QA 105 - Understanding Fundamentals of Vibration Control

Stweart Brashear

QUARRY ACADEMY

Improving Processes. Instilling Expertise.

DYNO
Dyno Nobel

SANDVIK

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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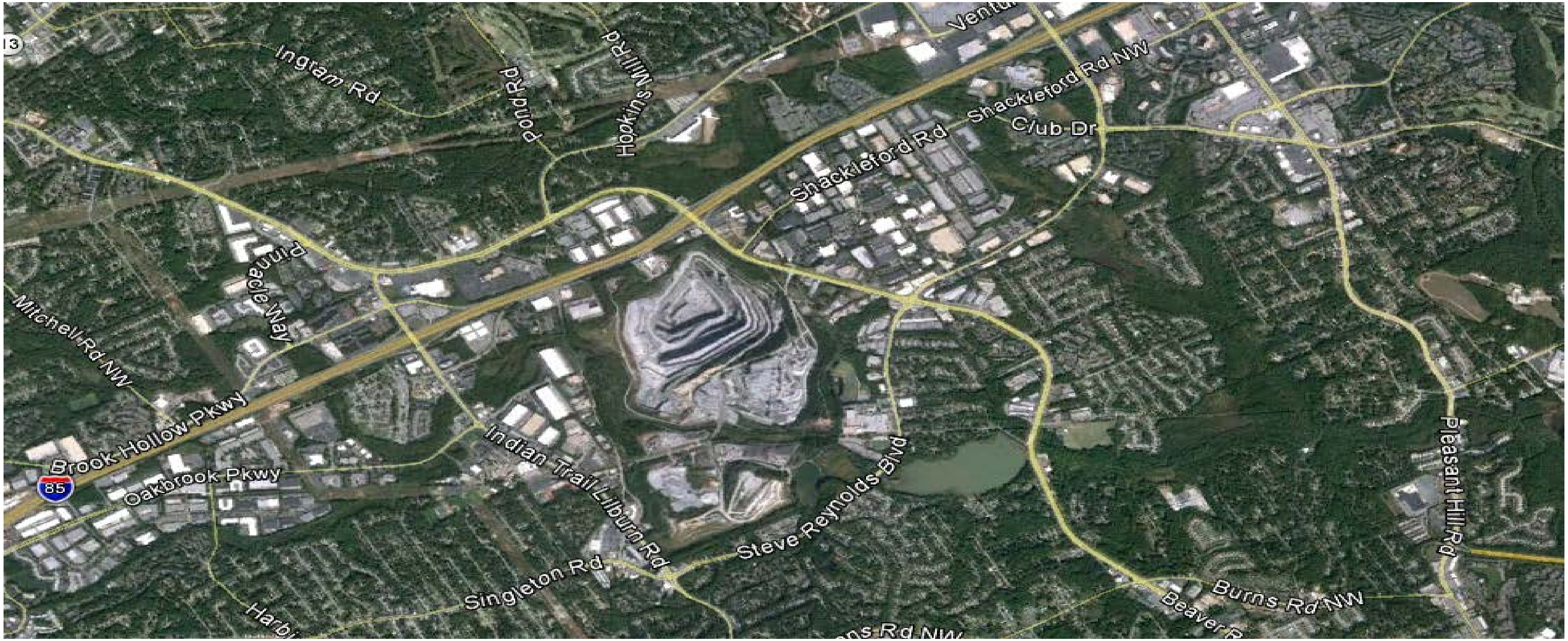
21
State St
S Assembly St
16
Olympia Ave
Rosewood Dr
2
12th Street Extension
New State Rd
State Rd S-3



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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

US Department of Interior
Office of Surface Mining Reclamation and Enforcement

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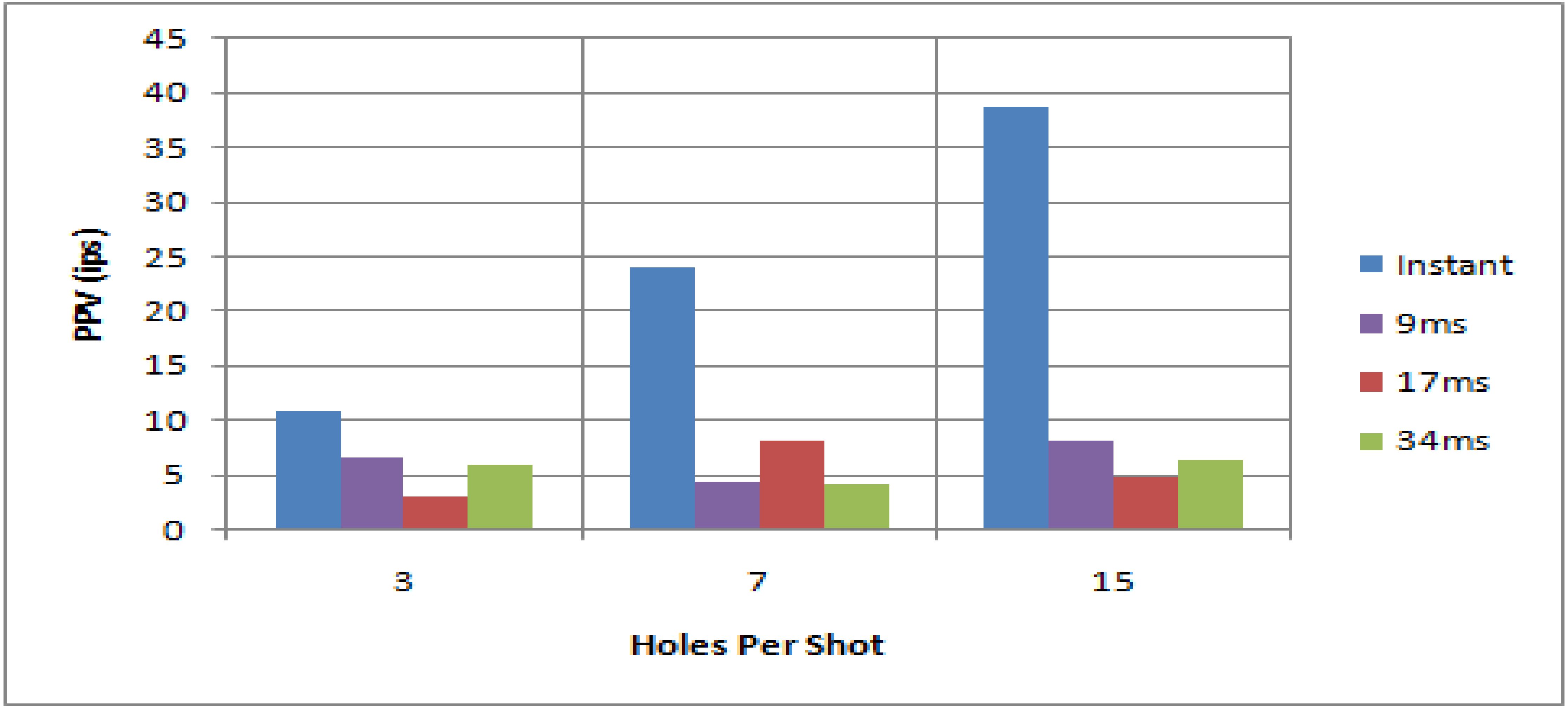
UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L. Udall, Secretary

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

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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UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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

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 (accuracy)
- Geology, rock type and orientation effects vibration within Scaled Distance limits
- Seismographs, not scaled distance is recommended to insure safe blasting limits are maintained

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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

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
Lindsay D. Norman, Director

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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).

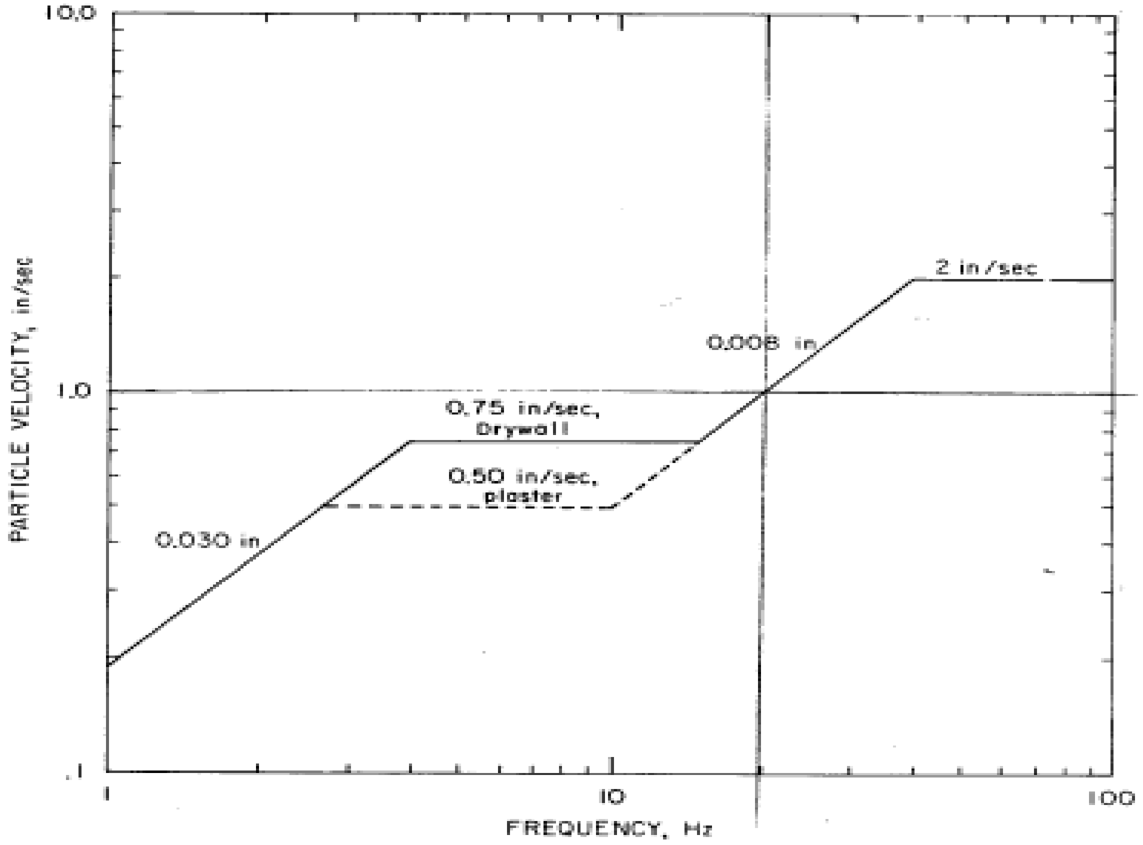

Figure B–1.—Safe levels of blasting vibration for houses using a combination of velocity and displacement.

