PSEUDO VELOCITY SHOCK ANALYSIS
Conclusions and Final Comments

Mechanical Shock Test Techniques and Data Analysis

SAVIAC

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Points to Learn

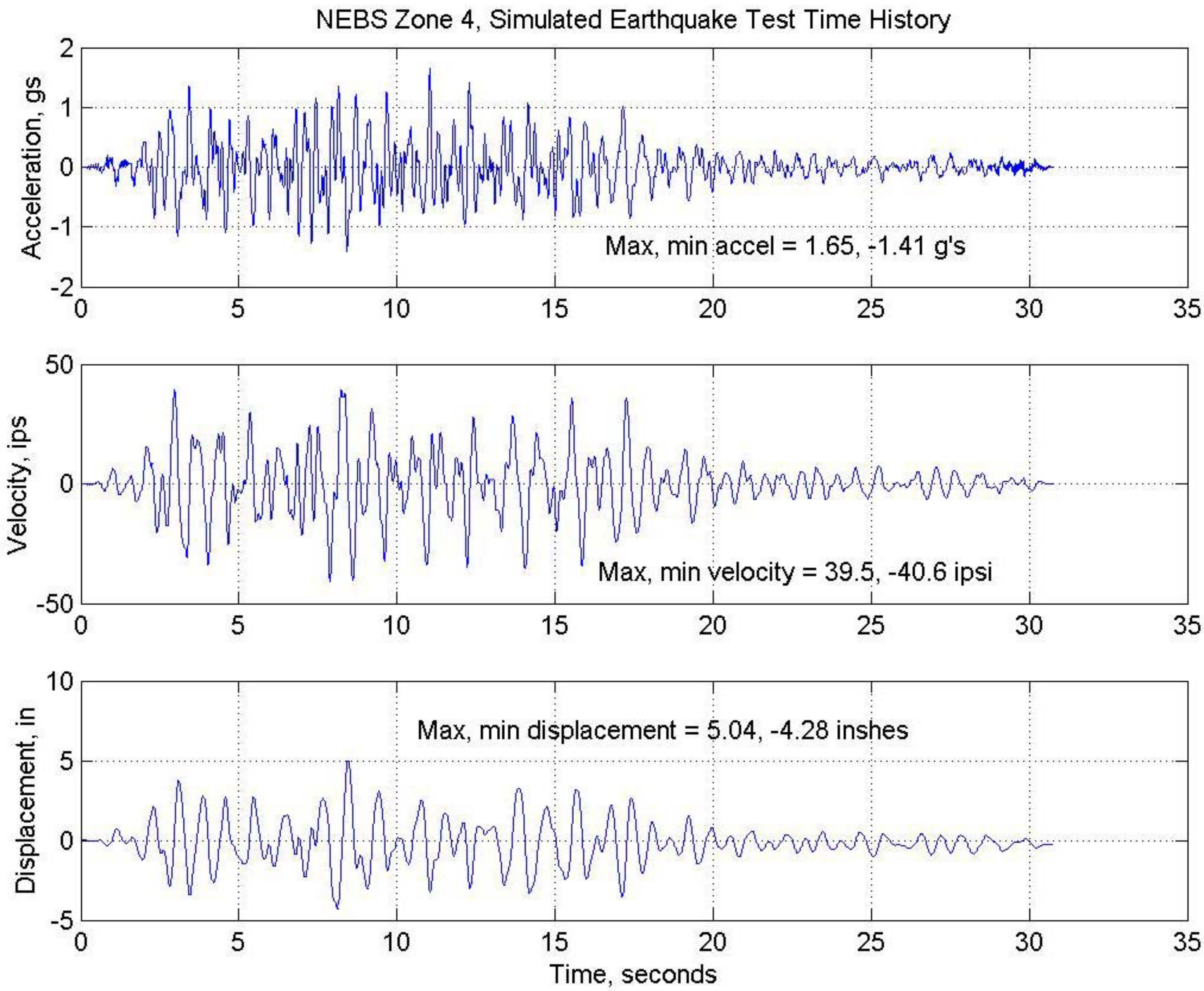
- Shock spectrum definitions
- Calculate; Do loop, Filter, Residual
- Plotting SS's with PV as ordinate on (4CP) log-log four coordinate paper.
- Proofs that stress is proportional to velocity for rods, beams, plates.
- $(PV)^2$,energy, severe frequencies.
- PVSS on 4CP asymptotes: peak displ, severity or vel change, and peak accel.
- PV vs Rel Vel, low freq. problem.
- Integrate to velocity and displacement
- Half sine example. Compare to explosive and EQ
- Shaker shock: wimpy..
- Applies to multi degree of freedom
- Shock Isolation
- Damping. Precludes multicycle build.
- Damping for polarity: pos & neg spectra.
- Mean removal and detrending. Editing
- Collision and Kickoff shocks
- Filtering plateau cut off

Facts

- Structure shock response is analyzed in modes at f_n's.
- Max modal velocity proven proportional max modal stress.
- High stress causes failures.
- Maximum stress limits allowable modal velocity.
- PVSS shows potential modal velocity, hence potential Stress !
- High PVSS shows freqs where shock can cause high stress.
- 4CP Handiest way to present.

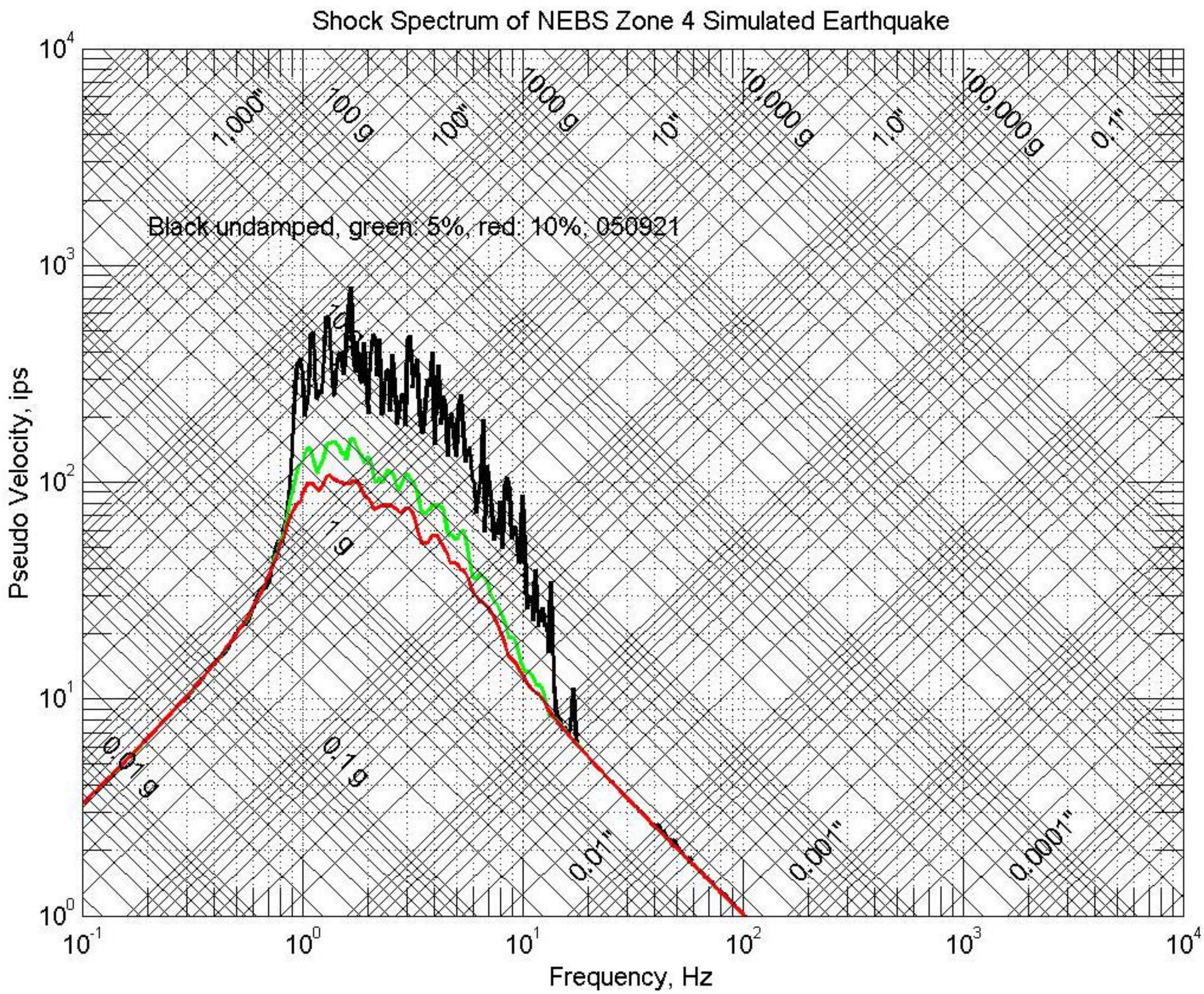
f_n: natural frequency; PV: pseudo velocity; SS: shock spectrum; 4CP four coordinate paper

Broccoli Shock: NEBS Zone 4 Synthesized Earthquake Shock



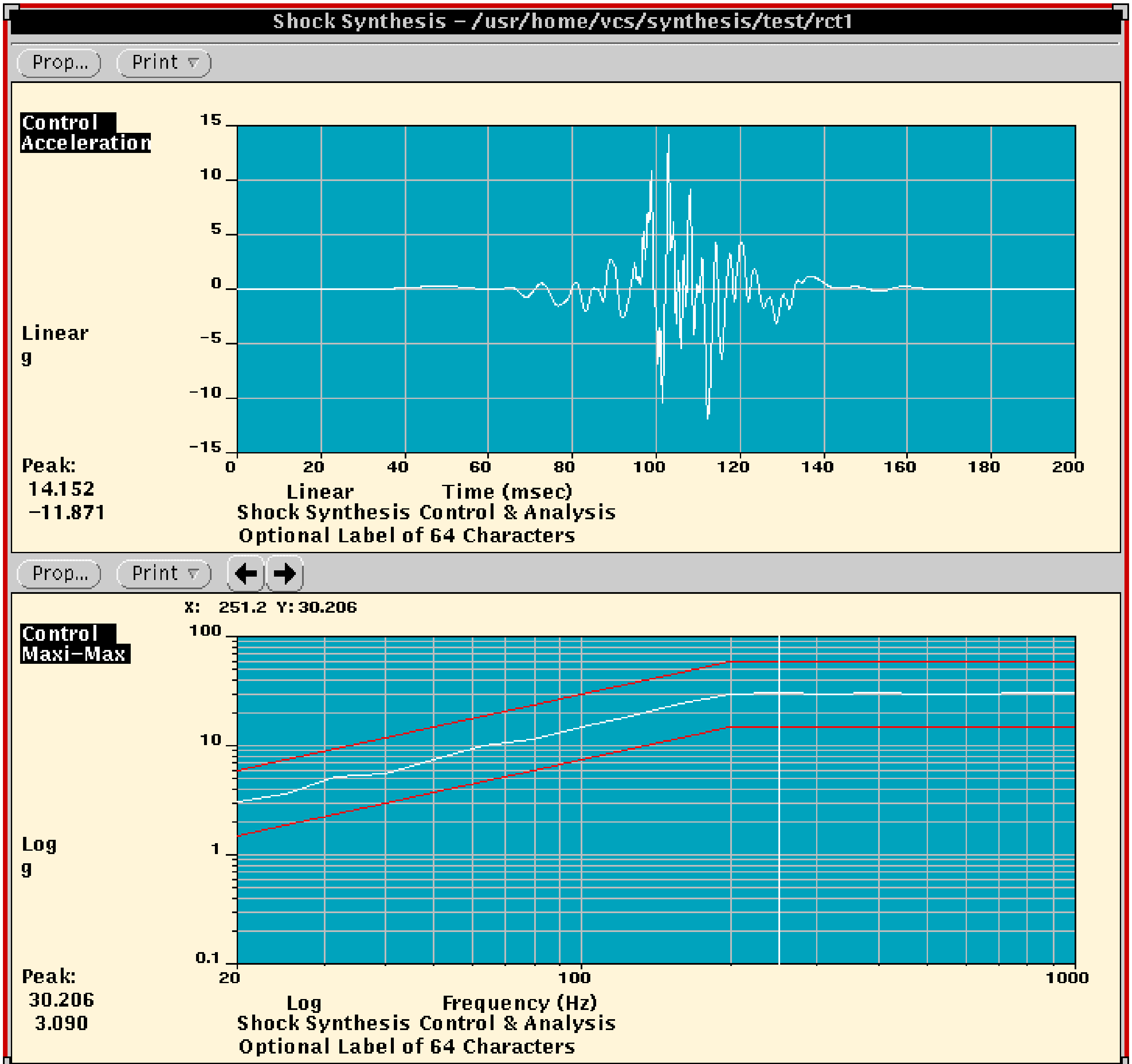
GR63-Core

Broccoli Shock Spectrum



Shaker synthesized time history to achieve this SRS acceleration shock spectrum. Tony Keller: good.

