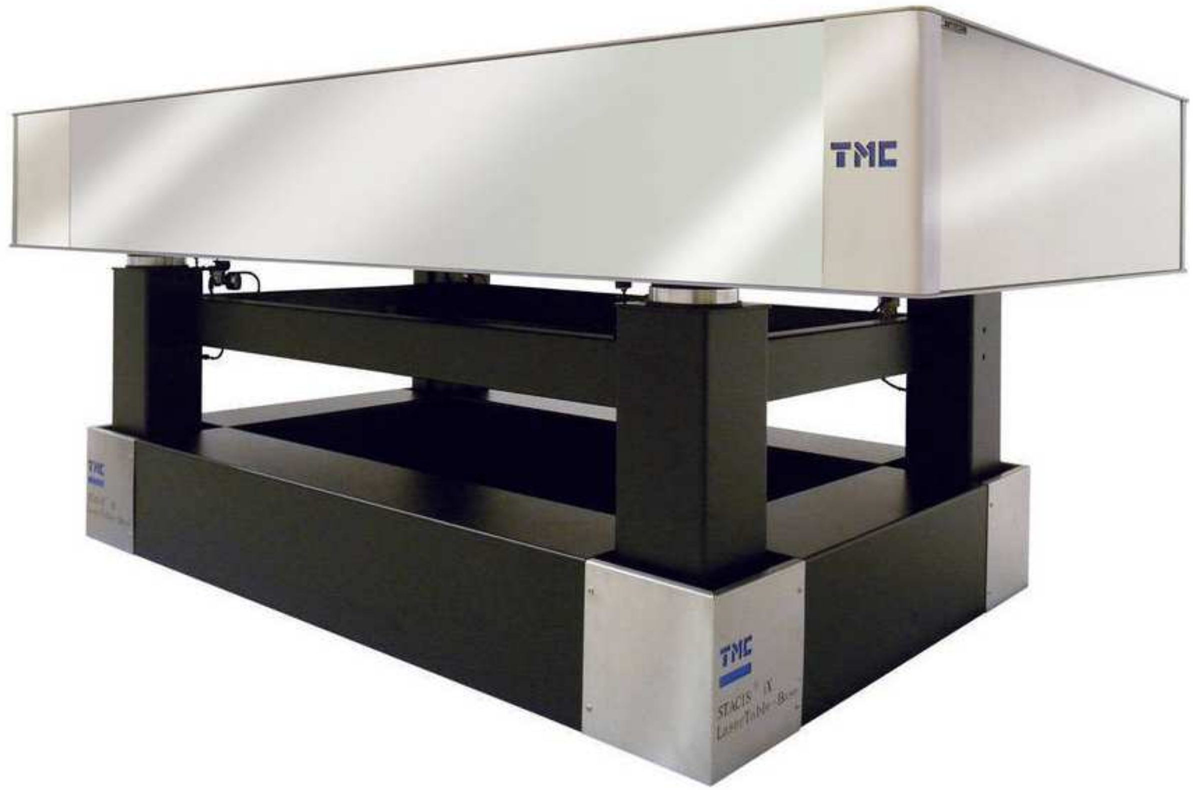

Tables for electron microscopes

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Active Vibration Cancellation

- In manufacturing, vibration is cancelled by using actuators to provide the out-of-phase signal

Active Vibration Cancellation

- In blasting we use explosive column detonations to cancel out vibrations from previous hole detonations

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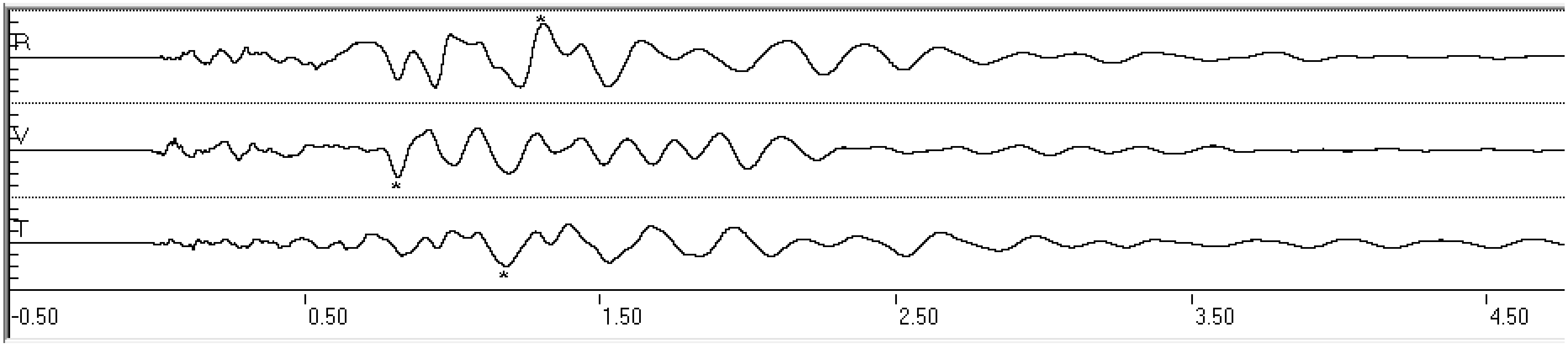
To do this we need….