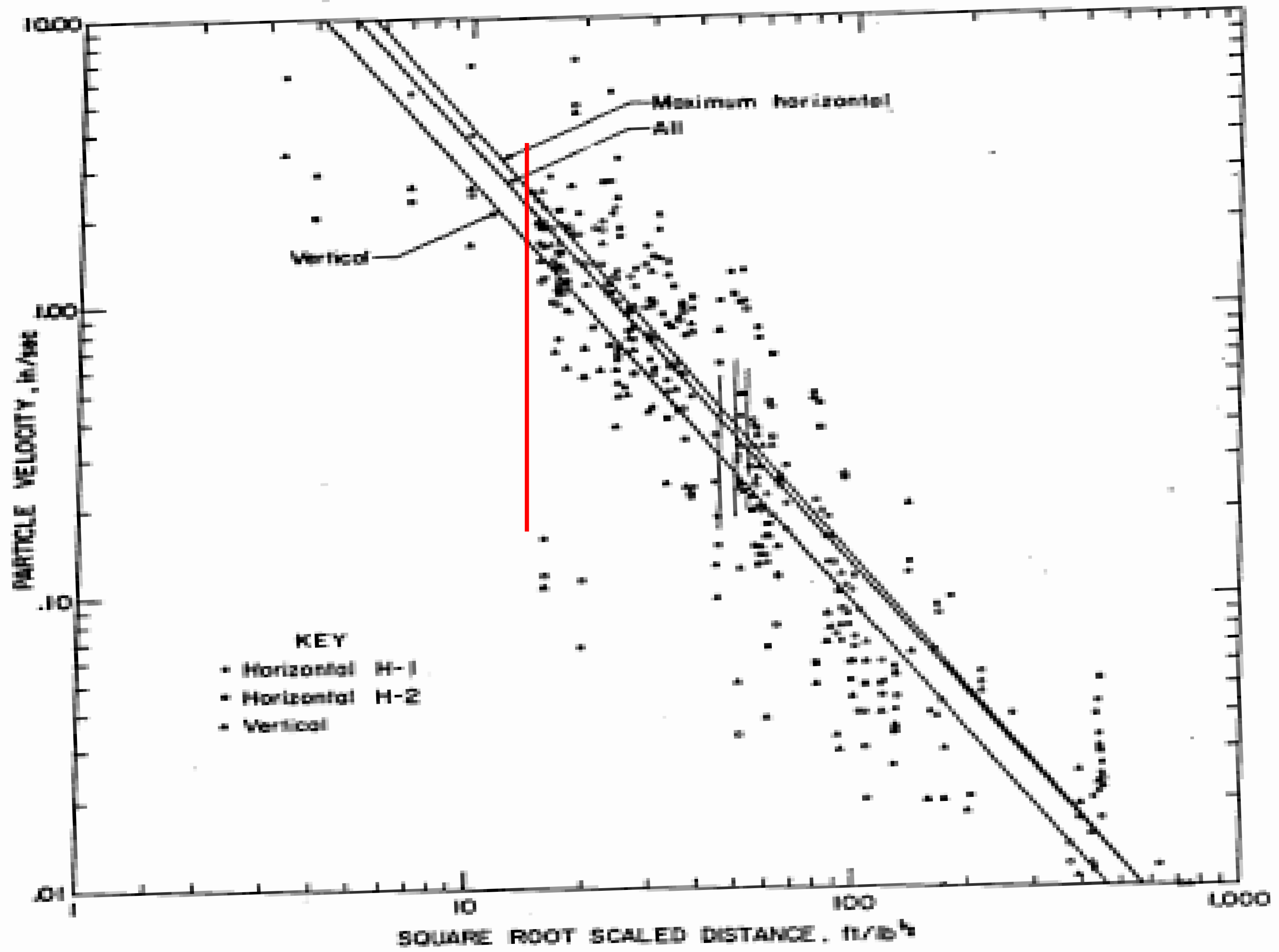

Figure 10.—Summary of ground vibrations from all surface coal mines. The component H–1 approximates "radial" and H–2 "transverse".

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

So where do we stand now ???

- RI 8507 provides documented, safe blasting criteria
- Still pays homage to scaled distance concept
- Predicted PPV using SD varies widely, not a good predictor at all

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So where do we stand now ???

- How can we change SD to impact vibration?
  - Smaller hole size
  - Reduced pattern
  - 1 hole per “delay”
  - Decking
- Most have impact on cost
- Not very effective tool for reducing vibration
- Other options available

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Vibration Control

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Vibration Control

- Passive
  - Reduced charge weights per hole
  - Decking
  - Smaller patterns
  - Smaller hole diameter

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Vibration Control

- Active
  - Linear Superpositioning
    - Established concept
    - Enhanced by accuracy of electronic detonators
    - Advanced by new concepts in software design

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Linear Superpositioning

- 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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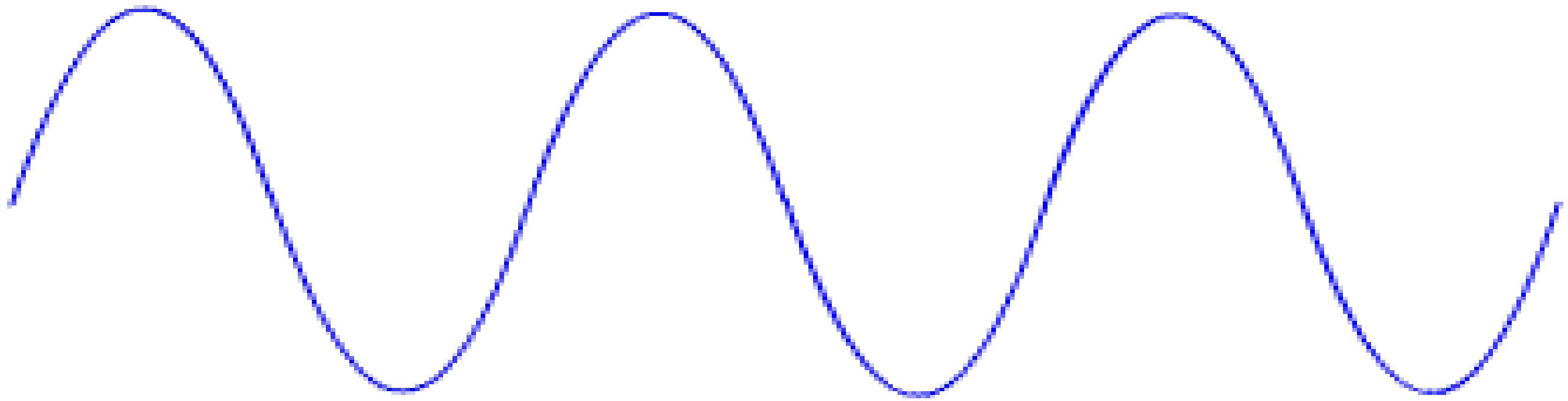
Sound can be represented by waves



Simple sine wave for single sound frequency

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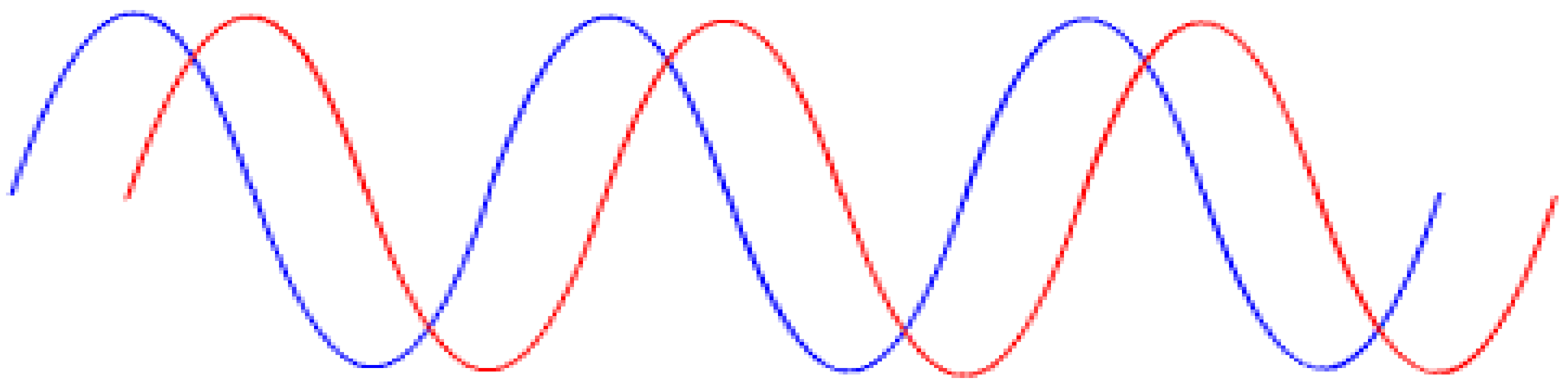
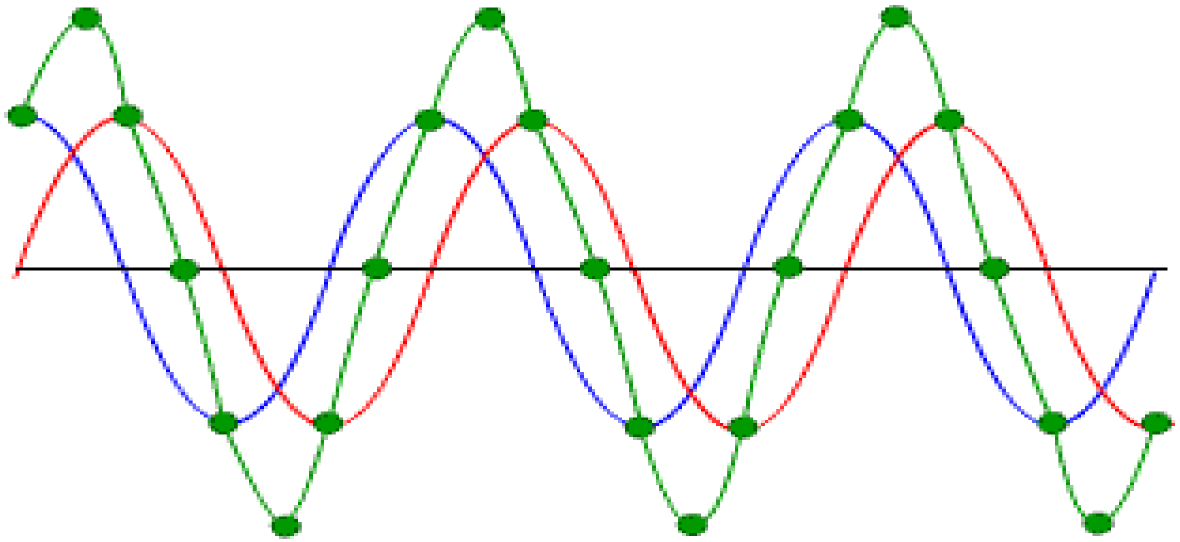
When two similar sounds are combined that are only slightly out of phase…