Spectral Dynamics Synthesized Time History for Shaker to Produce Acceleration Shock Spectrum



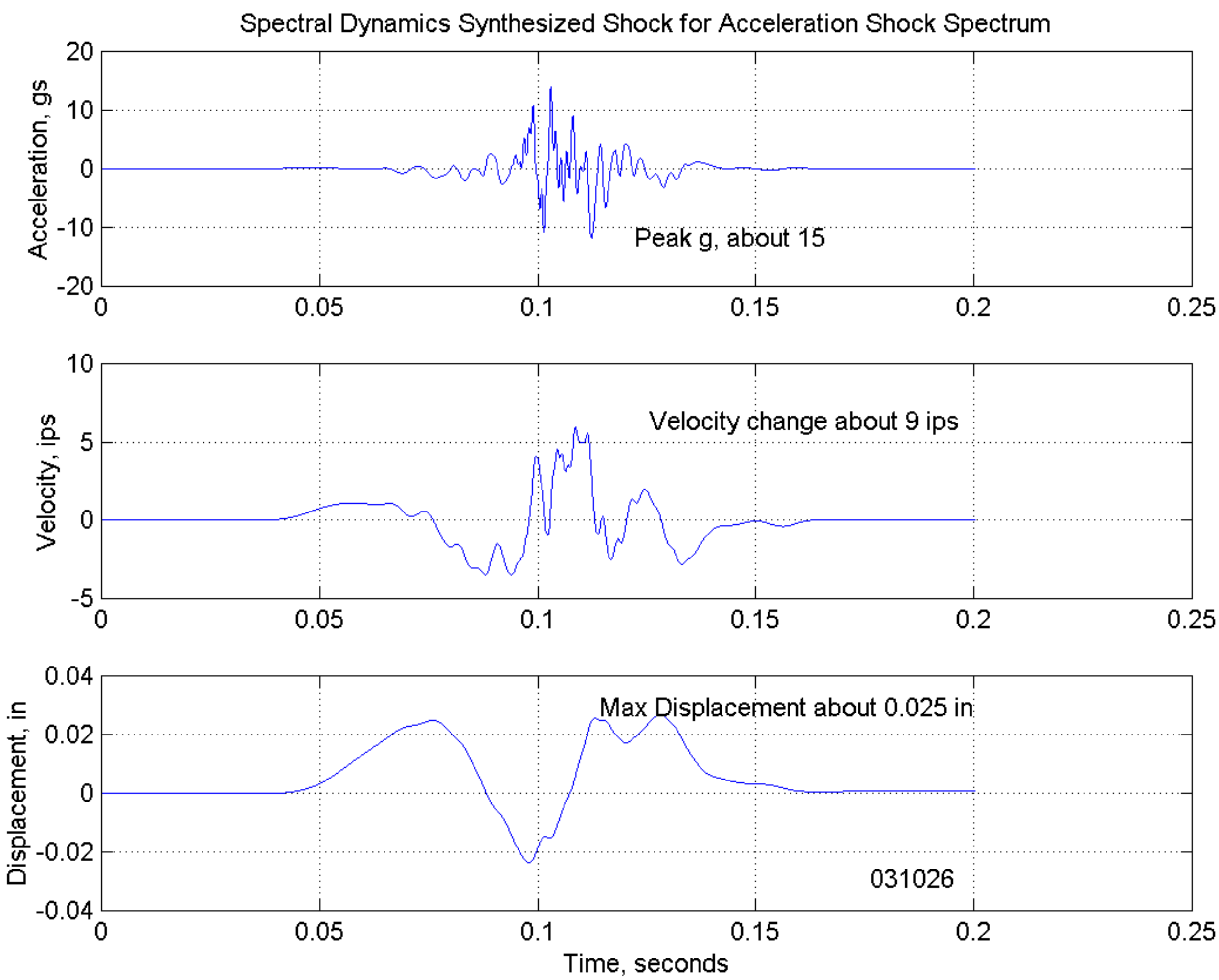
30 g's from 200 to 1000 Hz

Constant velocity from 20 to 200 Hz

Conclude

Integrate synthesized time history and evaluate maxima.

Time history and integrals for shaker shock to produce acceleration time history

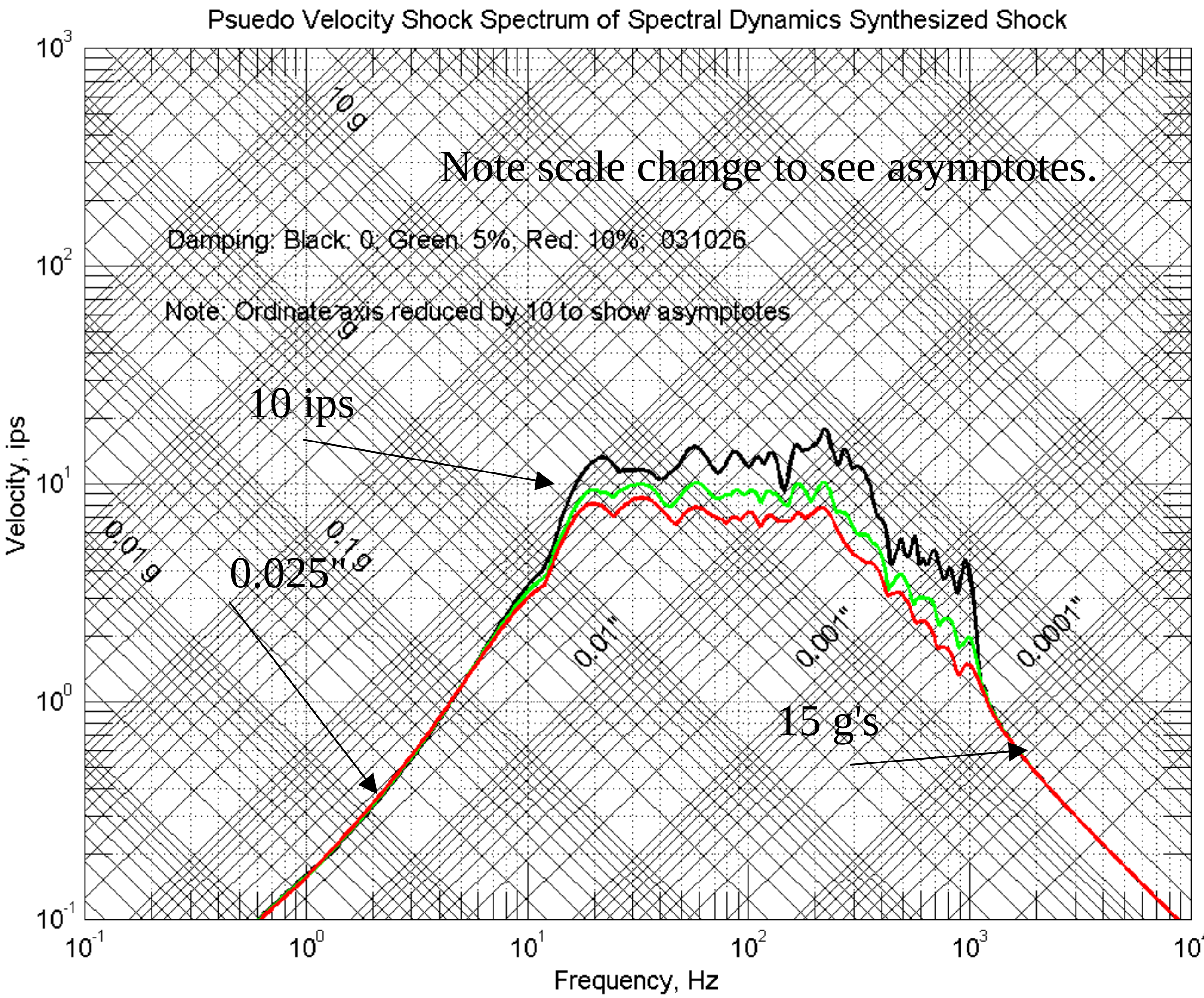


Peak g's, 15; Velocity change: 9 ips
Max displacement: 0.025 in

Conclude

PVSS of Synthesized Shaker time history

PVSS of Spectral Dynamics Synthesized Time History for Shaker to Develop Shock with Specific Acceleration Shock Spectrum



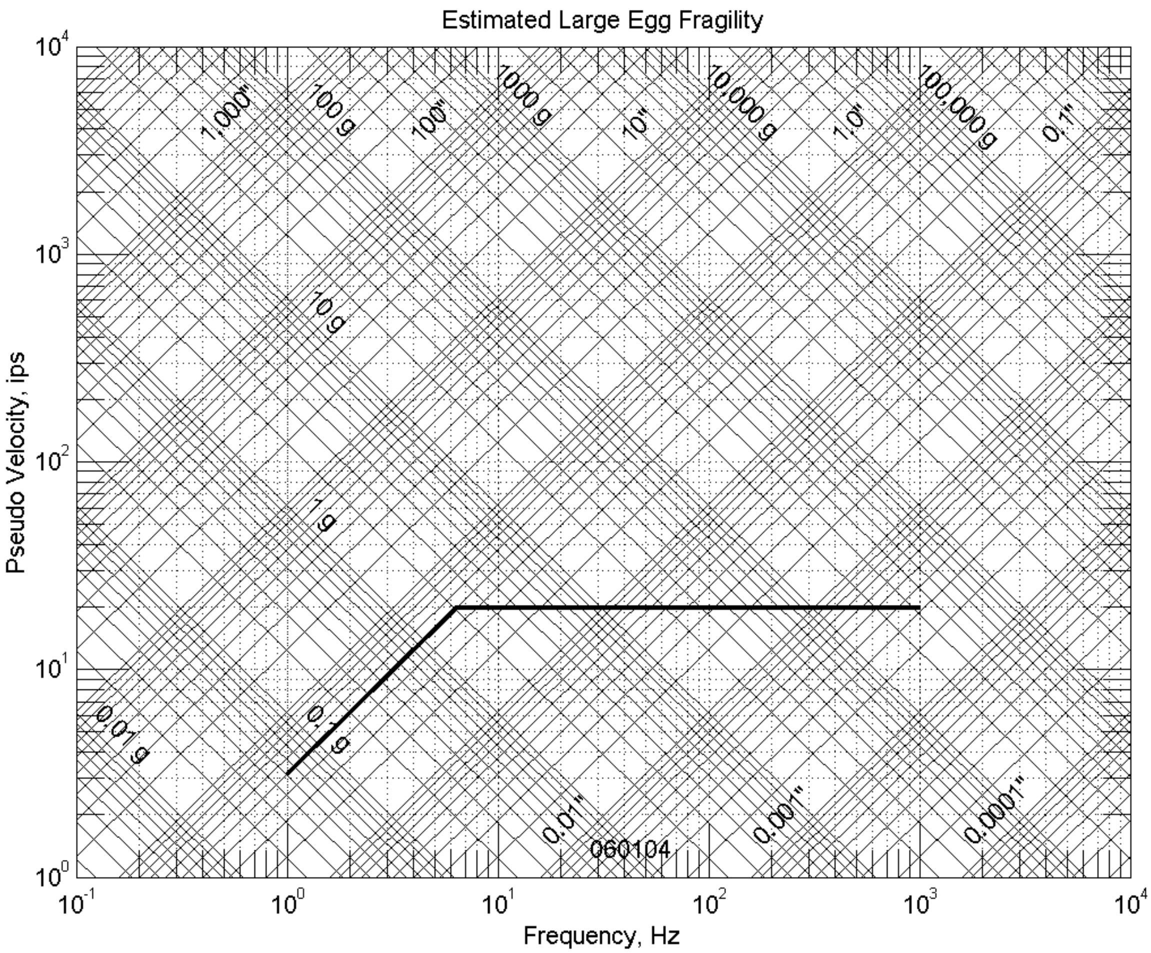
Gets 20 g's nicely at 5% from 200 - 1000 Hz. Get 10 ips nicely at 5% from 20 - 200 Hz . Most severe from 20 to 200 Hz, but 10 ips is just a 1/8 inch drop; not severe.