- **Seismic data from single hole test shot**



To do this we need….

- **Linear superpositioning software**

Hole	Row	Deck	Charges	Peak	R	RGraph	V	VGraph	T	TGraph	RHZ	RHZGraph	VHz	VHZGraph	THZ	THZGraph
35	400	0	2	1.936	1.936		0.944		1.733		2.50		2.50		2.50	
35	410	0	3	1.749	1.749		1.026		1.584		2.50		2.50		2.50	
35	420	0	5	1.886	1.657		1.886		1.594		2.50		28.56		4.81	
35	430	0	3	1.359	1.359		0.722		0.952		2.50		2.50		4.75	
35	440	0	2	1.373	1.373		0.704		0.896		2.44		2.13		2.44	
35	450	0	2	1.358	1.358		1.155		1.146		4.38		28.75		4.38	
35	460	0	2	1.408	1.408		1.262		1.278		4.38		28.38		4.38	
35	470	0	2	1.307	1.307		0.972		1.222		4.31		2.06		2.06	
35	480	0	2	1.299	1.299		1.208		1.127		4.25		2.06		2.00	
35	490	0	4	1.654	1.405		1.654		1.294		4.19		28.56		2.00	
35	500	0	2	0.869	0.869		0.822		0.799		2.06		2.00		2.00	
35	510	0	2	1.043	0.889		1.043		0.910		2.00		3.81		2.00	

AND…….

- **ELECTRONIC DETONATORS**
  - ✓ **Flexibility**
    - 0 to 20,000ms
  - ✓ **Precision**
    - 1 ms +/-

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Waveform Prediction

- **We can also use this technique to predict effects of any given delay (positioning of waves) for a blast**

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Lets return to our first calculations

- 1000 ft to target
- Three charge weights
  - ✓ 750 lbs
  - ✓ 1500 lbs
  - ✓ 2250 lbs
- Three predicted vibration results
  - ✓ 750 lbs = 0.50 ips
  - ✓ 1500 lbs = 0.88 ips
  - ✓ 2250 lbs = 1.22 ips

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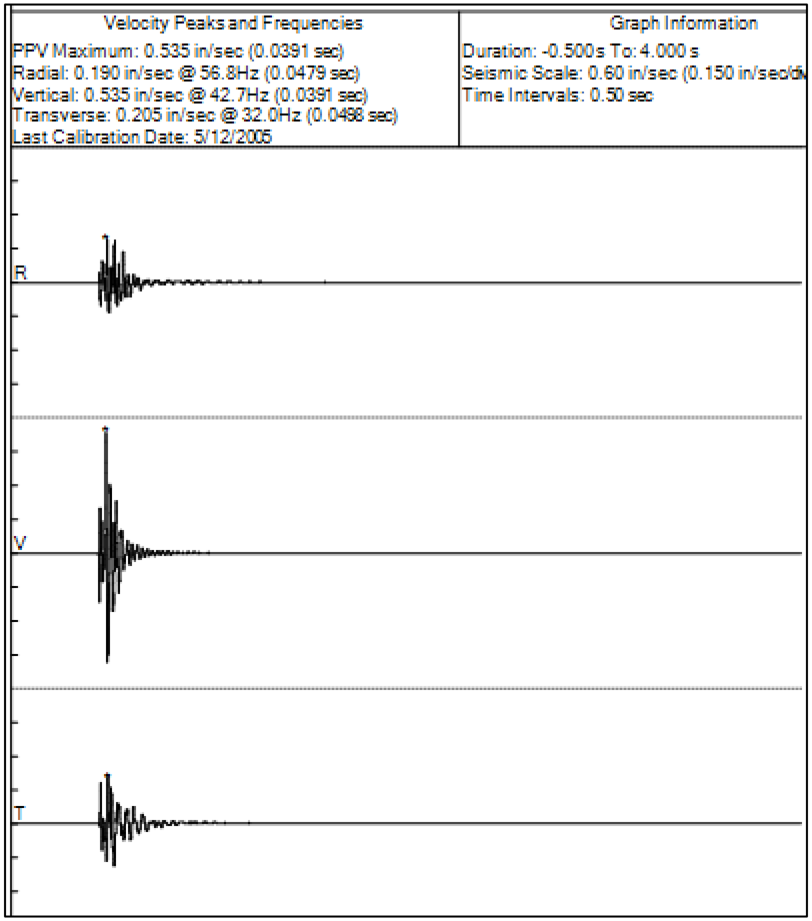
We can simulates these conditions using actual seismic data