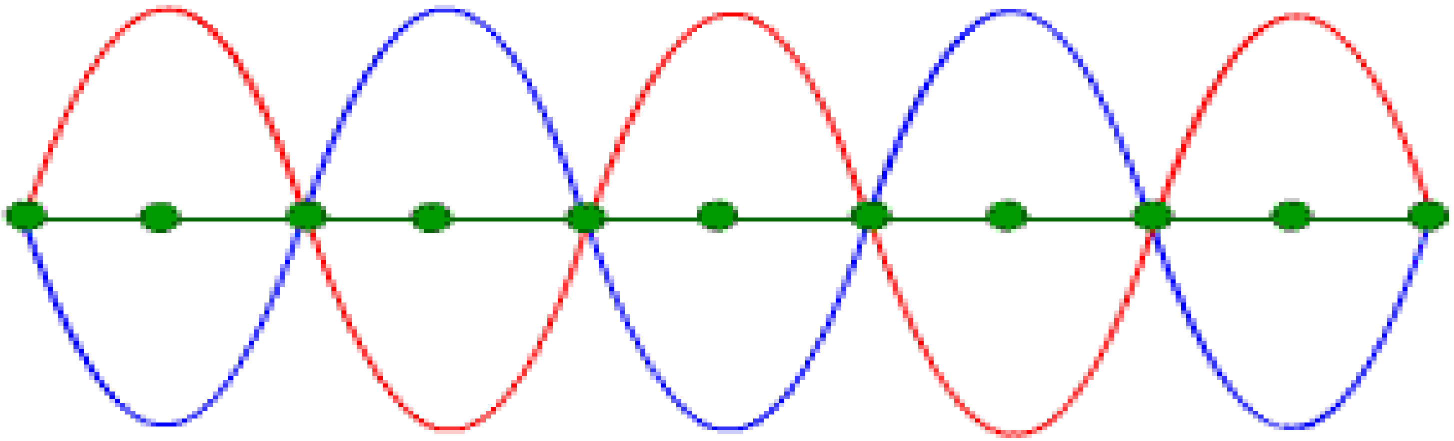
One pure sound a fraction of a second after the next

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

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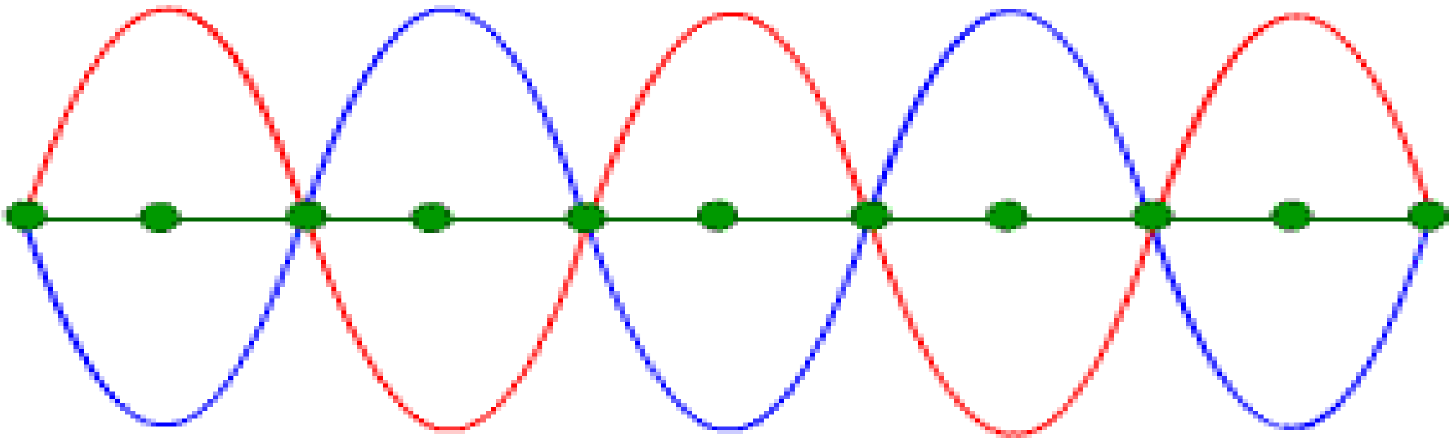
If the two sounds are perfectly out of phase….there would be no sound



Sum of waves equals zero sound

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
- Aircraft
- Heavy equipment

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

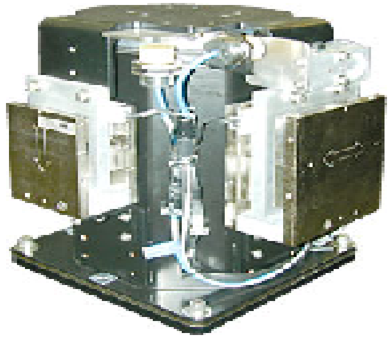
Expanding on the same concept used in noise-cancelling headphones, Toyota has developed a noise cancelling system for its Japanese-market Crown Hybrid that nearly eliminates engine sound within the passenger compartment. The system uses a complex system of microphones, speakers and sensors located around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

Quiet Island®

Sub-Floor Platforms and Supports

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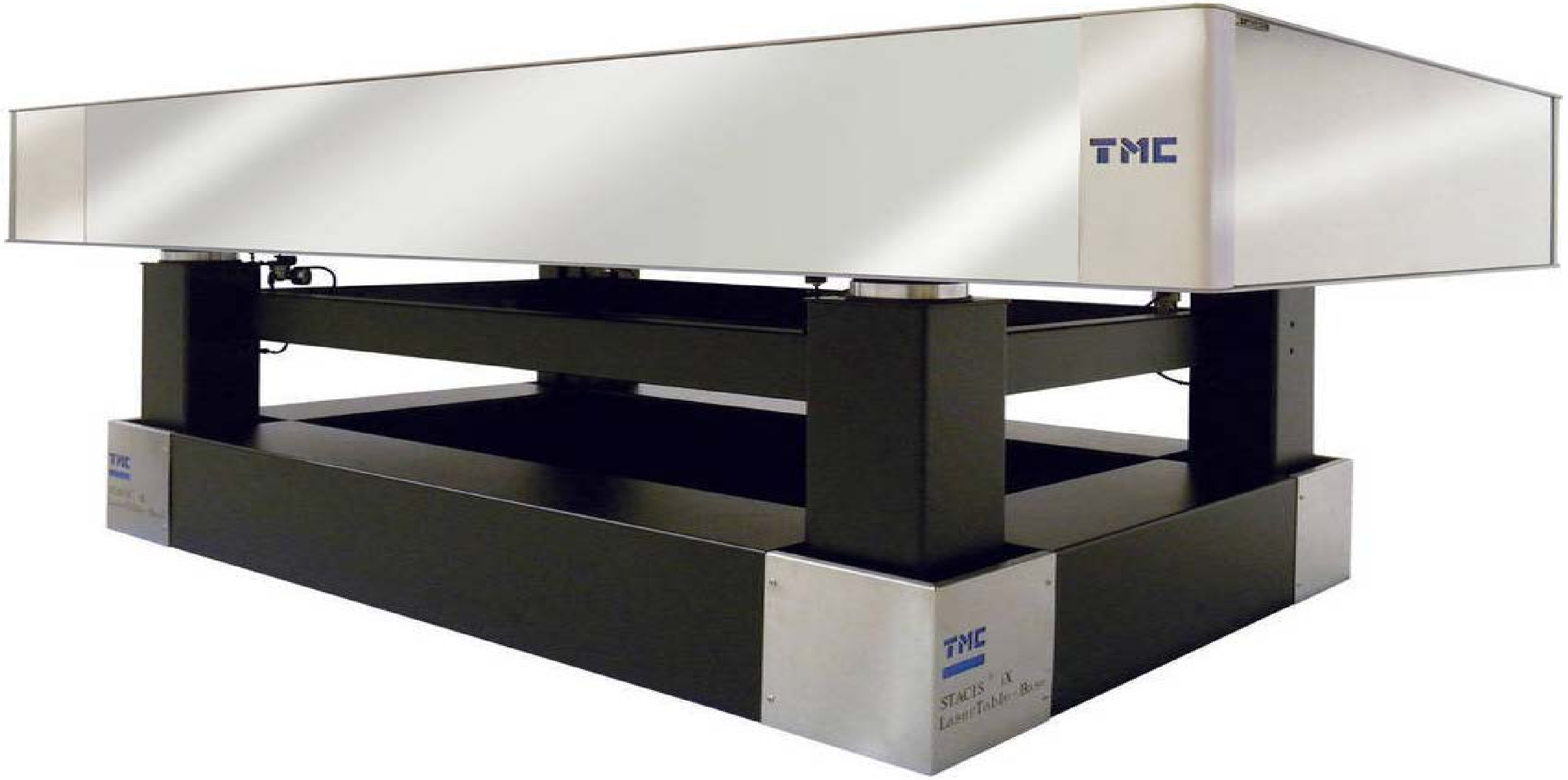

Tables for electron microscopes

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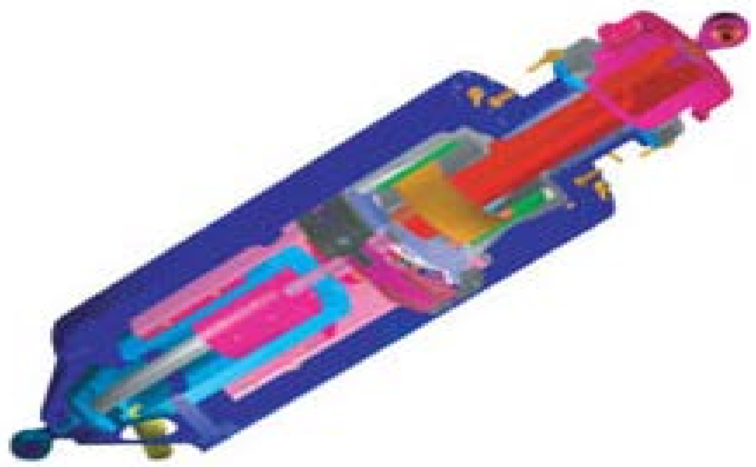
Active Vibration Cancellation

- 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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Signature Analysis Basics

- Similarities
  - All require seismogram from a single hole
  - Waveform is digitized
  - Wave is used over and over to simulate multiple hole shots
  - Delays simulated by time lagging waves on x axis
  - Waves are summed to represent delayed multiple hole shots
- ALL require use of electronic detonators to be effective

