Vibration Measurements in Support of ILC MDI Design Efforts

March 20, 2011

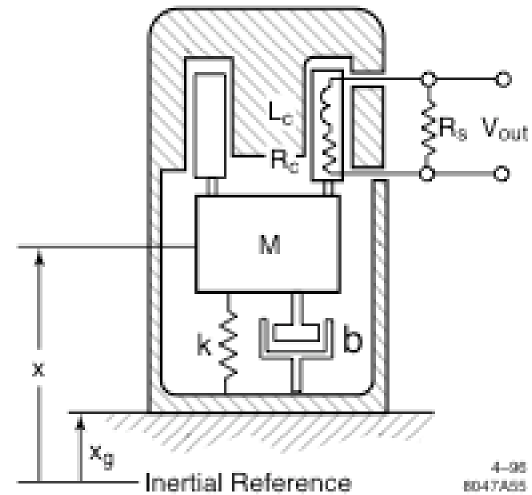
Kirk Bertsche, John Amann,
Marco Oriunno, Achim Weidemann

Goals

- Constrain and validate vibration performance of ANSYS-like calculations on platforms
  - Compare transfer functions of experiment to models on platform-like systems
  - Gain confidence that platform models are correct
- Determine structural parameters for models
  - Damping factor
  - Elastic modulus
- Understand importance of boundary conditions
  - grouted edge support (CMS Platform)
  - line support on 2 edges
  - point support array

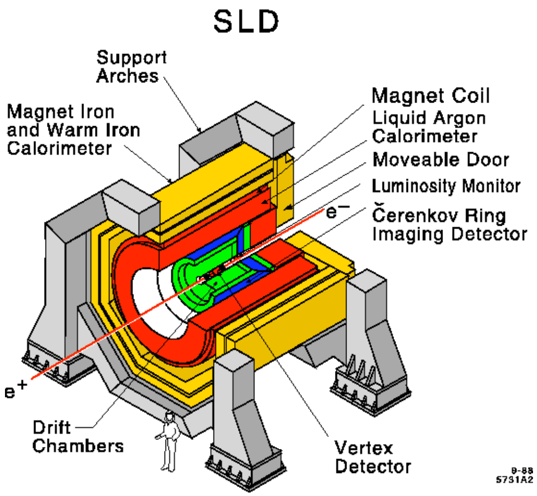
Vibration Measurements

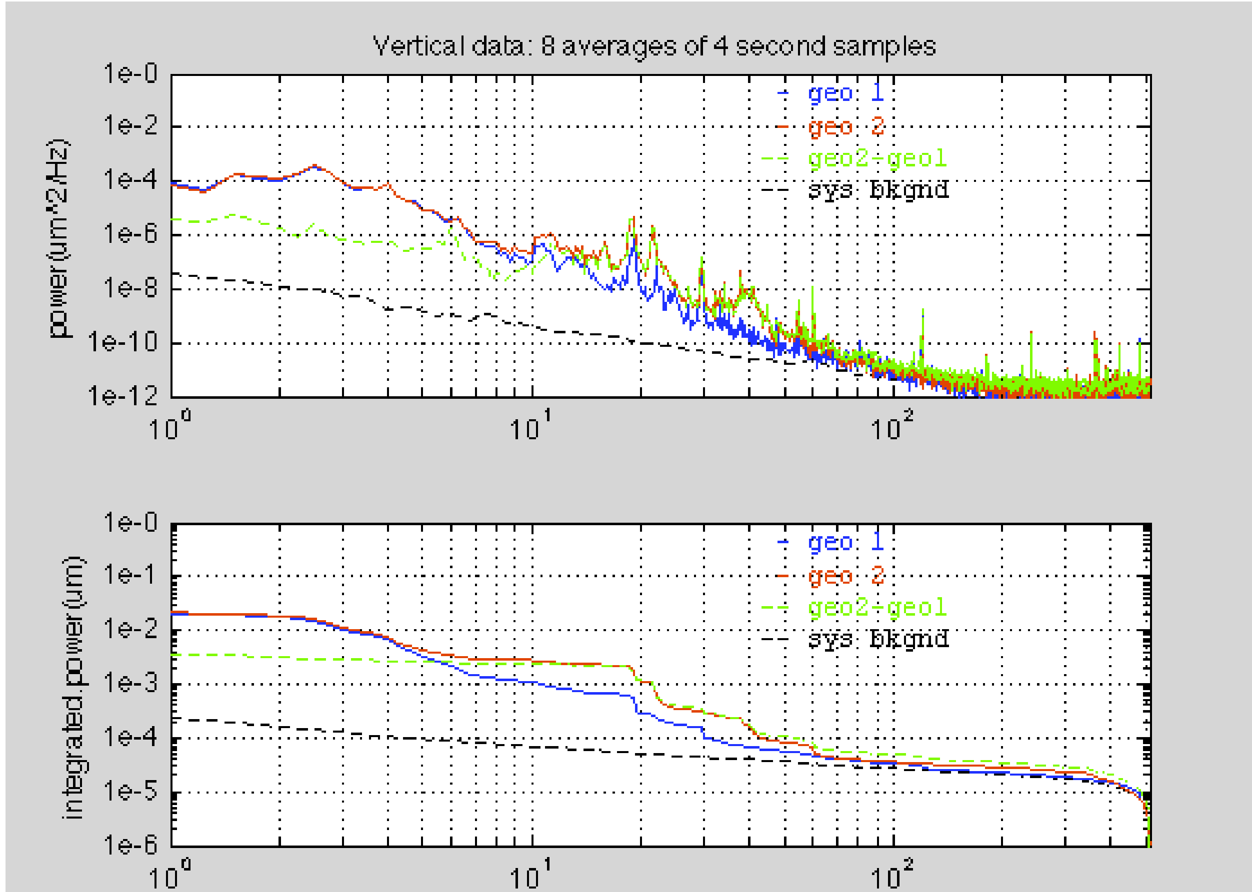
- Seismometers/Geophones
  - Simple damped mass-spring system: ~1 kg mass, ~1 Hz resonant frequency
  - Made by Sercel, Inc. (formerly Mark Products)
- System
  - Resuscitated Andrei Seryi's old hardware and software
  - Built new battery-operated preamps
  - System noise level very low: ~0.25 nm RMS (integrated noise > 1 Hz)