Drop Two on English

- Egg Dropping
- Need egg data for reference
- Fresh Large Egg from Fridge
- Drop ½ inch, no failure
- Sqrt(2*g*.5) = 19.65 ips
- Drop 1 inch, cracked shell
- Sqrt(2*g*1) = 27.79 ips

EGG FRAGILITY

DROP EGG 1/2 INCH, NO FRACTURE
AT ONE INCH IT BROKE,
v=sqrt(2*g*h)



Conclude

Mil Std 810 F

TABLE 516.5-I. Test shock response spectra for use if measured data are not available.

Test Category	Peak Acceleration (g's)	T_e (ms)	Cross-over Frequency (Hz)
Functional Test for Flight Equipment	20	15-23	45
Functional Test for Ground Equipment	40	15-23	45
Crash Hazard Test for Flight Equipment	40	15-23	45
Crash Hazard Test for Ground Equipment	75	8-13	80

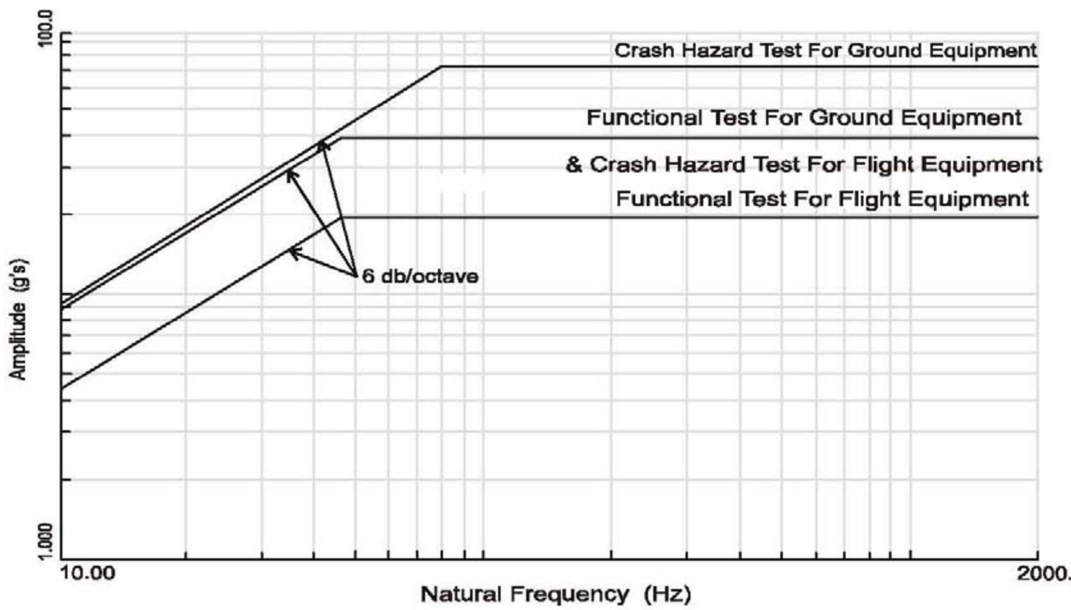


FIGURE 516.5-8. Test SRS for use if measured data are not available (for Procedure I - Functional Shock & Procedure V - Crash Hazard).

Conclude

4CP Equations

$$\omega, (\omega = 2\pi f),$$

$$\dot{z}_{\max} = \omega z_{\max}, \quad \ddot{z}_{\max} = \omega^2 z_{\max}$$

$z_{\max}$

$$\frac{\ddot{z}_{\max}}{\omega} = \omega z_{\max}, \quad \dot{z}_{\max} = \frac{\ddot{z}_{\max}}{\omega}$$

$$\dot{z}^2_{\max} = z_{\max} \ddot{z}_{\max}$$

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MIL-STD-810F
1 January 2000

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$$\dot{z}_{\max} = \frac{\ddot{z}_{\max}}{\omega}$$

Plateau Velocities:

$$v = 20 * 386.1 / (2\pi * 45) = 27.3\ ips$$

$$v = 40 * 386.1 / (2\pi * 45) = 54.6\ ips$$

$$v = 75 * 386.1 / (2\pi * 80) = 57.6\ ips$$

Conclude

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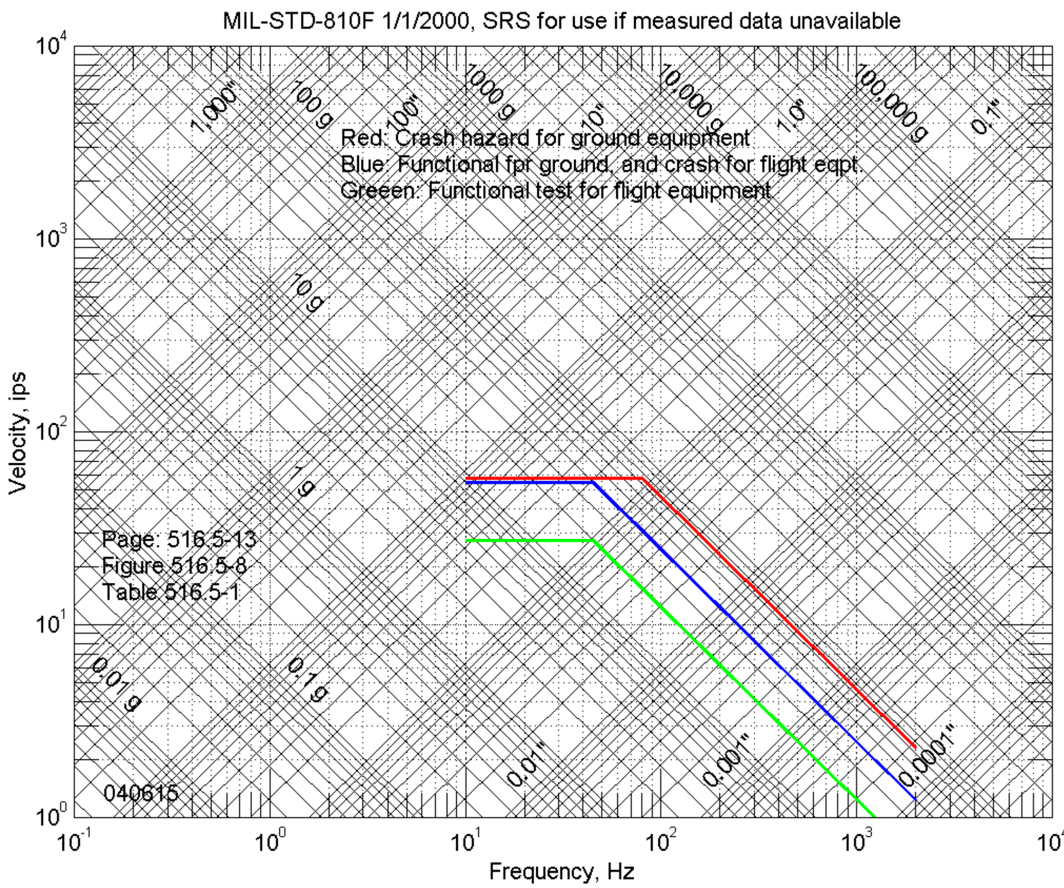
Page 516.5-13, Figure 516.5-8



Low plateau velocities of 27, 55, and 58 ips

Over frequency range from 10 to 45 and 80 Hz

Conclude

Crede's Spectra

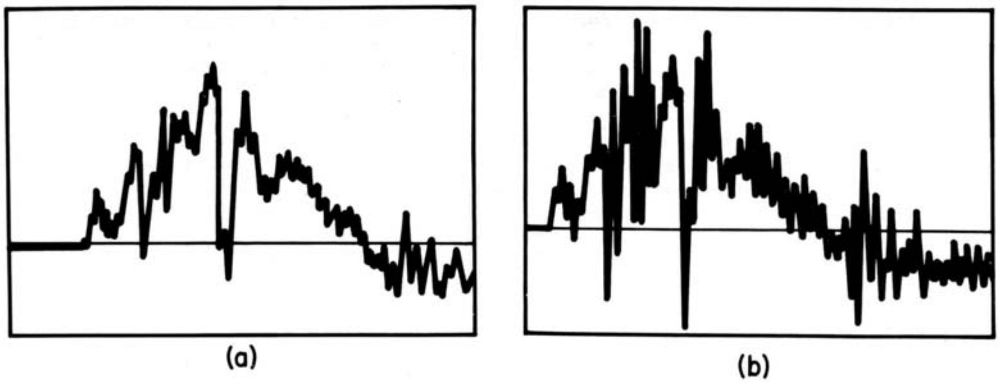


Fig. 7. Time-histories of acceleration: (a) Measured at the center-of-gravity of an aircraft during landing and (b) the resulting response acceleration of a system having a natural frequency of 60 cps and $Q = 10$.

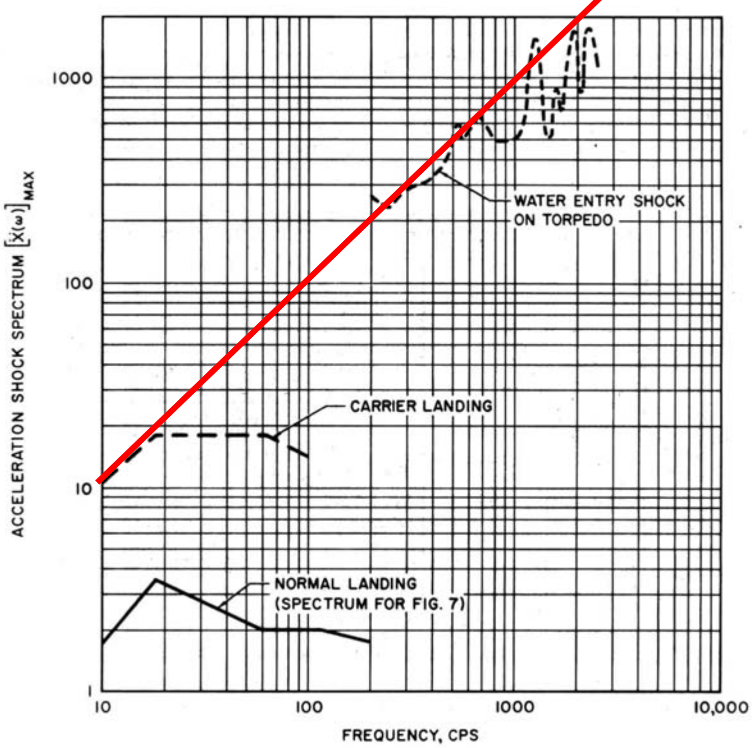


Fig. 8. Typical acceleration shock spectra defining the nature and severity of several service shocks.