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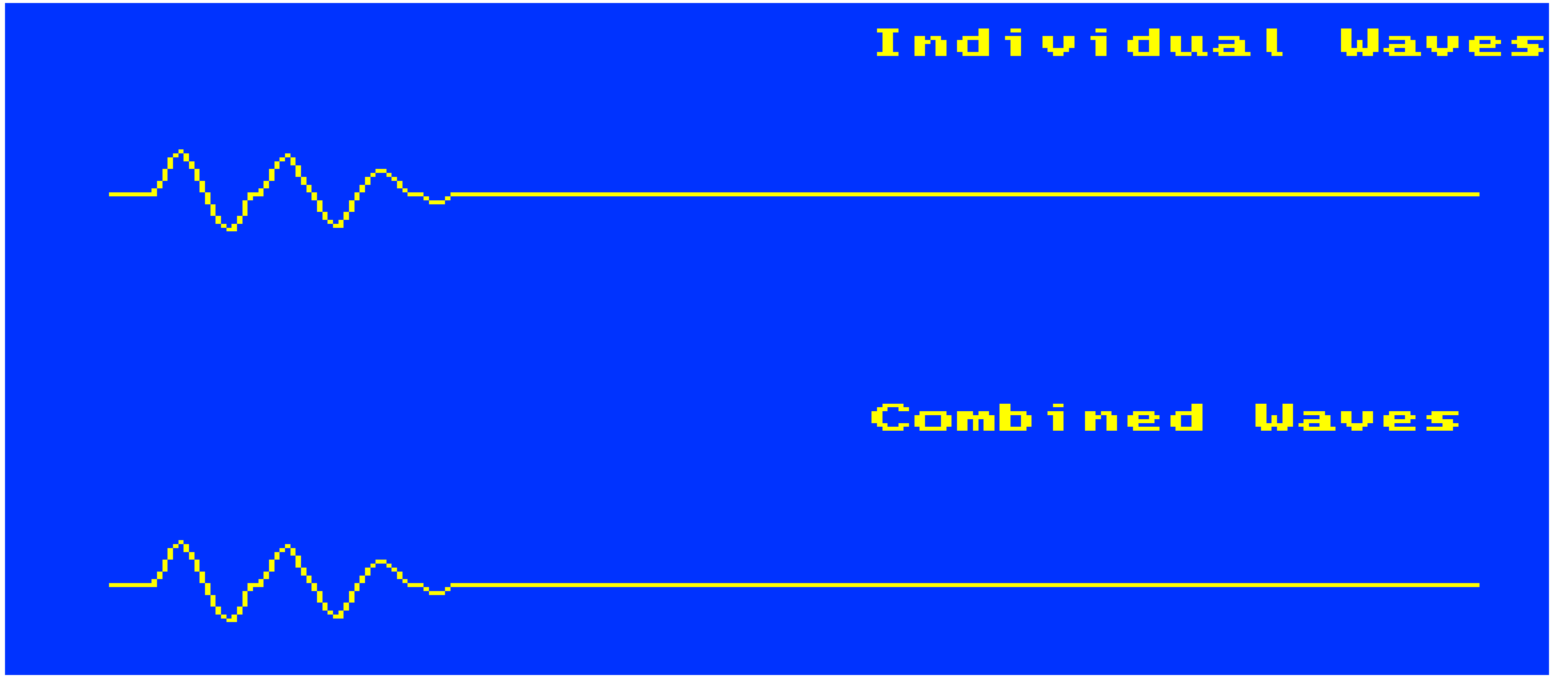
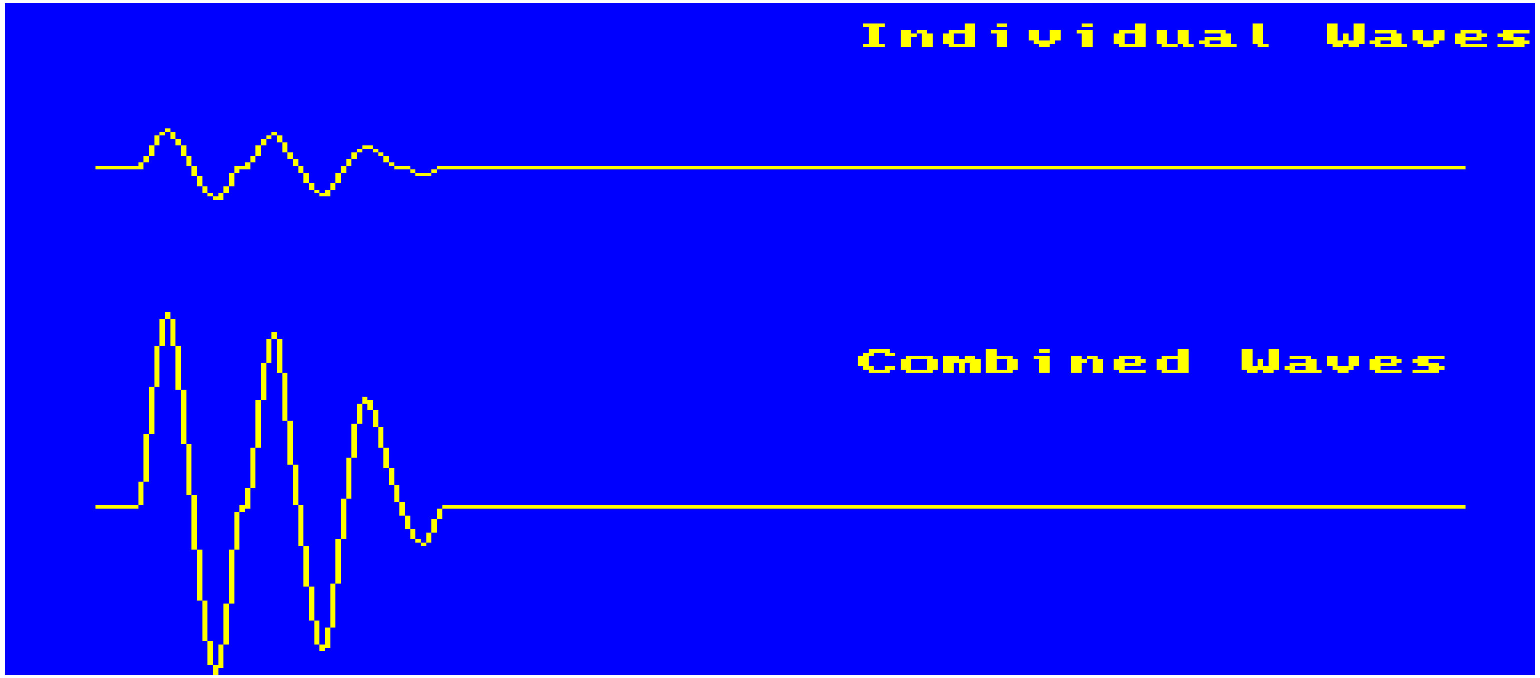
Linear Superpositioning