- Single hole blast with ppv of approx 0.53
- Time 3 row blast for 1, 2 and 3 holes per "delay"
- Compare results with our calculations based on scaled distance
- For now we will stick to standard Nonel delays

Single Hole, ppv = 0.535 ips



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Pick delays resulting in 1, 2 and 3 holes per delay

Hole	Row	Charges
25	75	3
25	76	3
25	77	3
25	78	3
25	79	2
25	80	2
25	81	2
25	82	2
25	83	1
25	84	2
25	85	2
25	86	2
25	87	2
25	88	2
25	89	2
25	90	2
25	91	2
25	92	1
25	93	2
25	94	2
25	95	2
25	96	2
25	97	3
25	98	3
25	99	3
25	100	3

Hole	Row	Charges
25	101	3
25	102	3
25	103	3
25	104	2
25	105	2
25	106	2
25	107	2
25	108	1
25	109	2
25	110	2
25	111	2
25	112	2
25	113	2
25	114	2
25	115	2
25	116	2
25	117	1
25	118	2
25	119	2
25	120	2
25	121	2
25	122	3
25	123	3
25	124	3
25	125	3

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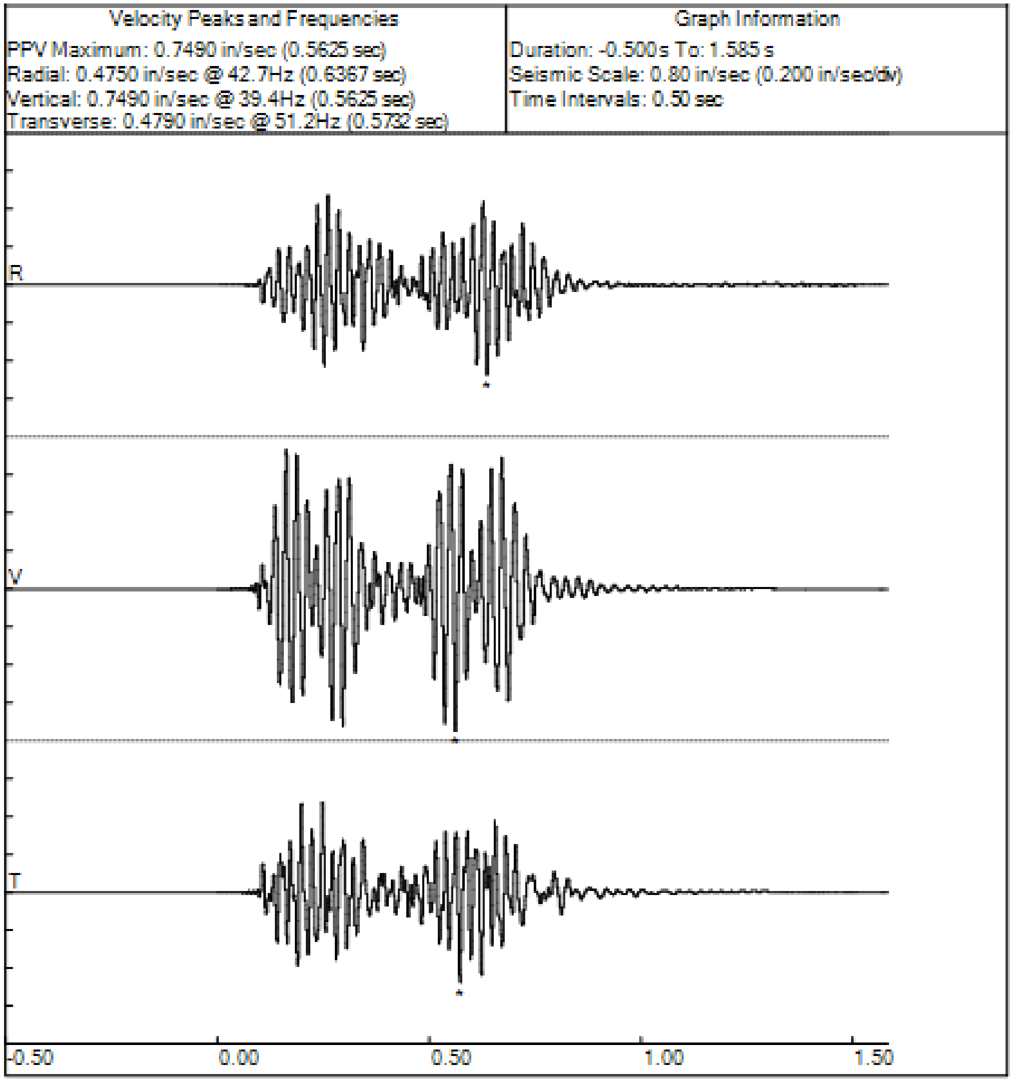
25ms/holes, 92ms/rows (1 hole/delay)