40

More Crede

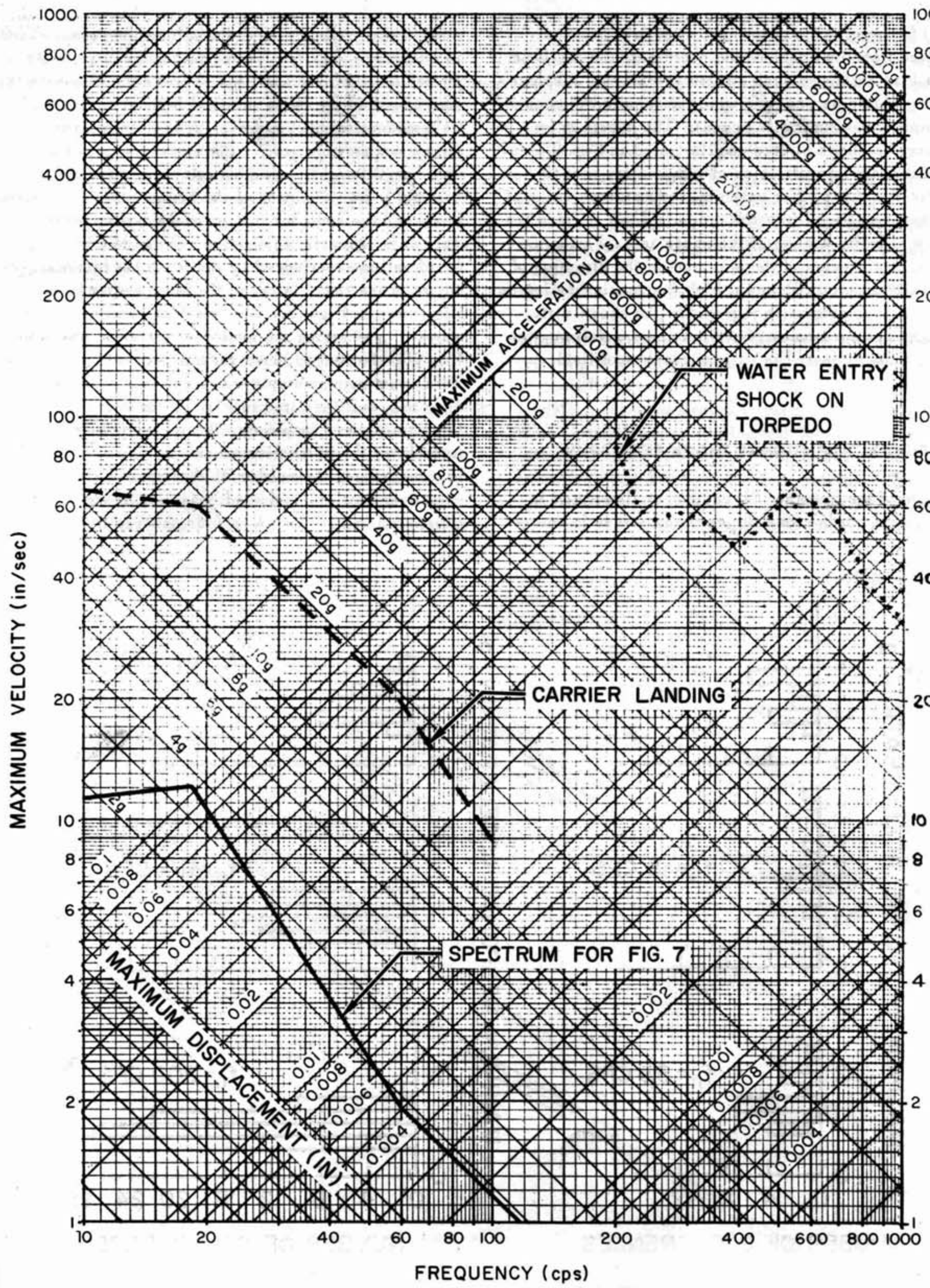


Fig. 9. Spectra of Fig. 8 plotted on four-coordinate paper.

One more Crede

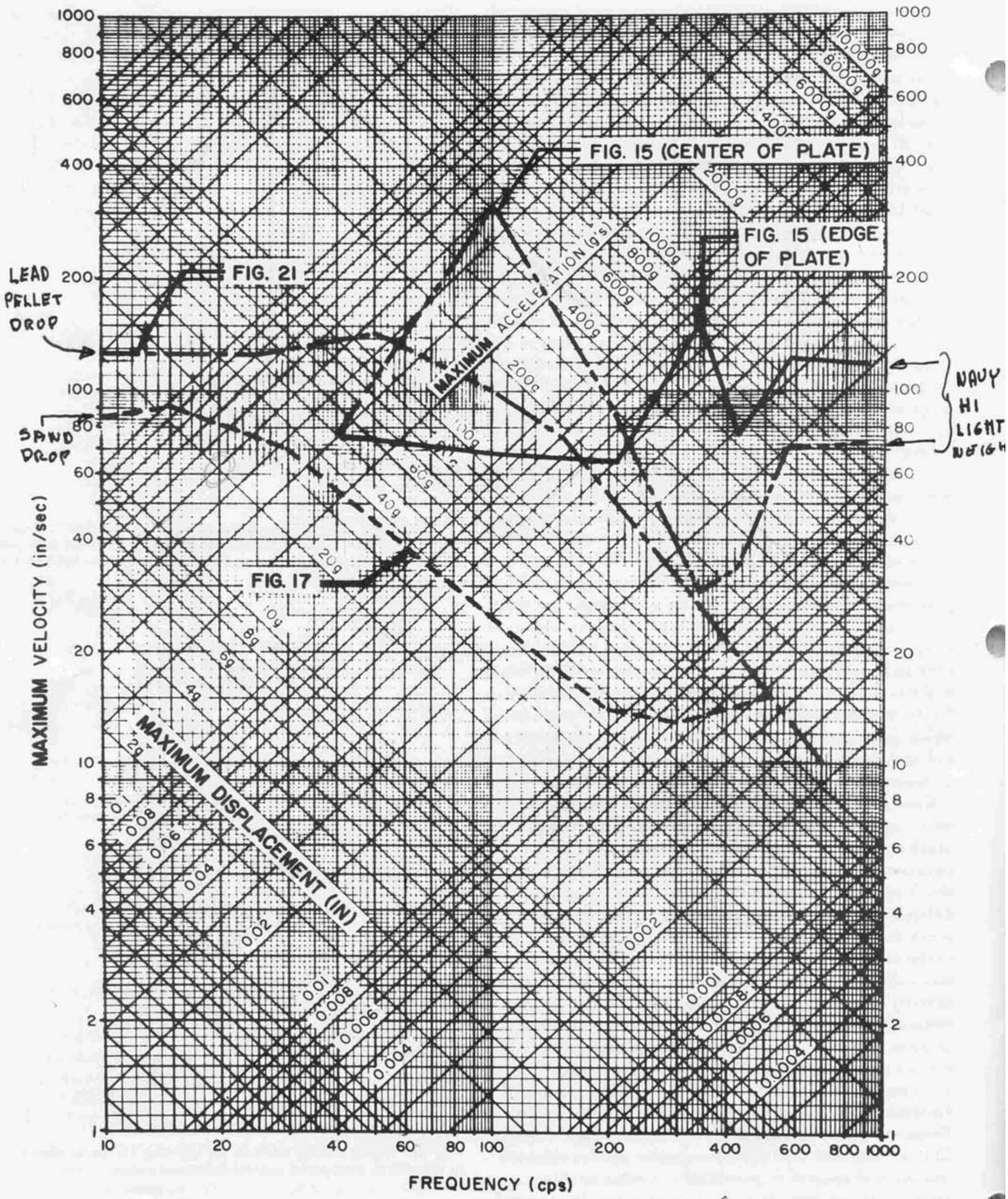


Fig. 22. Spectra defining typical operating conditions of the shock testing machines illustrated in Figs. 15, 17 and 21.

Robert's Drawing

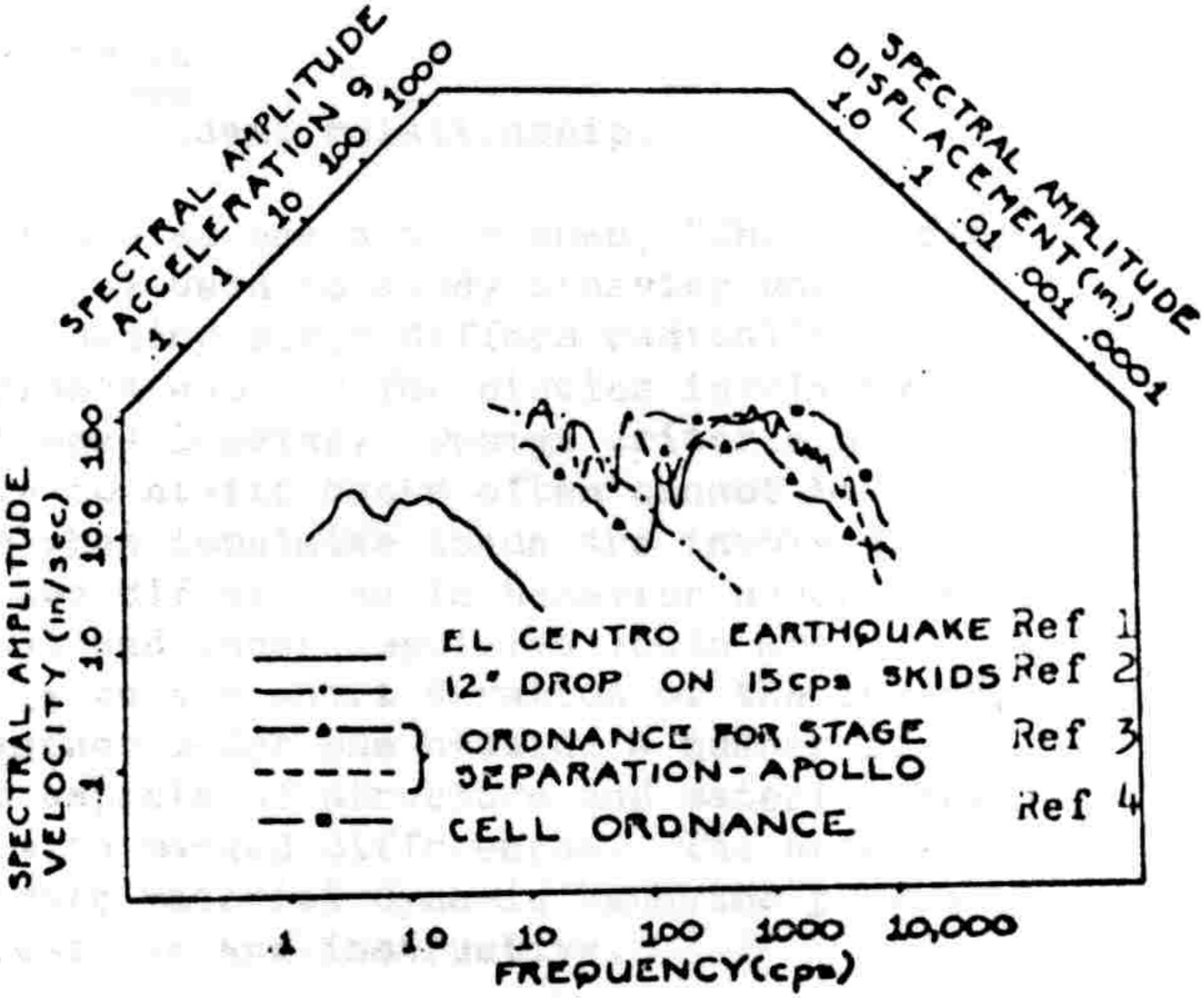


FIGURE 6. RESPONSE SPECTRA FOR VARIOUS EVENTS.

Miscellaneous Issues

- Damping must be used to check polarity or equivalence of the positive and negative SSs.
- Damping must be used to eliminate resonant buildup. The phony development of undamped SS amplitudes by sums of sine waves.
- Mean removal makes final velocity of shock zero which is often needed to understand low frequency severity.
- Be careful with mean removal; wavelet.
- Detrending or trend removal and addition can be used to adjust the final displacement which is needed to understand rattlespace requirements.

DAMPING REDUCES THE PLATEAU LEVEL AND MAKES IT LESS THAN THE IMPACT VELOCITY CHANGE.

Established plateau with undamped SS Eq solution for an initial velocity, Now need same damped sol of SS Eq with $\ddot{y}$ and z_0 set to zero.

$$z = \frac{\dot{z}_0 e^{-\zeta\omega t}}{\omega\eta} \sin \eta\omega t$$

Decaying vibration,. We get pos max and neg min in first period. Multiply by ω for PV plateau values. Divide by z_0 for ratios: R_1, R_2, max and min PV.

$$R = \frac{\omega z}{\dot{z}_0} = \left(\frac{e^{-\zeta\omega t}}{\eta} \sin \eta\omega t \right)_{max,min}$$

Conclude

Damping Makes the 2g Line Approximate:

Cute 2g line, only good for undamped, no rebound simple shocks.