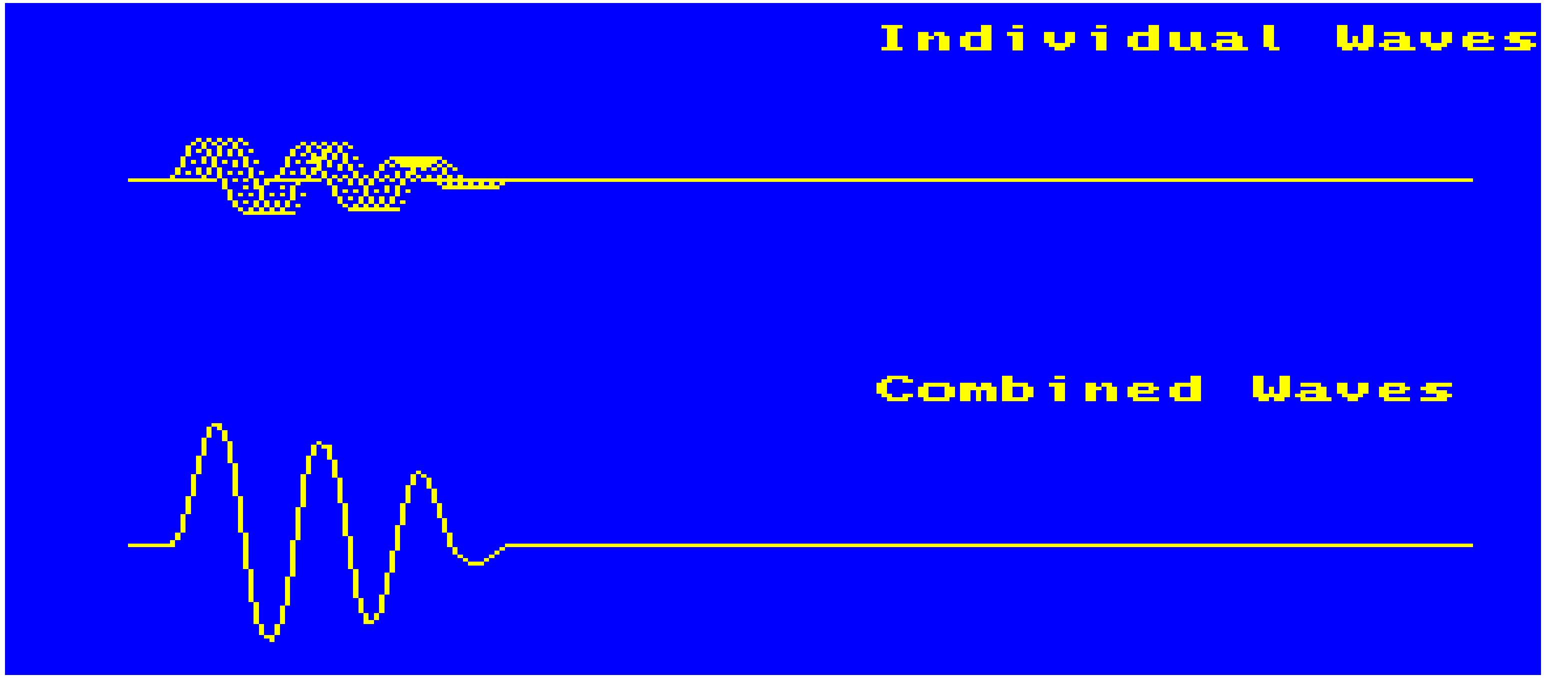


Linear Superpositioning



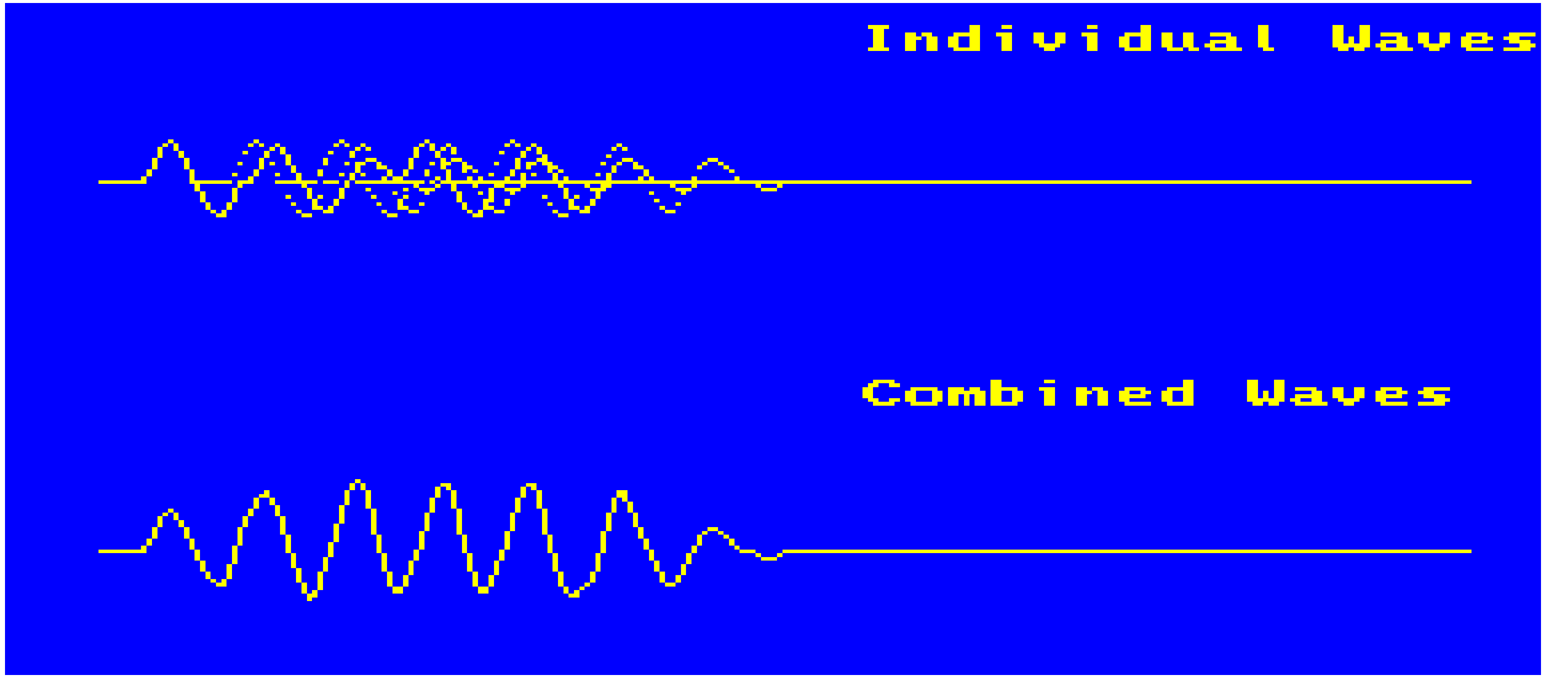
No delay

Linear Superpositioning



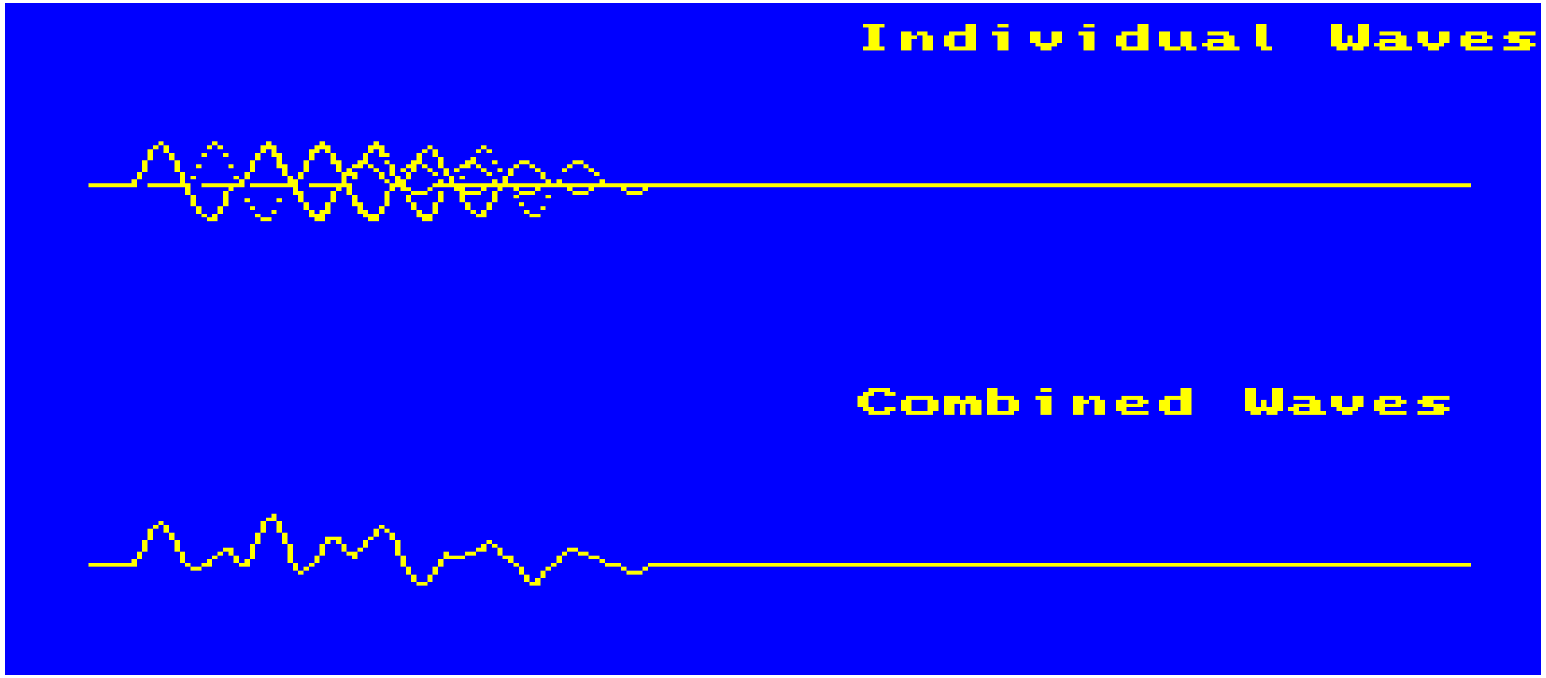
8 ms delay

Linear Superpositioning



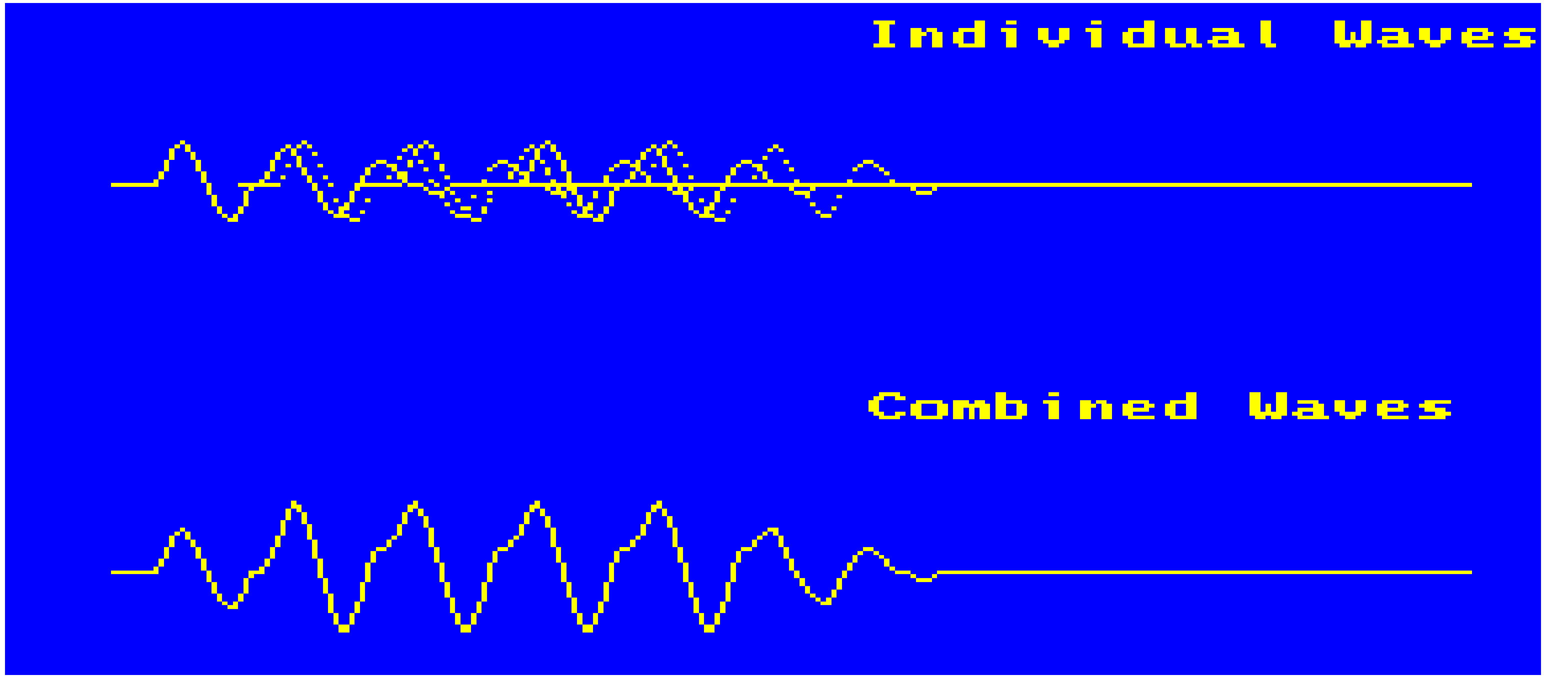
67 ms delay

Linear Superpositioning



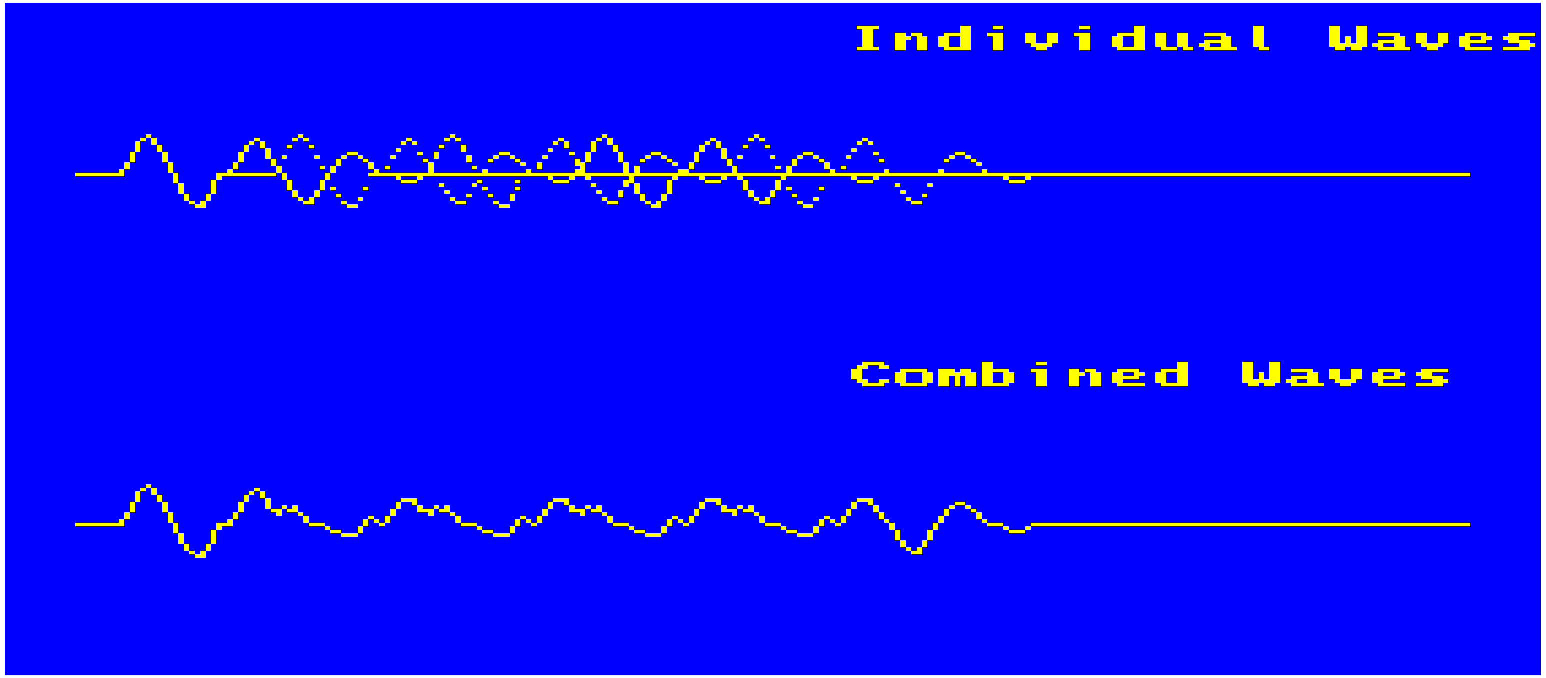
42 ms delay

Linear Superpositioning



92 ms delay

Linear Superpositioning



115 ms delay

Differences Between Programs

- Number of seismograms used
- Generic signature wave from production blast
- Shot design metrics
  - Simple shots (holes and rows)
  - More complex designs rows, number of holes per row
  - Added complexity
    - Import precise hole locations (GPS)
    - Import seismograph locations (GPS)
    - Import hole loading metrics
    - Import rock properties
    - Import p-wave velocity
    - Utilize multiple signature holes
    - Utilize existing production shot data