ppv = 0.75 ips

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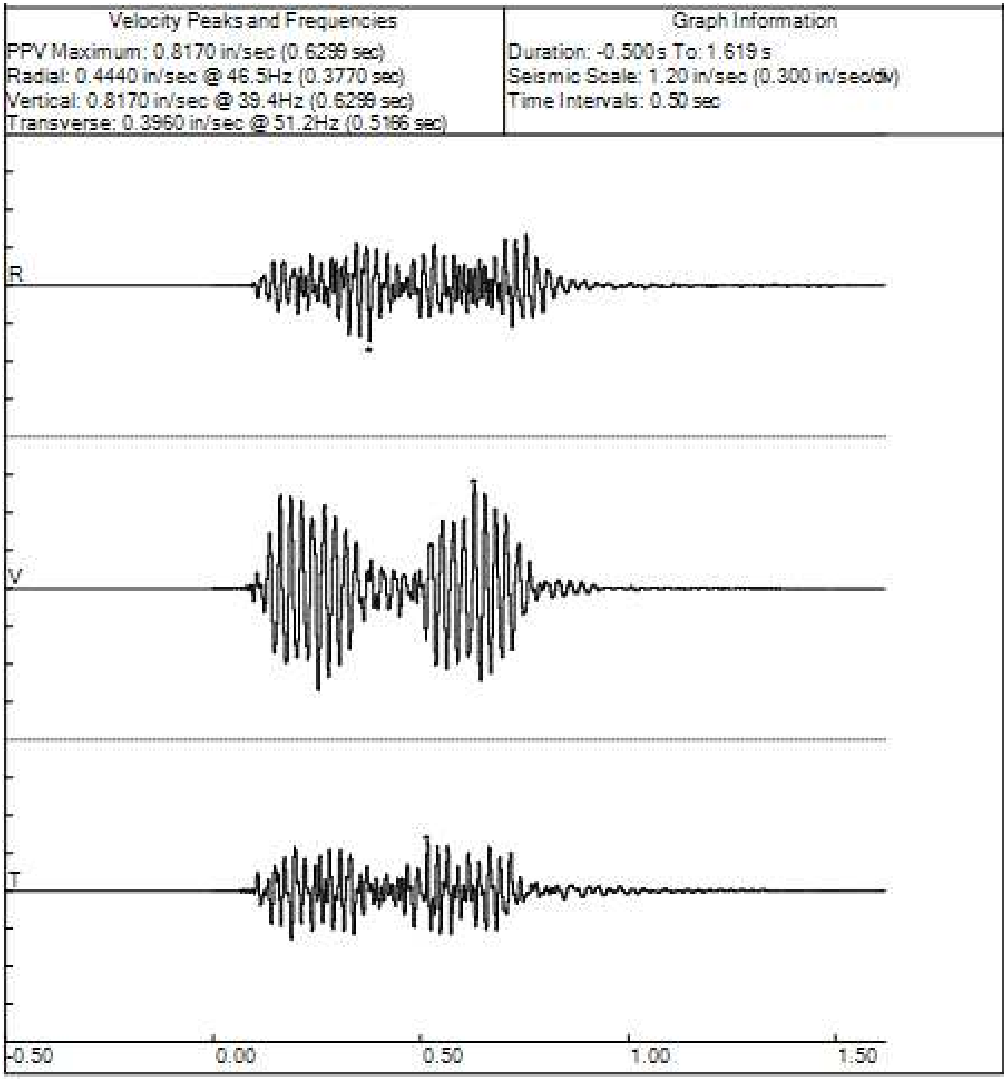
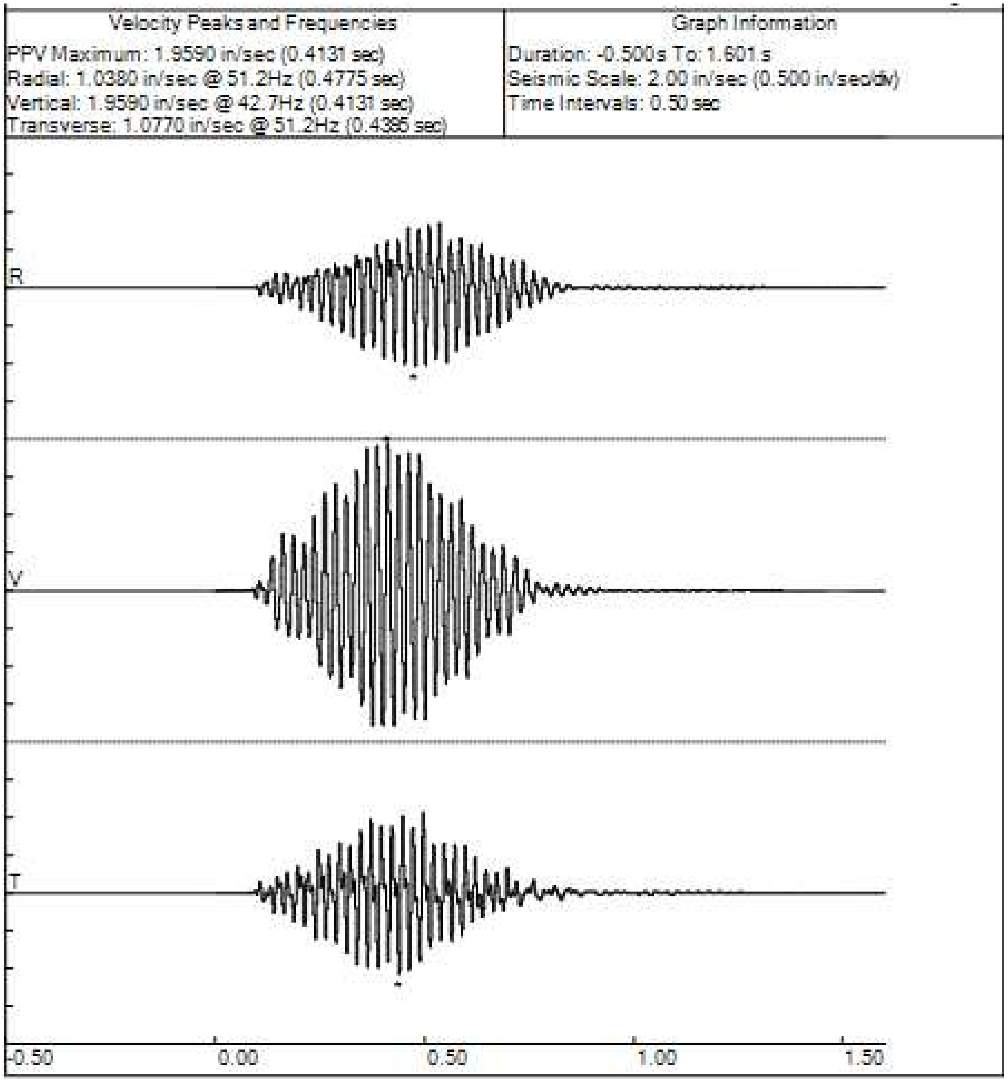
25ms/holes, 109ms/rows (2 holes/delay)