Still handy.

Roughly shows the LF limit of the plateau. Indicates a general drop height.

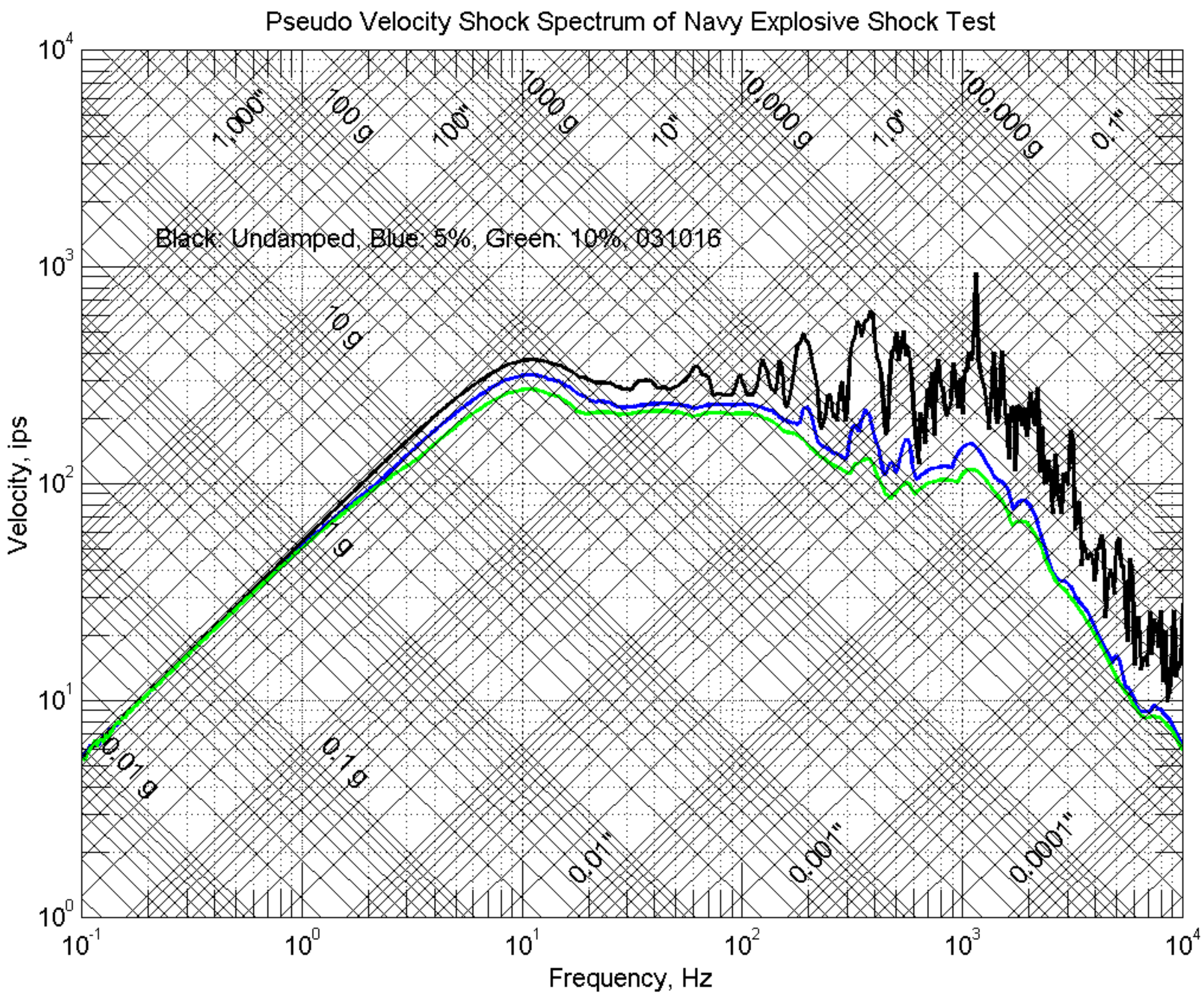
Damping in the Neg-Pos PVSS on 4CP Shows Shock Polarity

- ***The posnegative PVSS.*** Up until now, looking at the overall or maximax PVSS's.
- To calculate the maximax PVSS, calculate both the pos and neg max's and take greater value.
- Small program change to have the program collect and plot both.
- Axis orientation makes the negative spectrum have a higher plateau for a shock in the positive direction.

Damping in the Neg-Pos PVSS on 4CP Shows Shock Polarity

- Call simple shock polarity the ratio,R_{pos}/R_{neg}. Thus a $\zeta = .25$, simple shock will have a polarity of 44%. Its positive plateau will be 44% of its negative.
- Polarity is the ratio of positive to negative PV content in the plateau region of the PVSS.
- The simple shock tests have the strongest polarity I can imagine.

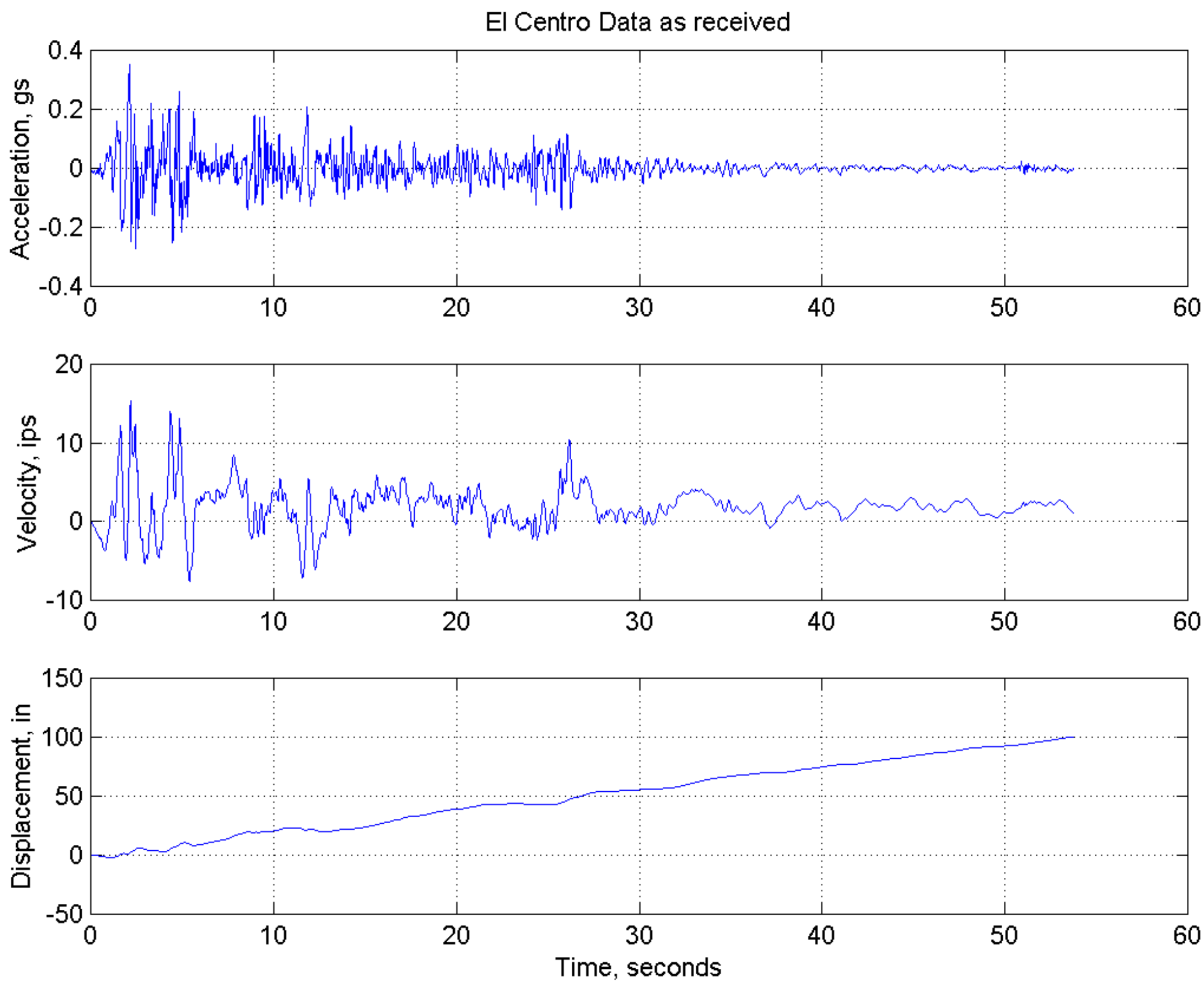
Slight Damping Reduces Resonant Build Up



Back to that explosive shock. Notice resonant buildup peak of 1000 ips near 1100 Hz. Just 5% damping drops that level to 140 ips. Good trick: allow SS calculation at only 20 1/3 octave frequencies. Build a weak shock of sines at those 20 freqs and connect the peaks.

Mean Removal and Detrending

Removing the mean makes velocity end at 0.
Detrending makes displacement end at 0.



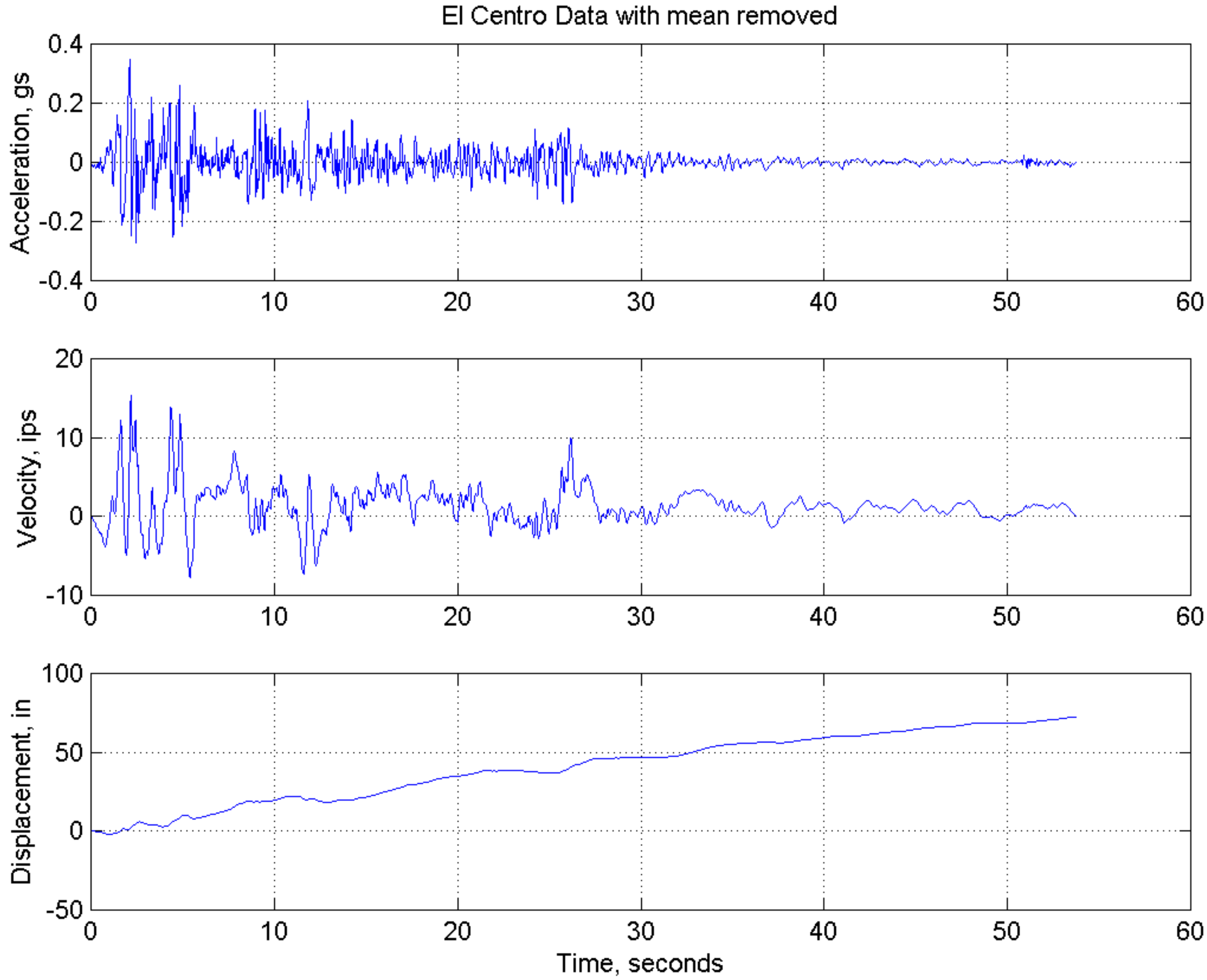
Here's El Centro as received. Integration shows it has a final velocity, and double integration shows the accelerometer has moved 100 in.