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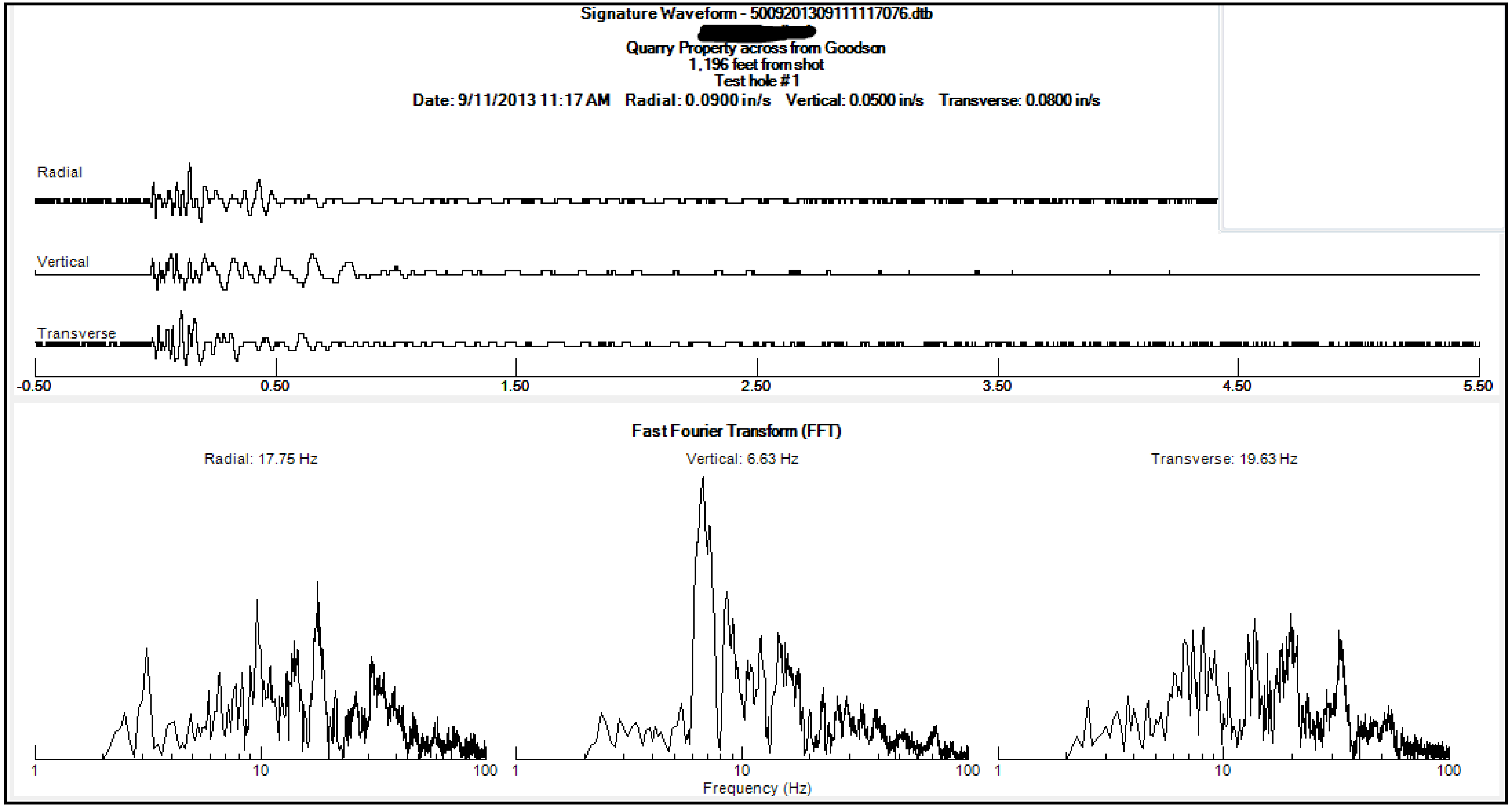
Simple Linear Superpositioning



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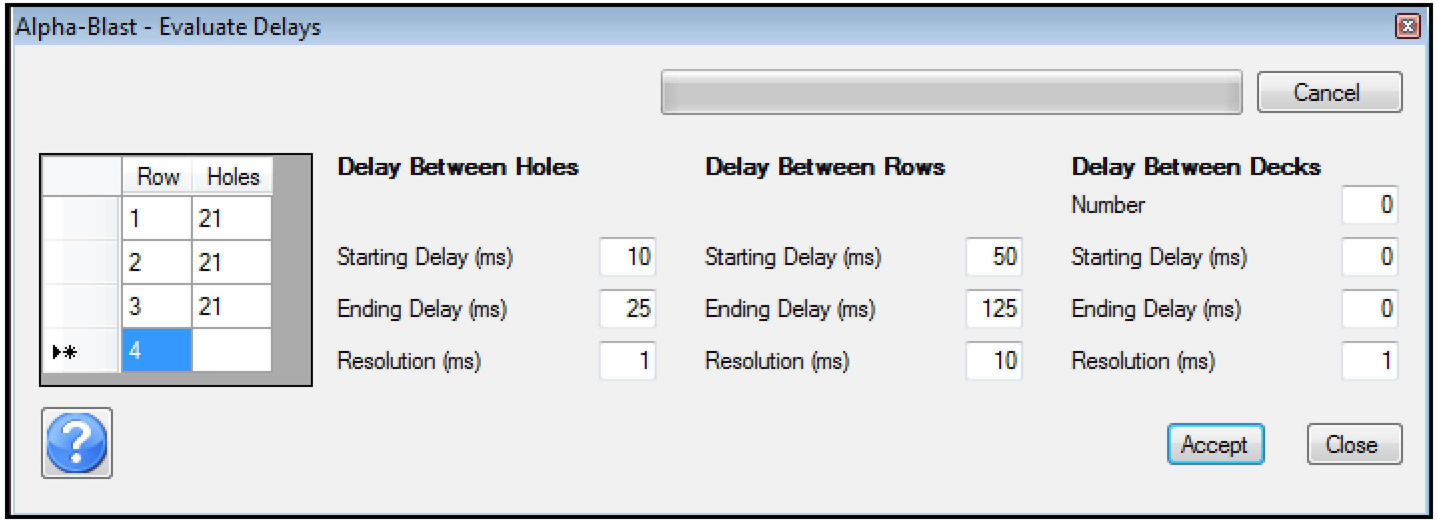
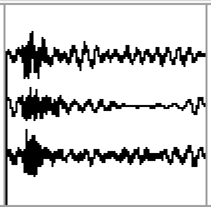
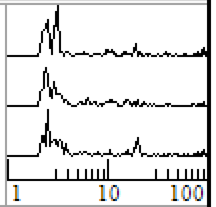
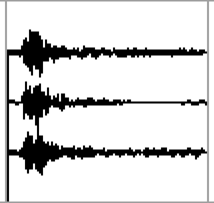
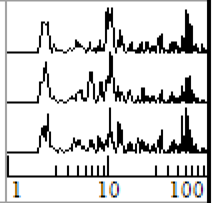
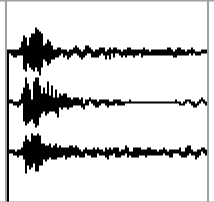
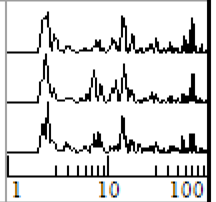
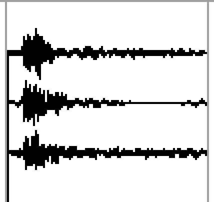
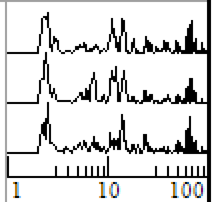
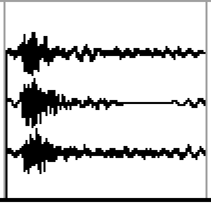
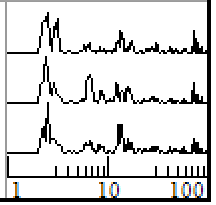
Simple Linear Superpositioning



Simple Linear Superpositioning

Hole	Row	Deck	Charges	Peak	Radial	Vertical	Transverse	Graphs	RHz	VHz	THz	FFT
11	50	0	3	0.239	0.225	0.181	0.239		3.00	2.25	2.38	
16	90	0	2	0.248	0.246	0.226	0.248		10.75	10.38	61.38	
15	70	0	2	0.252	0.238	0.252	0.196		2.38	2.25	2.38	
15	80	0	2	0.254	0.254	0.227	0.222		2.38	2.25	2.38	
13	70	0	2	0.263	0.225	0.263	0.247		2.38	2.25	2.38	

More Complex

Blast Locations

Location
Bench 1
Bench 2
Bench 3
Bench 4
Bench 5
Bench 6

Seismograph Stations

Station	UTM North	UTM West	Description
5009	3958436.49	536863.77	near Goodson
5010	3958316.48	536898.92	near Hastings
Campbell	3958633.34	536852.33	Campbell
Ferrell	3958022.95	536312.75	Ferrel
Good	3958486.47	536946.35	Goodson
Hastings	3958349.63	536934.62	Hastings
Lindsy	3958885.46	536802.83	Lindsy
Super	3958587.87	536816.44	near Campbell
Vitch	3957882.64	536652.56	Ivy Vitch
Wetmore	3958575.06	535947.27	Wetmore