ppv = 0.82 ips

QUARRY ACADEMY

25ms/holes, 100ms/rows (3 holes/delay)



ppv = 1.96 ips

Summary of results

Delay	Holes/delay	SD ppv	Wave ppv	Difference
25/92	1	0.51	0.75	+ 47%
25/109	2	0.88	0.82	- 7%
25/100	3	1.22	1.96	+ 61%

QUARRY ACADEMY

So what does all this tell us

- **Actual vibration amplitude does not follow predictions based on holes per delay**
- **Multiple holes per delay can result in higher or lower ppv values DEPENDING ON HOW THE INDIVIDUAL WAVES FROM EACH HOLE MATCH UP**

QUARRY ACADEMY

Using this concept, we can find optimum delays

- Record seismic waveform from single charge
- Use wave cancellation algorithms to predict results
- Find sequences resulting in the lowest vibration results

QUARRY ACADEMY

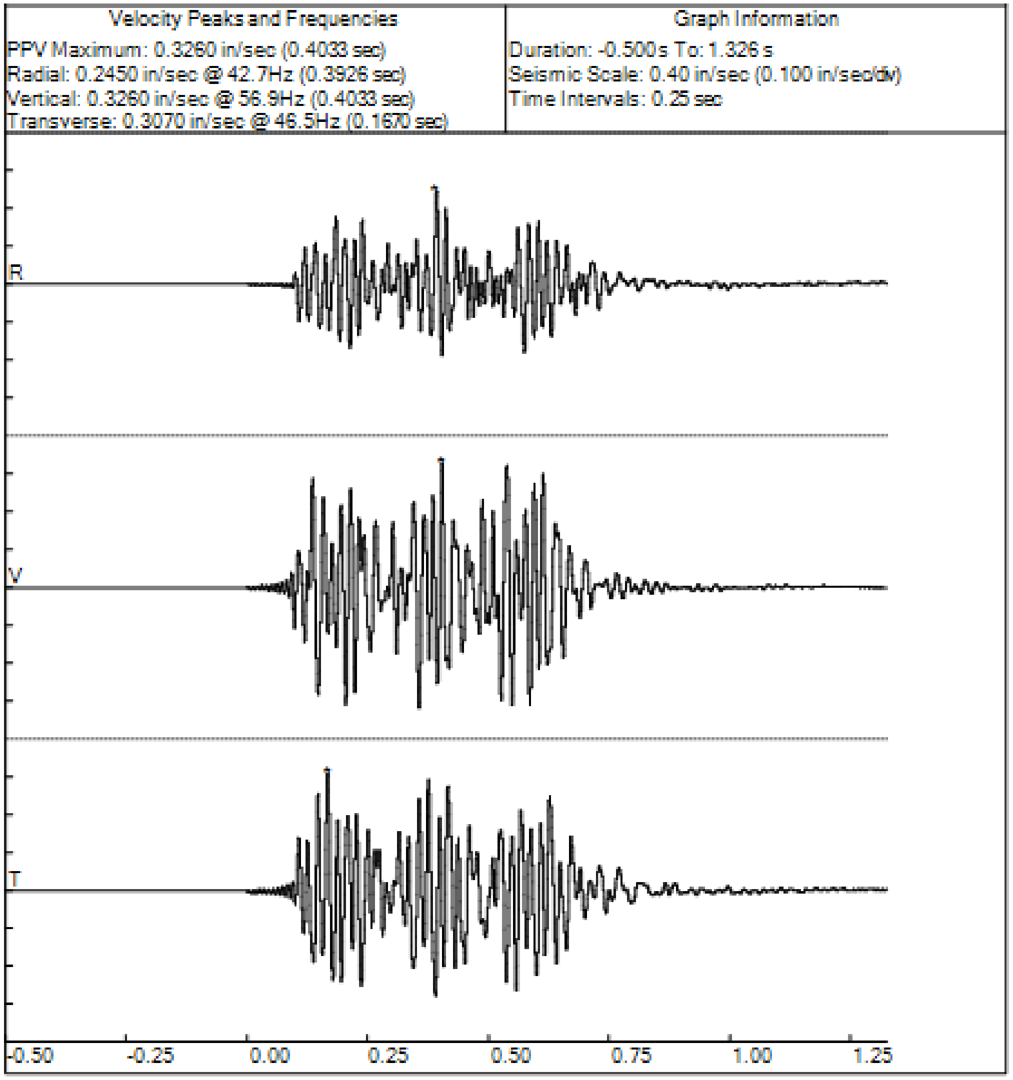
Hole	Row	Charges
19	105	2
13	111	3
19	106	2
19	107	3
13	98	3
13	110	3
18	81	2
18	82	2
19	103	2
19	84	2
19	104	2
18	100	2
18	78	3
13	97	3
18	80	2
13	96	2
19	108	3
17	113	3
17	112	3
17	111	2
18	79	3
17	78	3
17	110	2
18	98	2
18	83	3
19	121	3
17	79	3
18	115	3
19	120	3
19	83	3
18	97	3
18	101	3
17	75	3