Maybe?

Conclude

Remove mean from El Centro

El Centro modified with mean removed by Matlab command, y = y-mean(y);

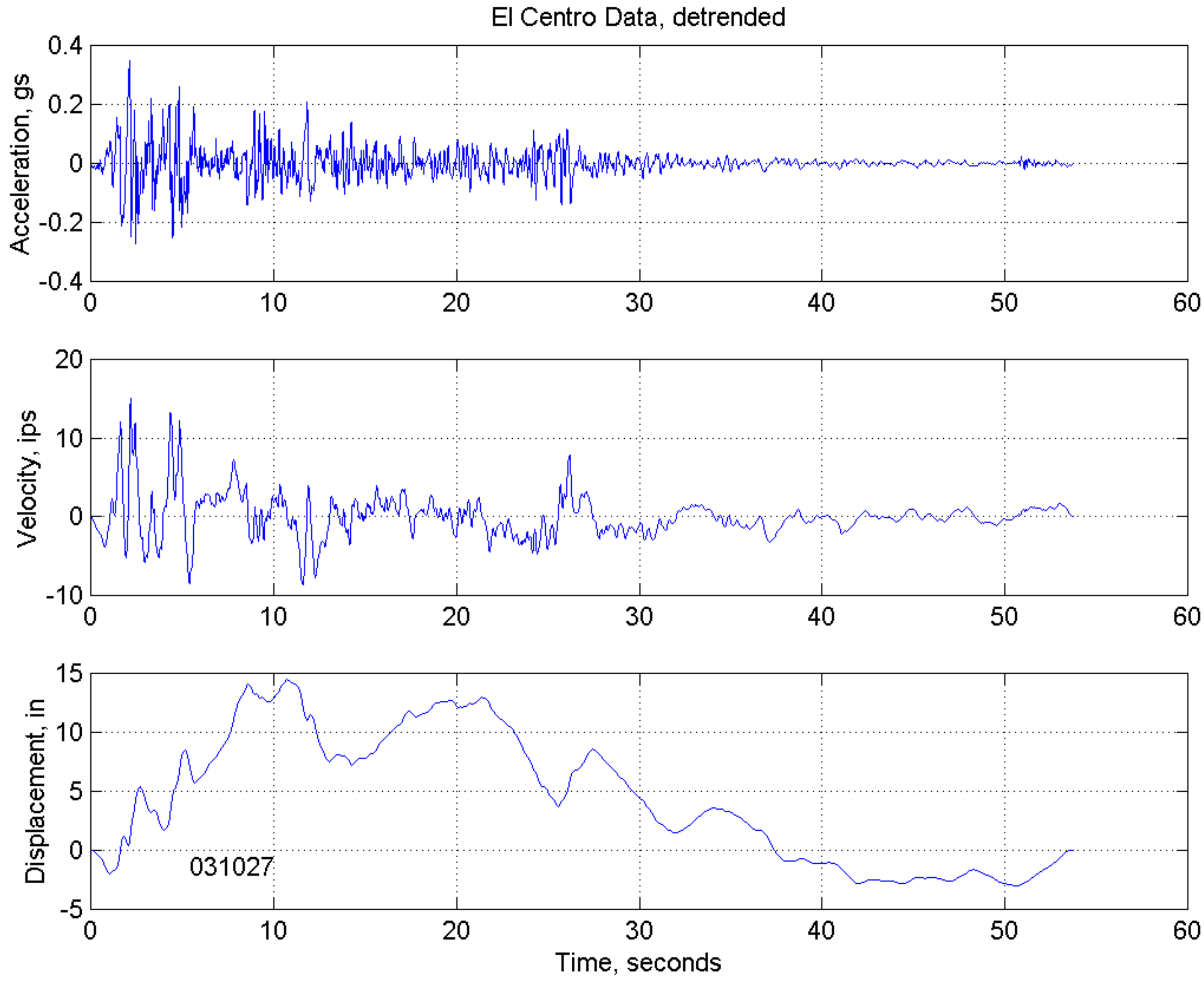


Now the velocity ends at zero (for this chunk), and the final displacement appears to be about 75 in. Maybe; could be.

Conclude

Detrend El Centro Acceleration

We can modify El Centro by removing any existing linear trend in the acceleration data With Matlab command: y = detrend(y).



Now velocity still ends at zero and displ ends at zero. Peak displ was about 15 in. Even went neg about 3 in. Maybe; certainly could be.

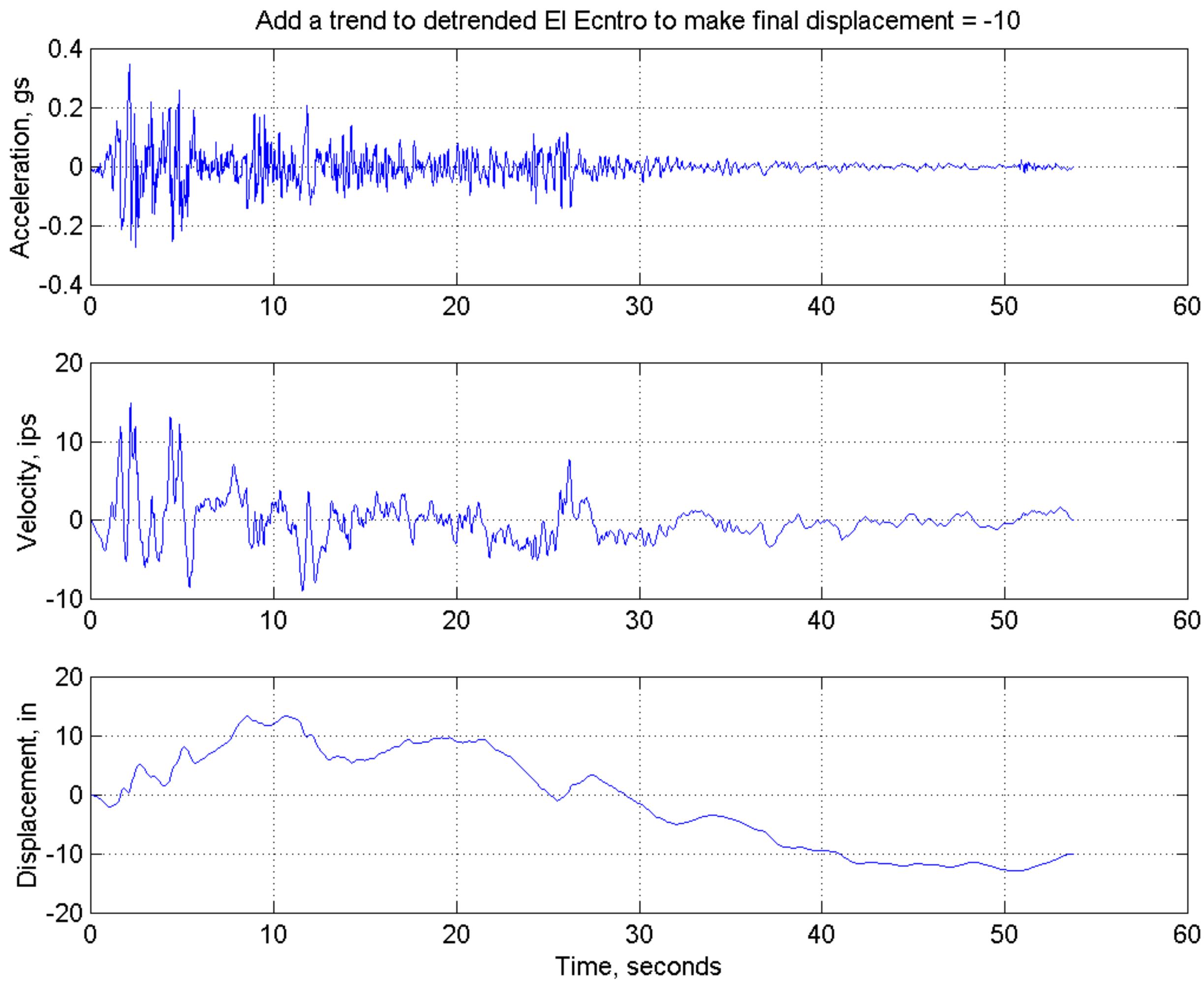
Conclude

Add any trend you want.

Finally: double integrate a no-mean linear acceleration trend and set constants to so final displacement is y_f at time t_f, you get:

$$\ddot{y} = \frac{6y_f}{t_f^2}\left(1 - \frac{2t}{t_f}\right)$$

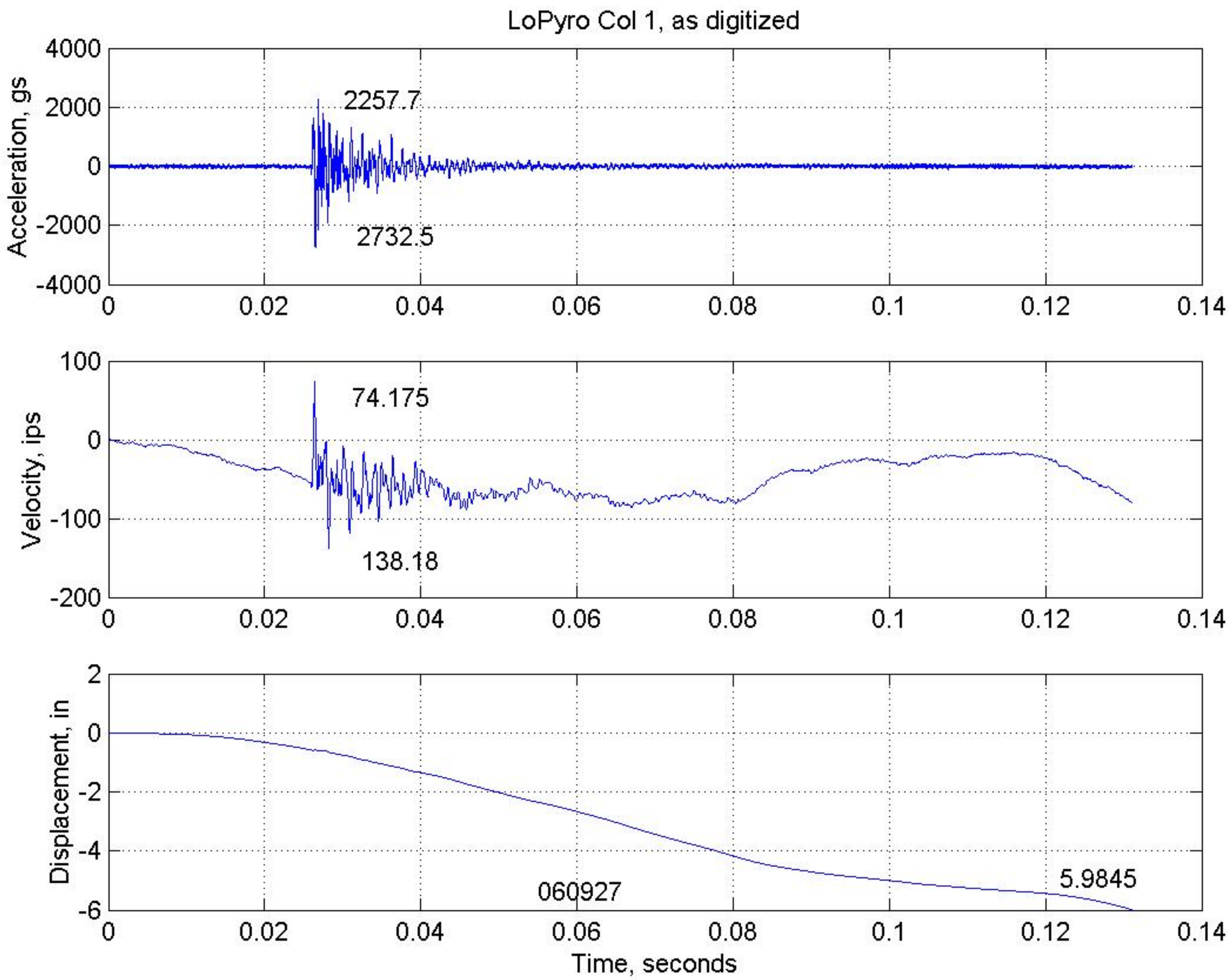
I set y_f = -10, and add this to the El Centro acceleration.