Update | Preview | Print

Blast Data

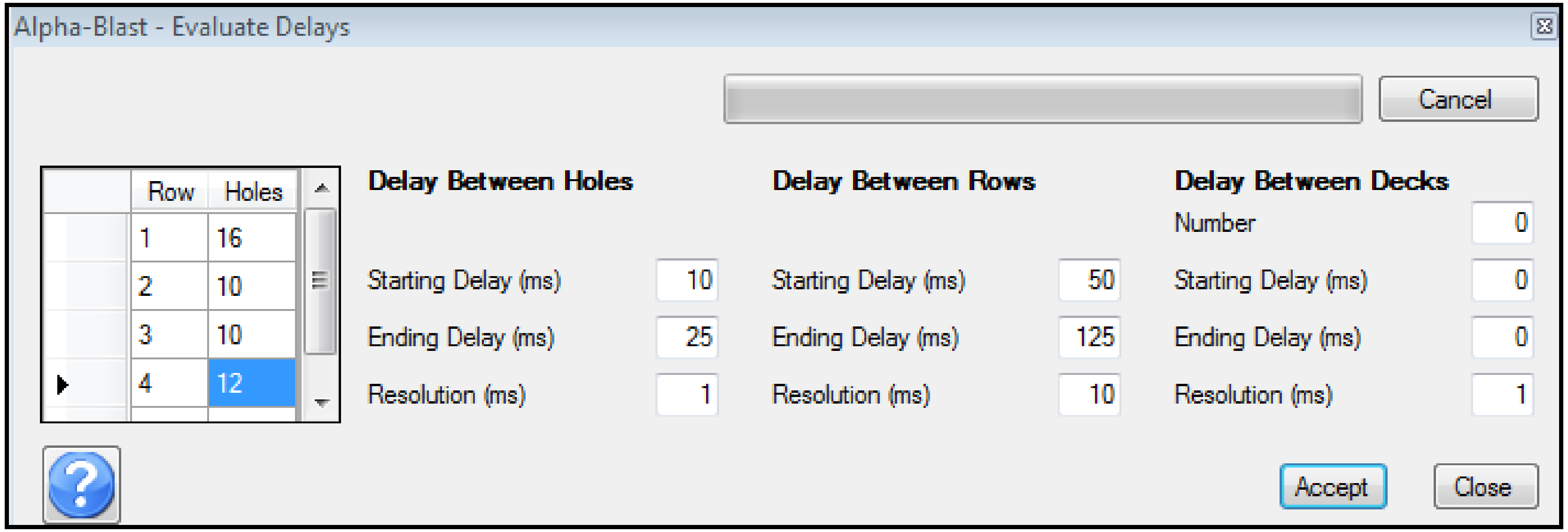
Blast No.	Date/Time	Holes	Total Weight	Charge Weight	Location	Is Signature	UTM North	UTM West
36-12	11/14/2012 12:00 PM	33	15180	460	Bench 2	☐	3958236.6	536572.51
37-12	11/28/2012 12:00 PM	85	8276	97.3	Bench 4	☐	3958468.43	536309.42
1	1/9/2013 12:00 PM	35	19304	551.5	Bench 2	☐	3958303.33	536617.43
2	1/21/2013 12:00 PM	73	12089	165.6	Bench 3	☐	3958446.4	536345.66
6	2/15/2013 12:00 PM	21	11059	526.6	Bench 2	☐	3958292.28	536626.51
8	2/19/2013 12:00 PM	1	412	412	Bench 2	☑	3958403.37	536671.25
10	3/5/2013 12:00 PM	25	9964	398.6	Bench 3	☐	3958280.85	536545.21
11	3/5/2013 12:00 PM	23	7192	312.7	Bench 1	☐	3958425.56	536671.16
13	3/20/2013 12:00 PM	14	7250	517.9	Bench 2	☐	3958258.93	536608.57
14	3/27/2013 12:00 PM	26	10060	386.9	Bench 3	☐	3958336.42	536572.1

More Complex

	Blast No.	DateTime
	36-12	11/14/2012 12:00 PM
	37-12	11/28/2012 12:00 PM
	1	1/9/2013 12:00 PM
	2	1/21/2013 12:00 PM
	6	2/15/2013 12:00 PM
	10	3/5/2013 12:00 PM
	11	3/5/2013 12:00 PM
	13	3/20/2013 12:00 PM
	14	3/27/2013 12:00 PM
	19	5/3/2013 12:00 PM
	20	5/14/2013 12:00 PM
	21	5/28/2013 12:00 PM
	24	6/11/2013 12:00 PM
	25	6/20/2013 12:00 PM
	26	7/12/2013 12:00 PM
	28	8/6/2013 12:00 PM
	29	8/6/2013 1:00 PM
	30	8/8/2013 12:00 PM
	31	8/20/2013 12:00 PM
	32	8/28/2013 12:00 PM
	33	9/4/2013 12:00 PM
	36	9/11/2013 12:59 PM
	37	9/18/2013 12:00 PM
▶	38	9/27/2013 12:00 PM

	Station	Distance	Ds	Radial	Vertical	Transverse	Acoustic	Radial Hz	Vertical Hz	Transverse Hz
▶	Campbell	1158	64.9	0.195	0.17	0.21	116	39.0	34.0	39
	Good	1089	61.1	0.101	0.134	0.125	114	27.0	34.0	27
	Hastings	951	53.3	0.146	0.116	0.0857	118	37.0	30.0	19
	Vitch	1525	85.5	0.046	0.028	0.044	121	27.0	49.0	24
*										

More Complex



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More Complex

Hole	Row	Deck	Charges	Peak	Radial	Vertical	Transverse	RHz	VHz	THz
15	80	0	2	0.298	0.229	0.298	0.257	2.25	6.25	2.00
11	50	0	4	0.311	0.291	0.253	0.311	2.25	2.00	2.00
20	50	0	2	0.311	0.311	0.307	0.286	2.25	2.00	2.00
17	80	0	3	0.314	0.283	0.314	0.277	60.75	2.00	2.00
17	90	0	2	0.316	0.269	0.226	0.316	9.50	2.00	56.25
11	110	0	2	0.321	0.27	0.321	0.264	9.50	7.00	6.75
13	70	0	2	0.327	0.291	0.327	0.256	2.25	6.50	2.00
22	60	0	2	0.328	0.246	0.27	0.328	2.25	2.00	2.00
16	70	0	3	0.329	0.308	0.282	0.329	2.25	6.50	2.00
22	120	0	2	0.33	0.323	0.33	0.31	42.50	7.00	6.75
13	60	0	3	0.332	0.302	0.332	0.326	2.25	6.50	2.00
21	80	0	2	0.333	0.309	0.311	0.333	48.75	6.50	49.25
22	100	0	2	0.335	0.335	0.304	0.29	9.75	6.25	46.50
16	60	0	2	0.337	0.295	0.337	0.328	2.25	6.50	2.00
11	60	0	3	0.342	0.342	0.306	0.287	2.25	2.00	2.00
17	60	0	2	0.342	0.255	0.269	0.342	2.25	6.50	2.00
22	80	0	2	0.345	0.337	0.266	0.345	39.00	6.50	45.50
21	90	0	2	0.346	0.289	0.242	0.346	48.00	6.50	45.50
18	80	0	2	0.348	0.289	0.206	0.348	2.25	2.00	54.25
23	100	0	2	0.353	0.353	0.307	0.319	41.00	40.75	44.00
10	50	0	3	0.354	0.274	0.354	0.278	2.25	2.00	2.00
11	100	0	2	0.356	0.356	0.298	0.323	89.50	7.25	8.00
14	120	0	2	0.356	0.356	0.35	0.296	75.00	6.50	6.50
10	100	0	2	0.358	0.205	0.358	0.25	9.50	7.25	8.00

Advanced Techniques

- Have not hit mainstream industry
- Testing new concepts
- ALL require use of electronic initiators

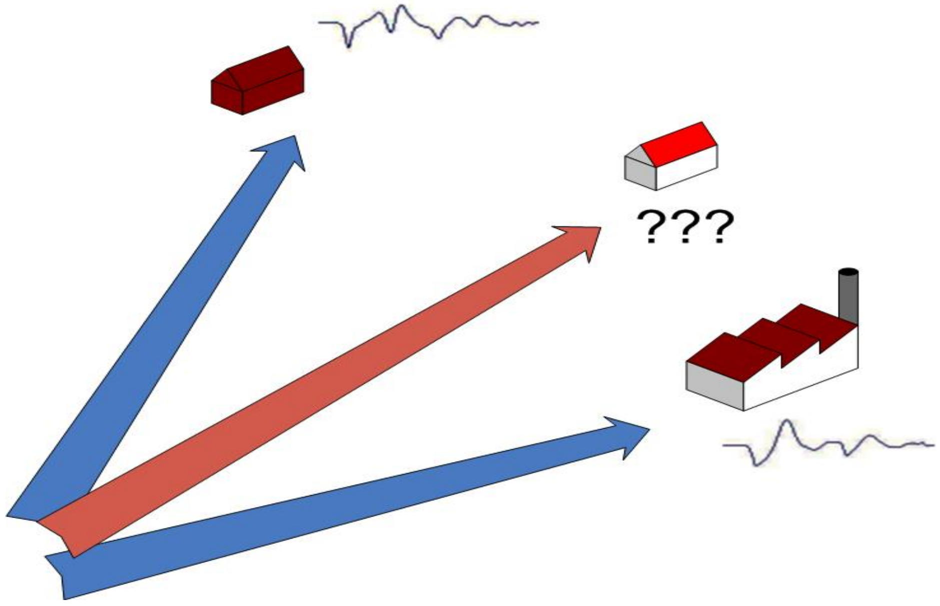
QUARRY ACADEMY

Multiple Seed Waveform

- Multiple Seed Wave (MSW)
  - Extension of Standard Method
- Can’t Measure Everywhere
  - Establish Local Variability
  - Interpolate Between Measured Sites
- Some Locations Are Shielded
  - By Broken Rock
  - By Open Face
  - Develop Local Shielding Parameters

Multiple Seed Waveform

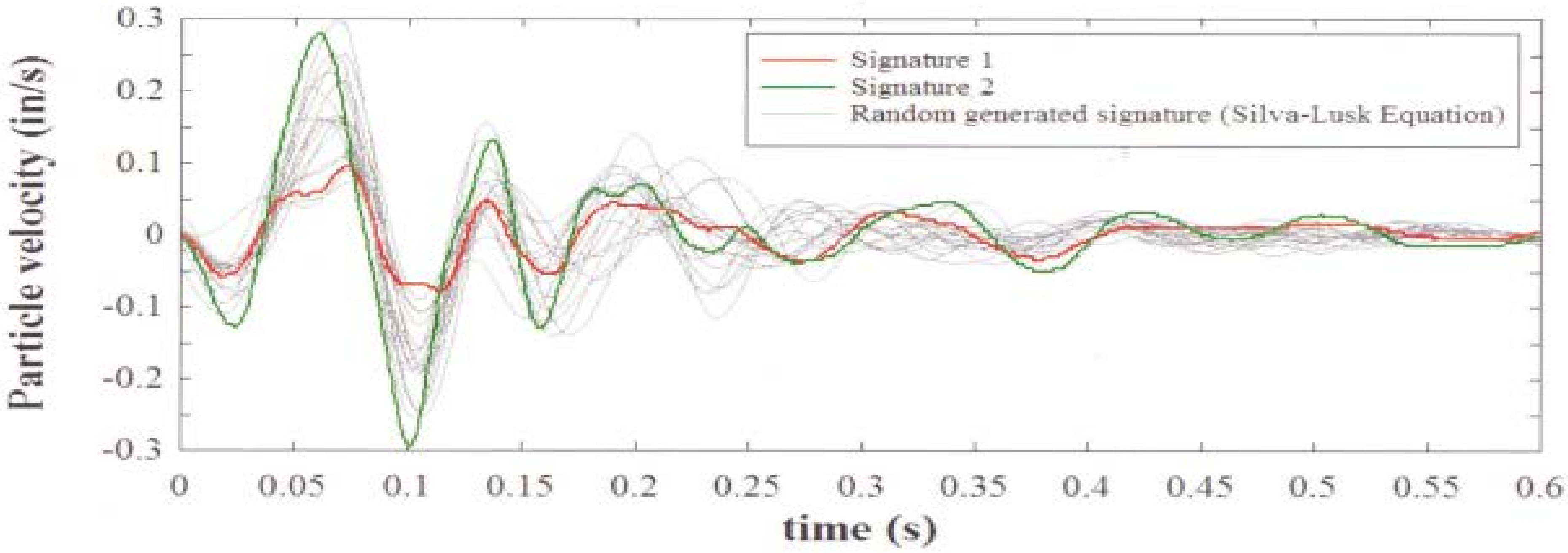
- Waveforms for Measured Sites
  - Existing Single-hole Data
- New Location Becomes Critical
  - Complaints
  - New Construction
- Technique Resolves Problem
  - Use Existing Data
  - “Average” the Waveforms
  - No Need for Additional Holes