Analysis Parameters

3 rows of 15 holes
10 – 25 ms inter hole
75 – 150 ms inter row

Approx 1200 possible sequences

19ms/holes, 105ms/rows – 2 holes/delay

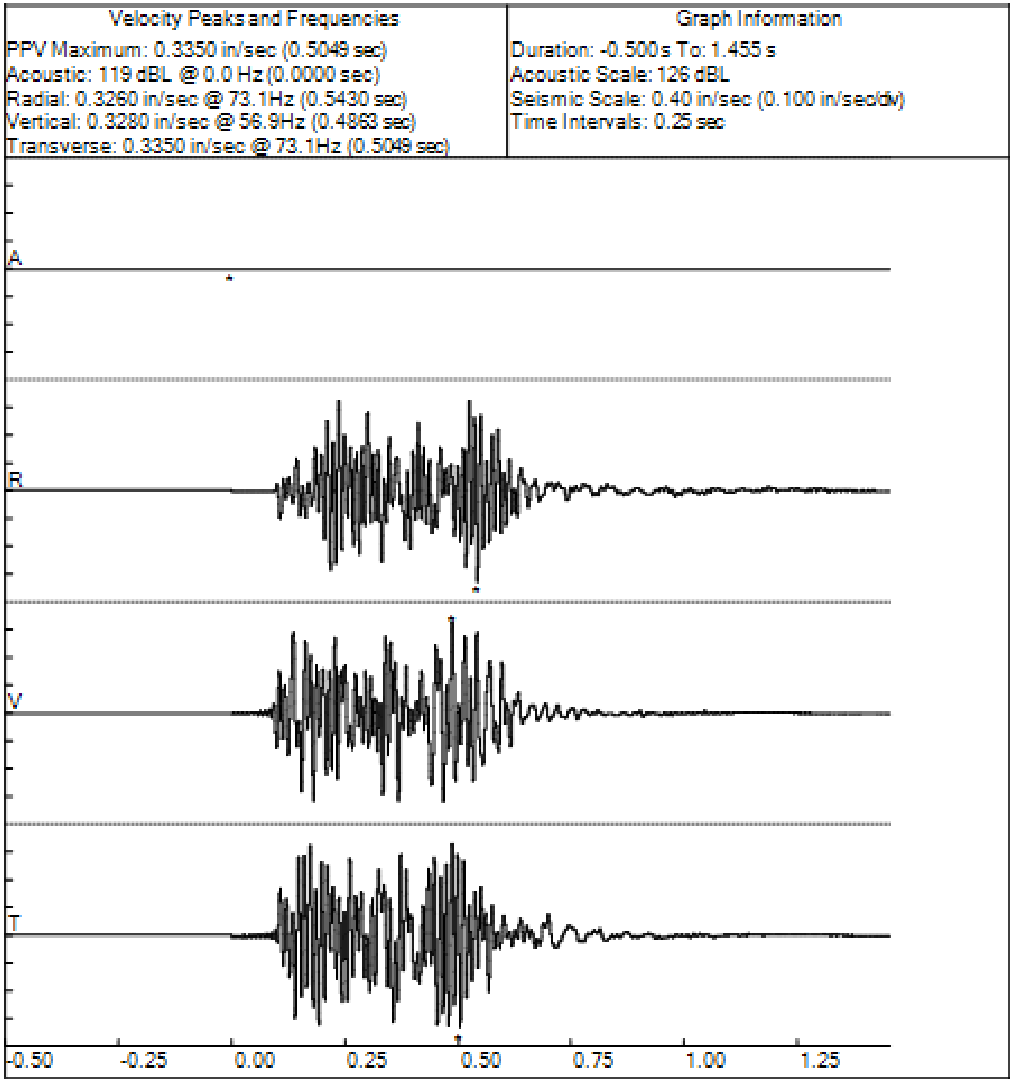


ppv = 0.33 ips

calculated = 0.88 ips

QUARRY ACADEMY

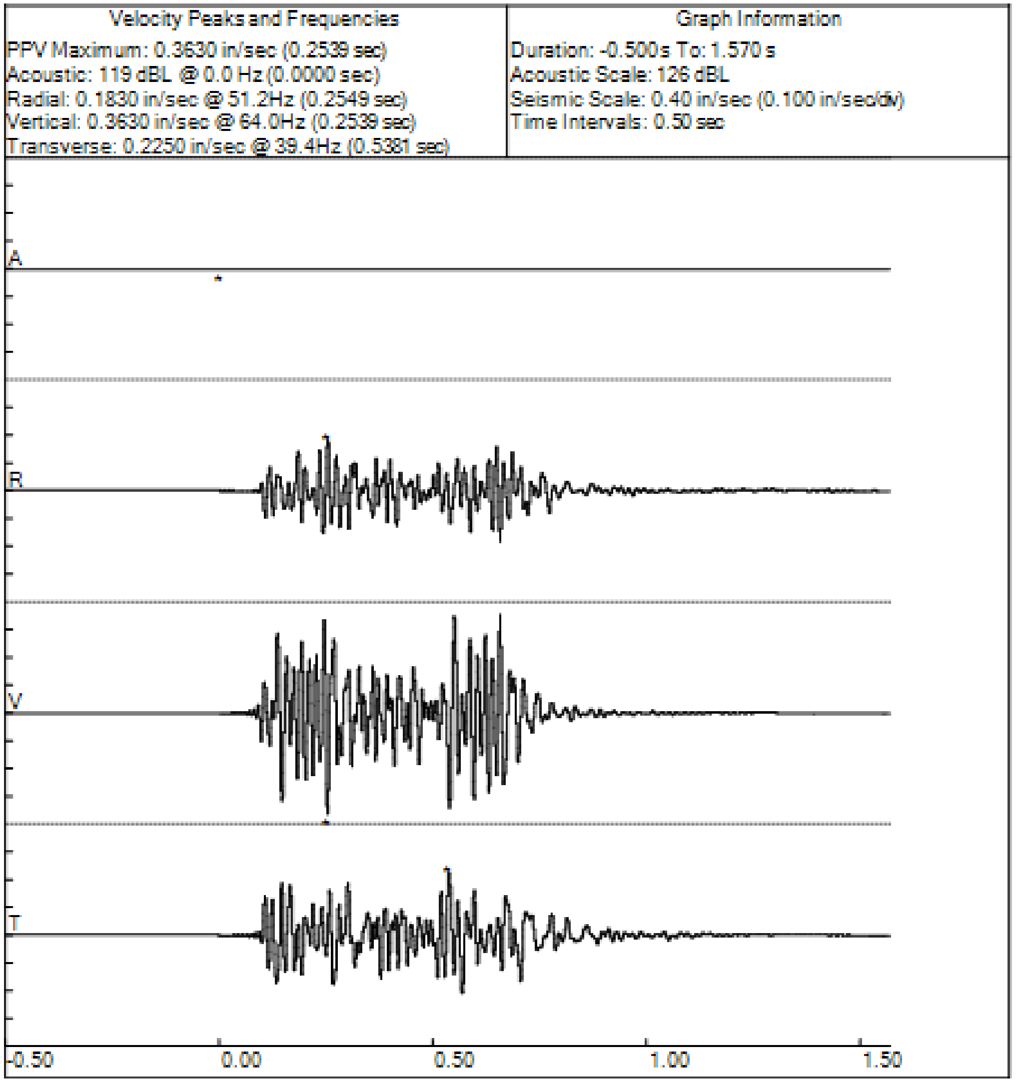
13ms/holes, 111ms/rows – 3 holes/delay



ppv = 0.33 ips

calculated = 1.22 ips

18ms/holes, 134ms/rows – 1 hole/delay

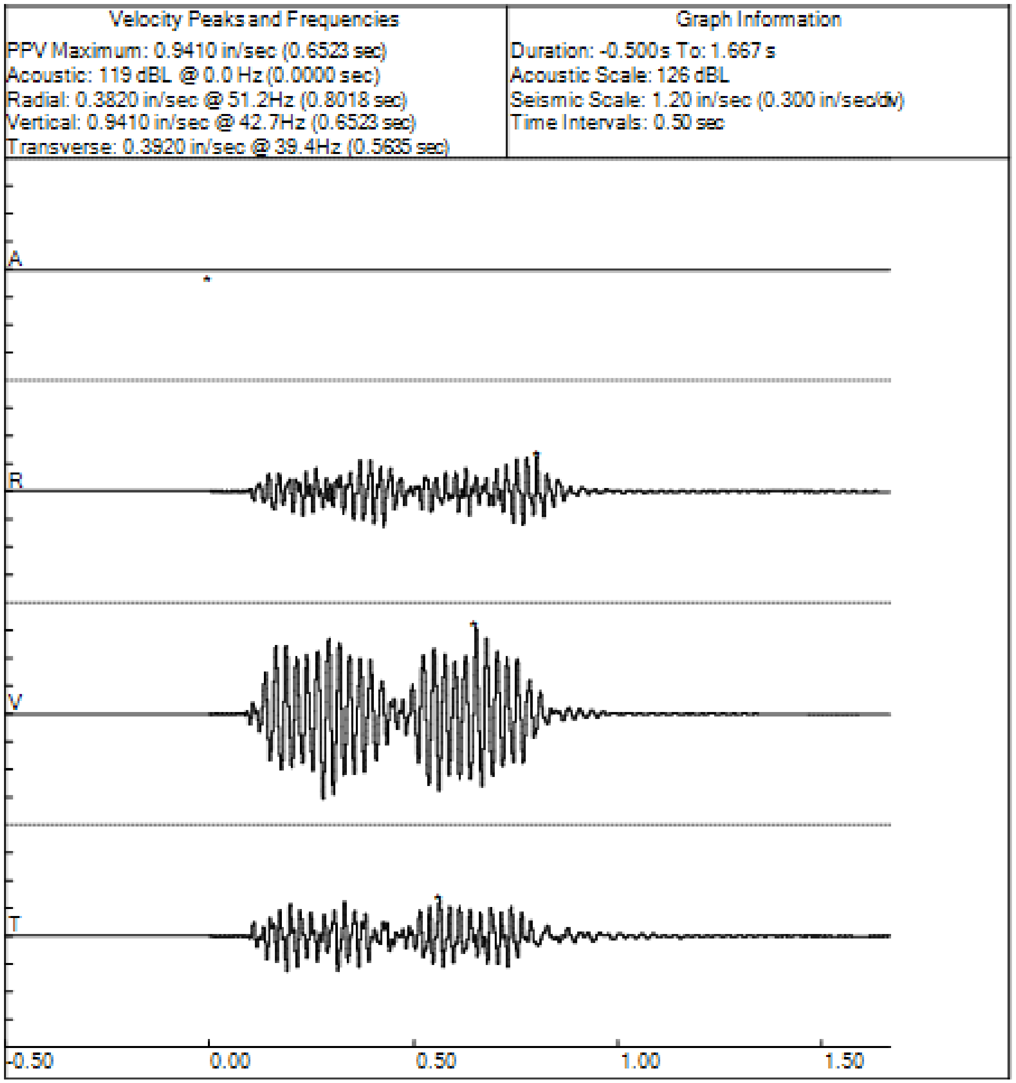


ppv = 0.33 ips

calculated = 0.51 ips

QUARRY ACADEMY

Important !! "Bad" delays have opposite effect



25ms/holes,
133ms/rows
1 hole/delay

ppv = 0.94 ips

calculated = 0.54 ips

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What conclusions can we draw ???

- It is clear that scaled distance alone cannot be considered an accurate means of determining off site impact
- It is wave interaction that is decisive in determining vibration amplitude
- Only through the use of programmable electronic detonators and waveform analysis can true vibration control be attained

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Where do we go from here ??

- Understand limitations of scaled distance
- Scaled distance based regulations may impair ability to further reduce off site effects
- Shot designs should be based on reducing vibration, not reducing charge weight per delay
- Seismic data is the only means of insuring conformity with safe blasting limits

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