Now we get velocity to end at zero and the displacement to end at -10. If that's what you would like, you can have it. Probably could be. Could use sine.

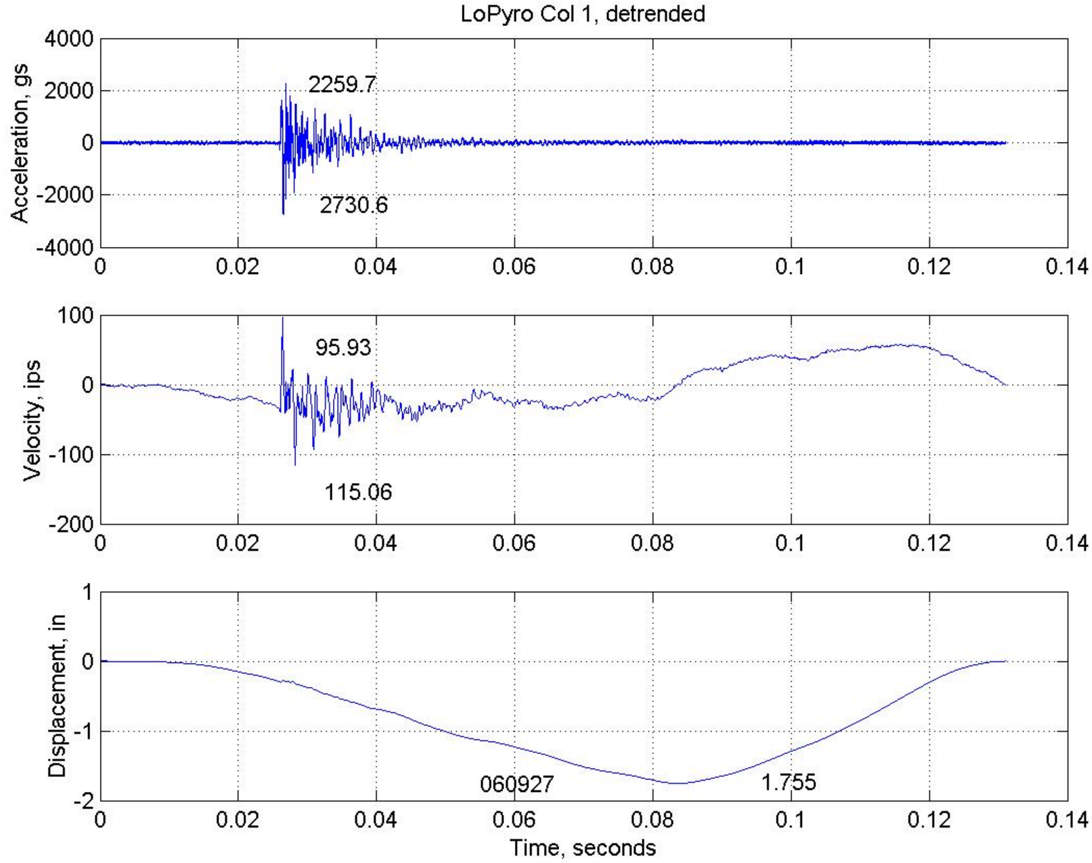
Conclude

Pyro: Data Col 1; as received



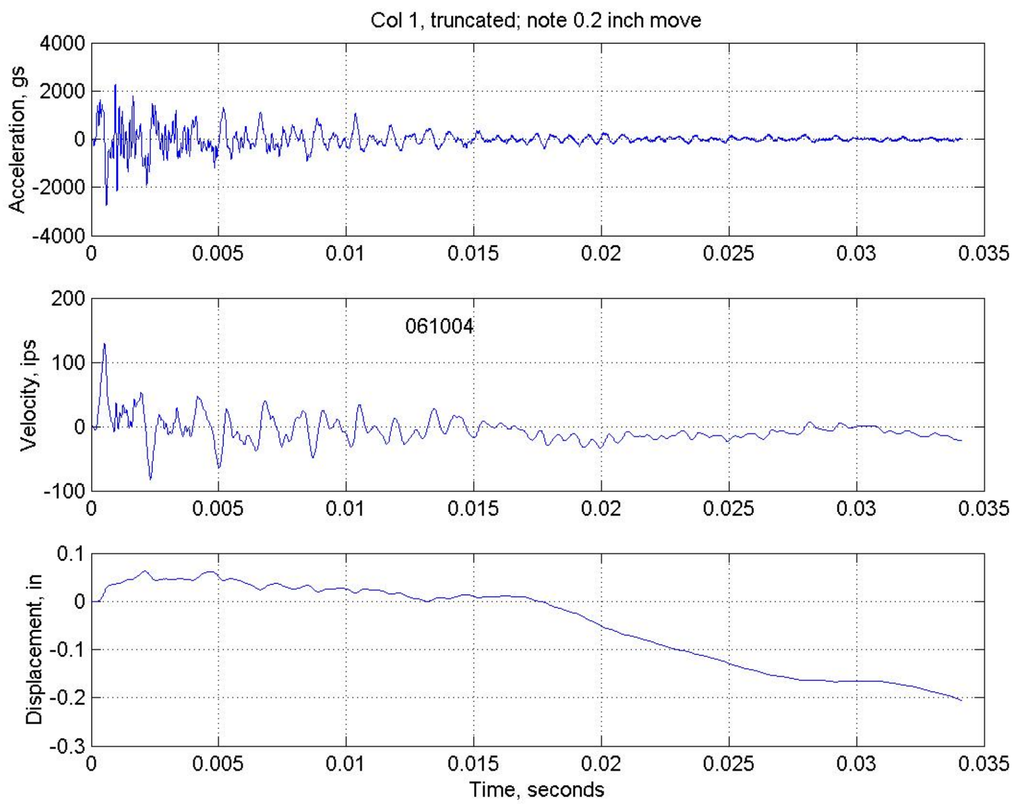
Conclude

Detrend the as received data



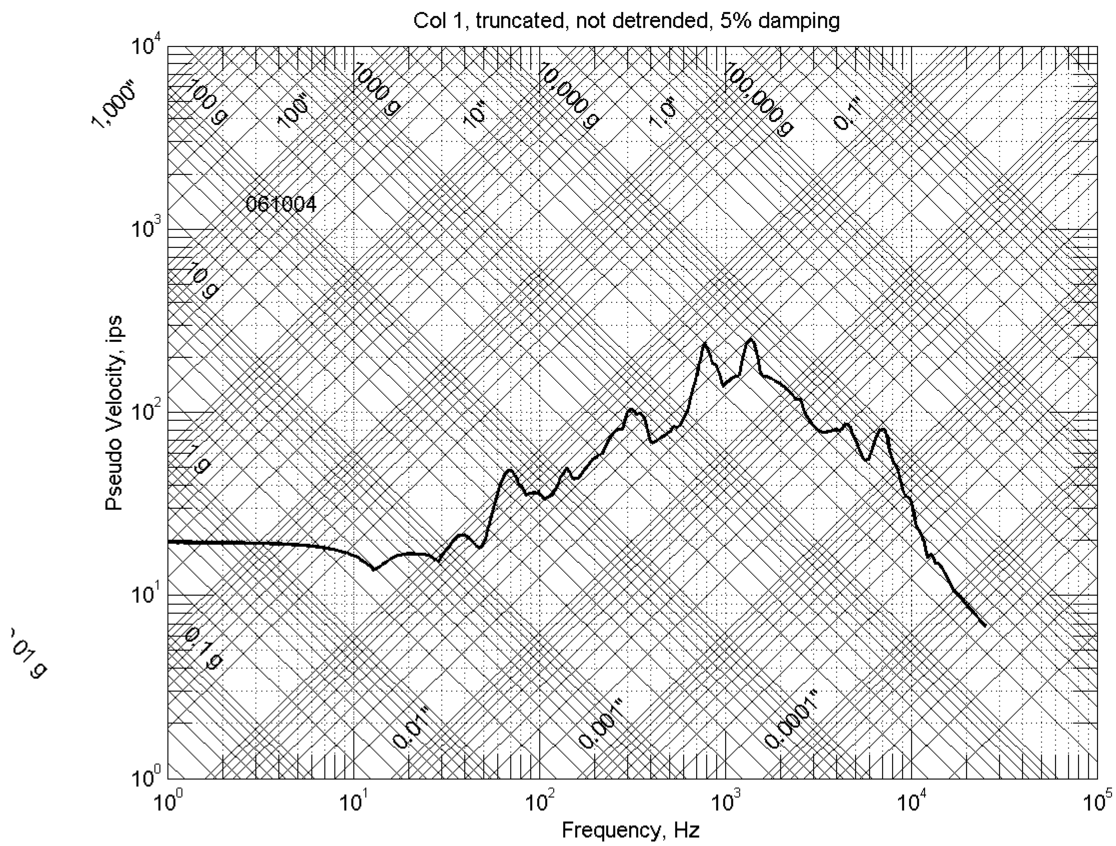
Displacement has that half sine shape; polynomial correction edit looks a good idea.