QUARRY ACADEMY

Silva – Lusk Method

- Variation Between Signatures
- “Monte Carlo” Technique
  - Random Signatures
  - Fit to Existing Signatures



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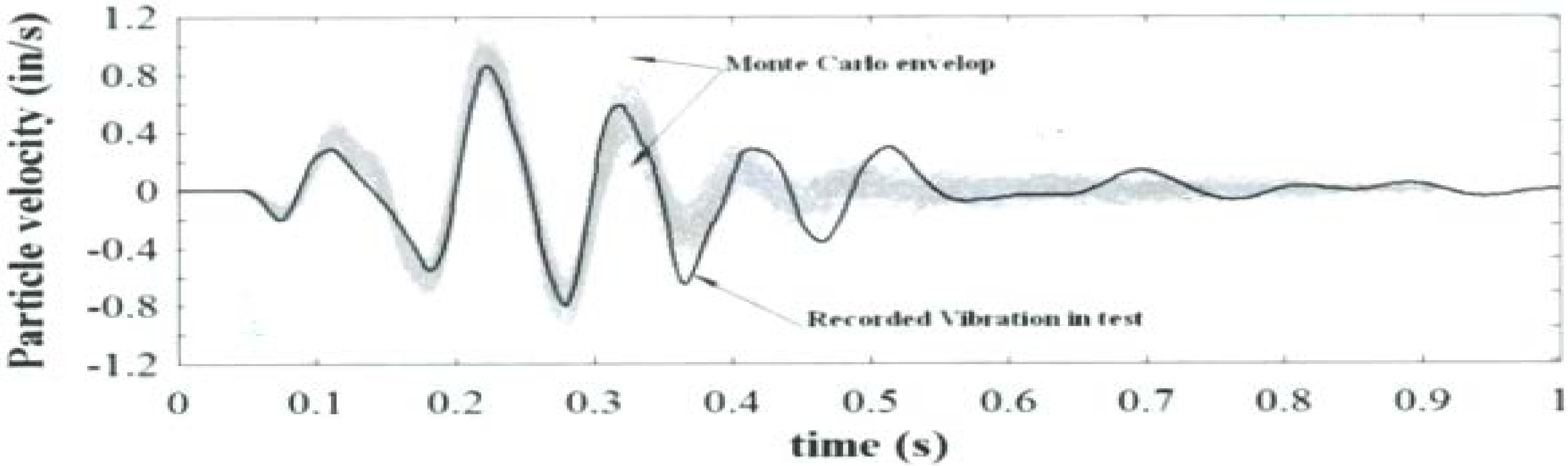
Silva – Lusk Method



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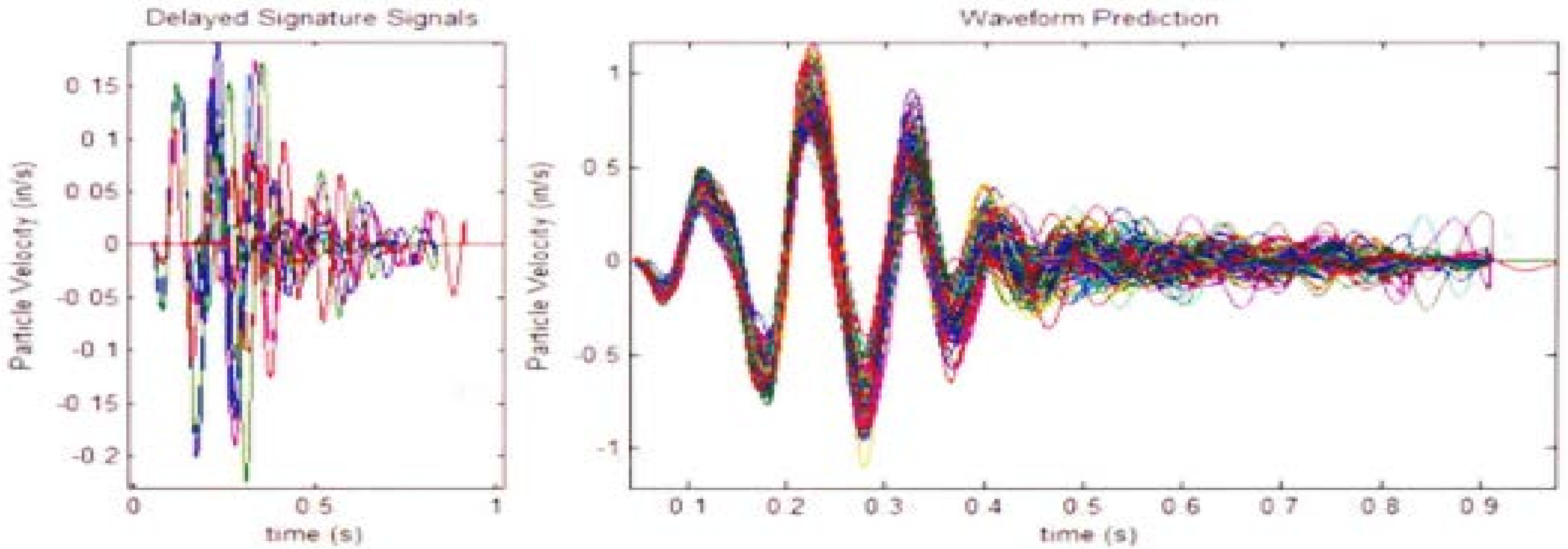
Silva – Lusk Method

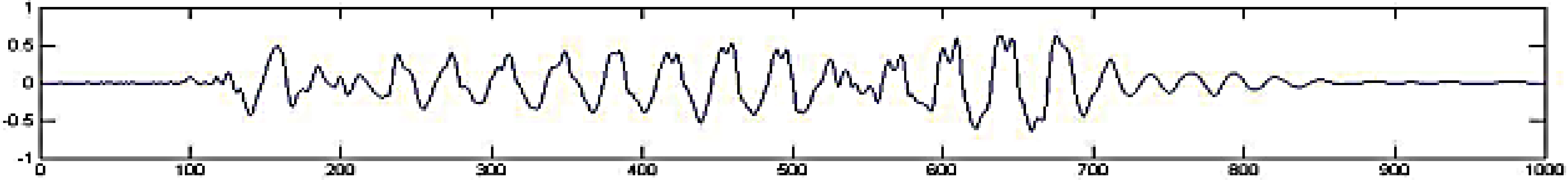
- Use an Array of Randomized Signatures
- Find out the Bounds of Vibration
  - What is the "Worst" you might get?



QUARRY ACADEMY

Wavelet Transform

- Analyzing Blast Performance from Seismograph Data
- Use Existing Compliance Records
- Perform “Wavelet Transform”
- Shows Details of Shot Performance
  - “Buried” in Complex Waveform



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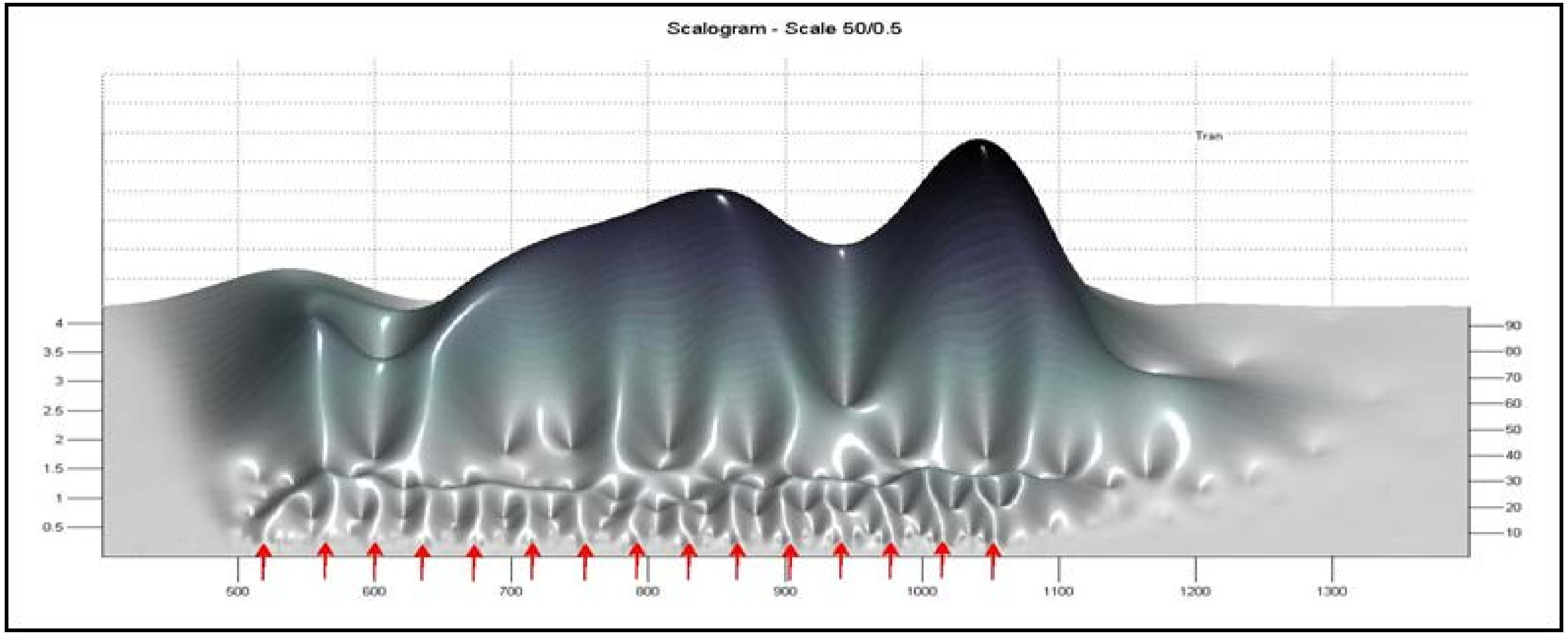
Wavelet Transform

- Wavelet Transform
- High Peaks in Background Due to Geology
- Low Peaks in Foreground Due to Detonations
  - Hole Firings Marked by Arrows!



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