Truncate the data

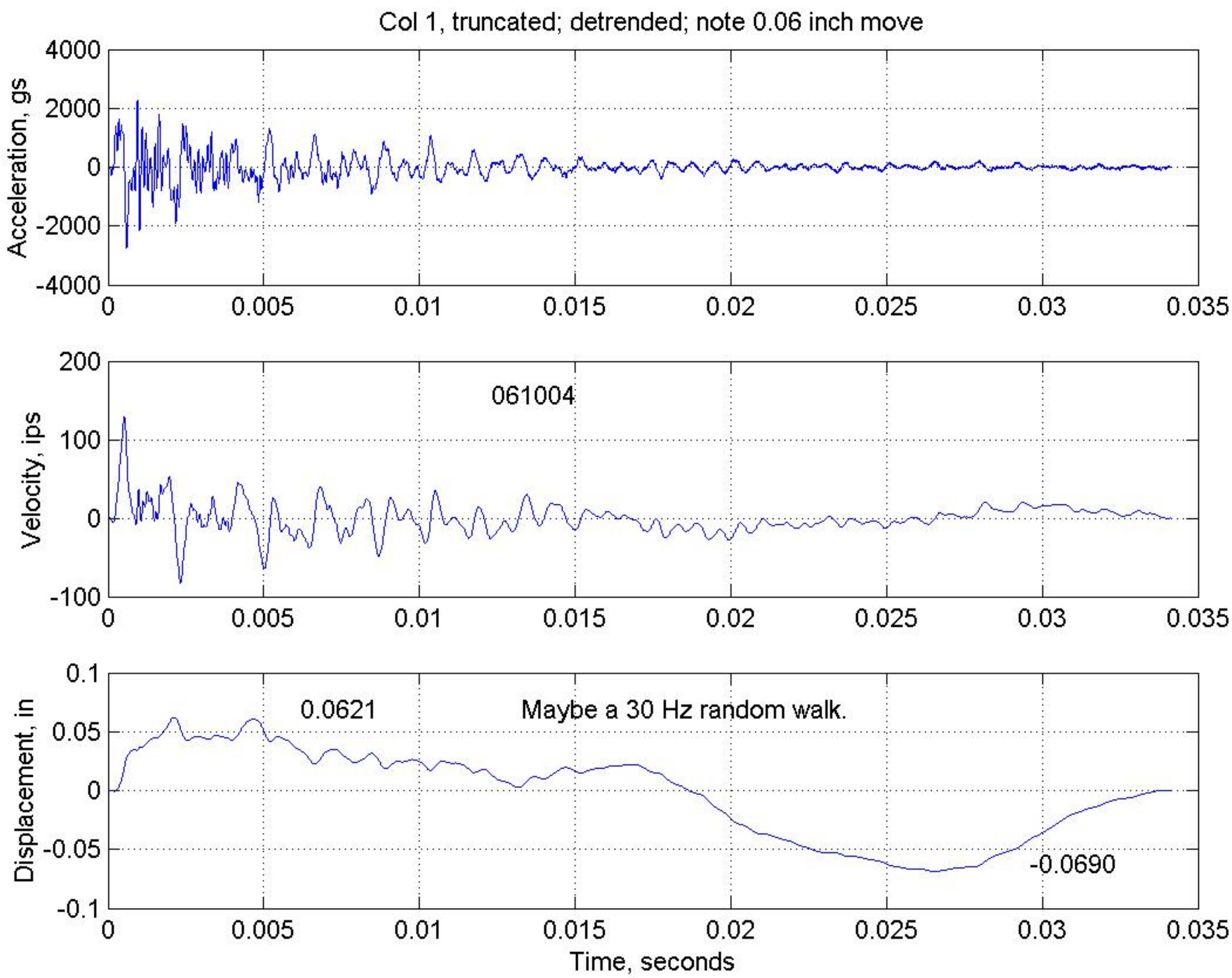


Conclude

PVSS the Truncated Raw

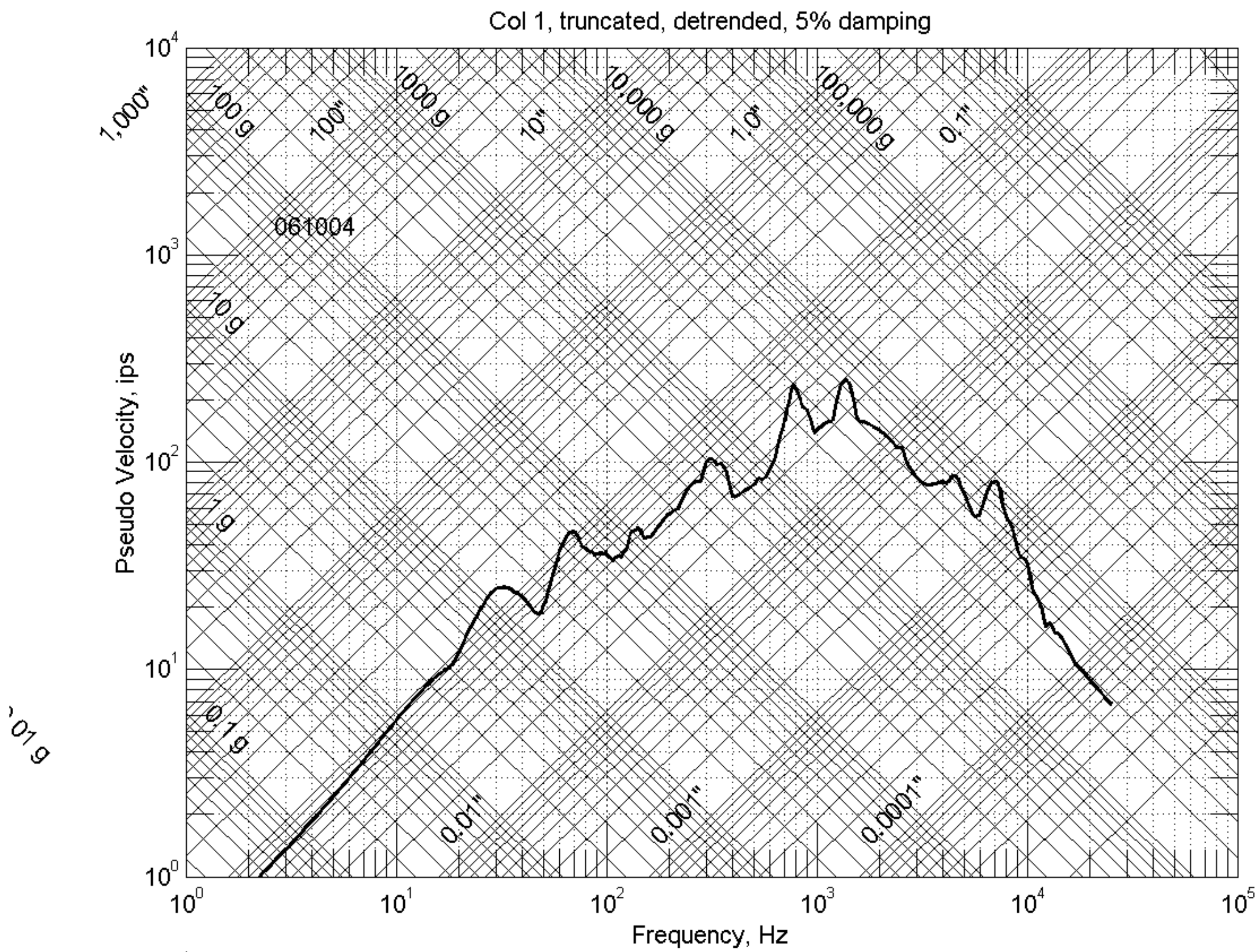


Pyro: Data Col 1; detrended



Note 30 Hz in displacement.

Pyro: LoPyro Col 1; detrended; 5% Damping



Notice the little bump at 30 Hz.

Conclude

Seagulls, Crows, and the Baby

- Seagulls drop clam 10 ft onto asphalt v=sqrt(2*G*h)=304 ips
- Crow drops walnut 18 ft onto asphalt v=sqrt(2*G*h)=408 ips
- Baby falls 18 inches onto carpet: v=sqrt(2*G*h)=118 ips
- Stone drops the computer 2 inches onto the desk: v=sqrt(2*G*h)=39 ips
- Egg safe ½ inch drop=19.6 ips

We've Covered

- Shock spectrum definitions
- Args for PVSS on 4CP
- Theoretical proofs that stress is proportional to velocity
- Experimental shock data requires the least dynamic range in terms of velocities
- Structural, nuke, CWE, EQ, Navy: use PVSS
- $(PV)^2$ proportional to energy. PVSS shows capacity to deliver energy.
- PVSS on 4CP asymptotes: displ, severity or vel change, and peak accel; 3 regions.
- PV beats Rel Vel.
- Half sines. Compare to explosive
- Tests show PVSS best for damage
- Shaker shock: wimpy.
- Damping for polarity; creams swept sines.
- Mean removal and detrending.

The references are old and trouble to find. I promise to write all this in detail as a report, but I'm not there yet. Here's a few if you want to begin.

- Gaberson, H.A,, "Pseudo Velocity Shock Spectrum Rules for Analysis of Mechanical Shock"; IMAC XXV, Orlando, FL; Society of Experimental Mechanics; Bethel, CT, Feb 2007; p 367
- Eubanks, R.A. and Juskie, B.R., "Shock Hardening of Equipment," Shock and Vibration Bulletin 32, Part III, 1963, pp 23-73.
- "Reasons for Presenting Shock Spectra with Velocity as the Ordinate", by H.A. Gaberson, and R. H. Chalmers; Proceedings of the 66th Shock and Vibration Symposium, Vol;. 2. 1996, pp 181-191
- Gertel, Mike, and Holland, R.,"A Study of Selected Shock Analysis Methods", A Report Allied Research Associates, Inc, Concord, MA done under contract for U.S. Army, Quality Assurance Directorate, Frankford Arsenal, Philadelphia, PA April 1967; AD# AD814820
- Gaberson, H.A. and Chalmers, R.H., "Modal Velocity as a Criterion of Shock Severity," Shock and Vibration Bulletin 40, Part 2, Dec 1969, pp 31-49.
- Gaberson, H.A., "Shock Spectrum Calculation from Acceleration Time Histories," Technical Note N-1590, Civil Engineering Laboratory, Port Hueneme, CA, 1980 (ADA097162).
- Vigness, Irwin, "Elementary Considerations of Shock Spectra", Shock and Vibration Bulletin, No. 34, Part 3, pp 211-222. Dec 1964
- Young, Dana, "Response of Structural Systems to Ground Shock, " in Shock and Structural Response, Ed. By M.V. Barton; ASME, New York, 1960 pp 52-68.
- Sound and Vibration, v37, n9, September 2003.

This list contains the Eubanks and Juskie paper and most of my pseudo velocity shock spectrum analysis concepts papers.

- Gaberson, H.A., “Shock Spectrum Calculation from Acceleration Time Histories,” Technical Note N-1590, Civil Engineering Laboratory, Port Hueneme, CA, 1980 (ADA097162).(Calculation documentation.)
- Gaberson, H.A., and Eubanks, Ph.D., S.E.,R.A.,"Simplified Shock Design for Equipment Installation," NCEL Technical Note, N-1622, March 1982 ADA AD114331 (Shock fragility concept.)
- "Reasons for Presenting Shock Spectra with Velocity as the Ordinate", by H.A. Gaberson, and R. H. Chalmers; Proceedings of the 66th Shock and Vibration Symposium, Vol;. 2. 1996, pp 181-191 (PVSS is best.)
- Gaberson, H. A., D. Pal, and R.S. Chapler, "Shock Severity Measurement for Facilities Equipment" 69th Shock and Vibration Symposium, October 1998; proceedings spring of 1999. (Blower shock test analysis.)
- Gaberson, H.A. "Half Sine Shock Tests to Assure Machinery Survival in Explosive Environments". IMAC XXII, Dearborn, MI; Society of Experimental Mechanics, Jan 29, 2004 (All simple shocks the same.)
- Gaberson, H. A, "Pseudo Velocity Shock Spectrum Rules and Concepts", Proceedings of the Annual Meeting of the Mechanical Failure Prevention Technology Society [www.mfpt.org] April 19, 2007 (Summary)
- Gaberson, H. A., "Conditions Under Which Displacement, Velocity, or Acceleration, Should Be Used for Diagnostic Vibration Monitoring", Vibration Institute Annual Meeting, San Antonio, TX, June 33, 2007; (stress velocity ideas)
- Gaberson, H.A., "Use of Damping in Pseudo Velocity Shock Analysis", IMAC XXVI, Orlando, FL; Society of Experimental Mechanics; Bethel, CT, Feb 2008
- Gaberson, H.A., "Pseudo Velocity Shock Spectrum Analysis Data Editing", IMAC XXVII, Orlando, FL; Society of Experimental Mechanics; Bethel, CT, Feb 2009
- "Estimating Shock Severity", IMAC XXIX, Jacksonville, FL; Society of Experimental Mechanics; Bethel, CT, www.sem.org; Feb 2011
- "Shock Severity Estimation", Proceedings of the 2010 Shock and Vibration Symposium, November 2010, available from www.saviac.org
- "Simple Shocks Have a Szimilar PVSS on 4CP", Proceedings of the 2010 Shock and Vibration Symposium, November 2010, available from www.saviac.org
- "Filtering Pseudo Velocity Shock Spectrum Data", Proceedings of the 2009 Shock and Vibration Symposium, November 2009, available from www.saviac.org
- "Pseudo Velocity Shock Spectrum Analysis Editing Tools", Proceedings of the 2009 Shock and Vibration Symposium, November 2009, available from www.saviac.org

Conclude

Facts

- Structure shock response is analyzed in modes at f_n's.
- Max modal velocity proven proportional to max modal stress.
- Maximum stress limits allowable modal velocity.
- PVSS shows potential modal velocity. PV shows Stress !
- High PVSS shows freqs where shock can cause high stress.
- 4CP Handiest way to present.

f_n: natural frequency; PV: pseudo velocity; SS: shock spectrum; 4CP four coordinate paper

This Completes the Conclusions

- It's been a pleasure.
- Thank you.