from NLC Zeroth-Order Design Report, Snowmass 96

SLD Detector: S PacMan





Blue: Floor at S end of SLD detector
Red: Top of Pacman at S end of SLD detector

Data file: 05095503.no0, Nov 5, 2010
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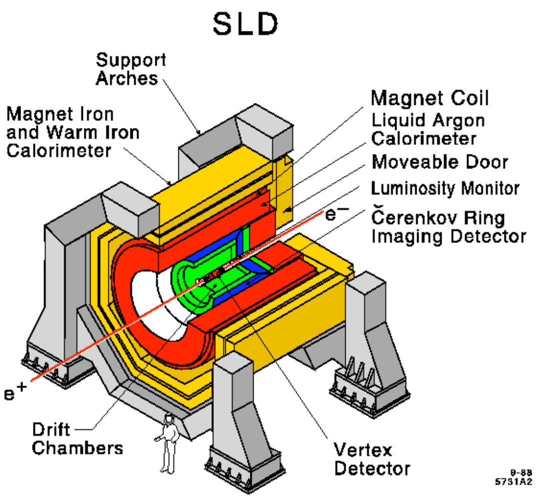
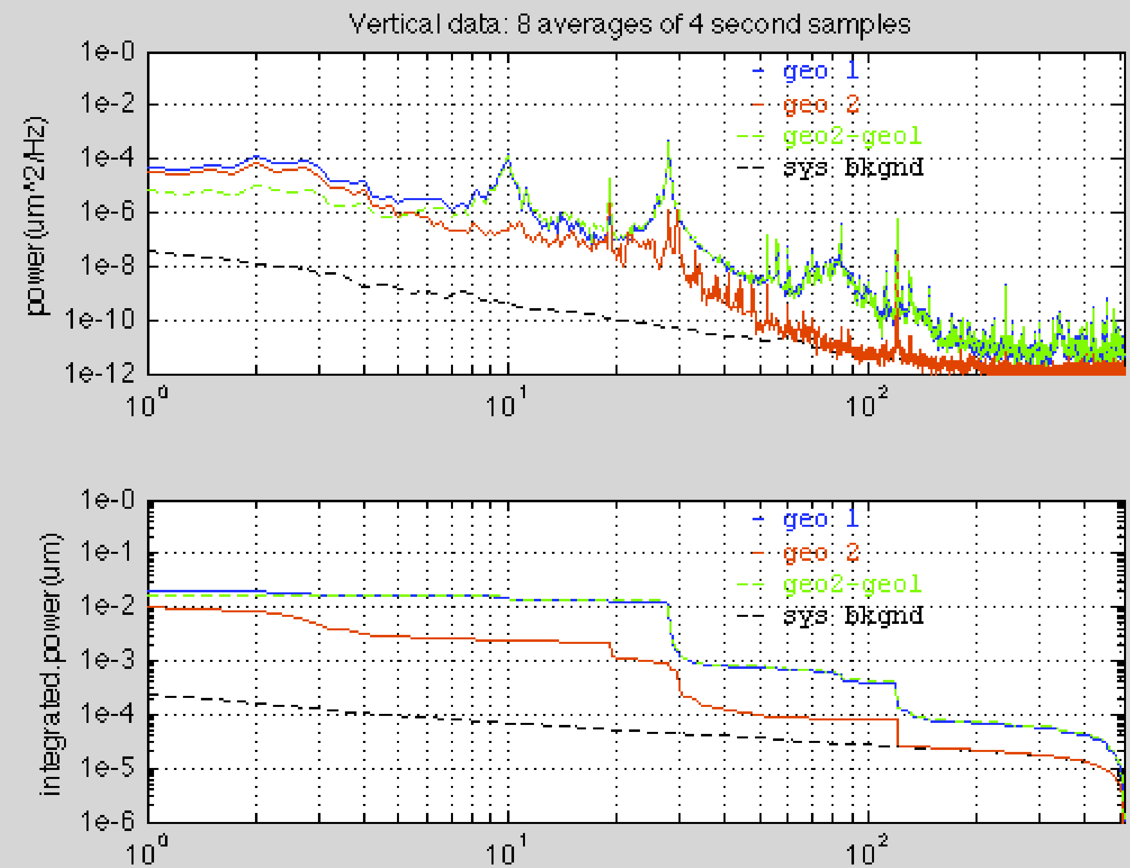
- Pacman vertical motion:
  - Reaches about 5x larger than ground from 10-50 Hz
  - Correlated with ground only up to ~20 Hz
  - <2x larger than ground integrated above 5 Hz

SLD Detector: N Door





Blue: N door of SLD detector
Red: Floor at N end of SLD detector

Data file: 03155349.no3, Nov 3, 2010
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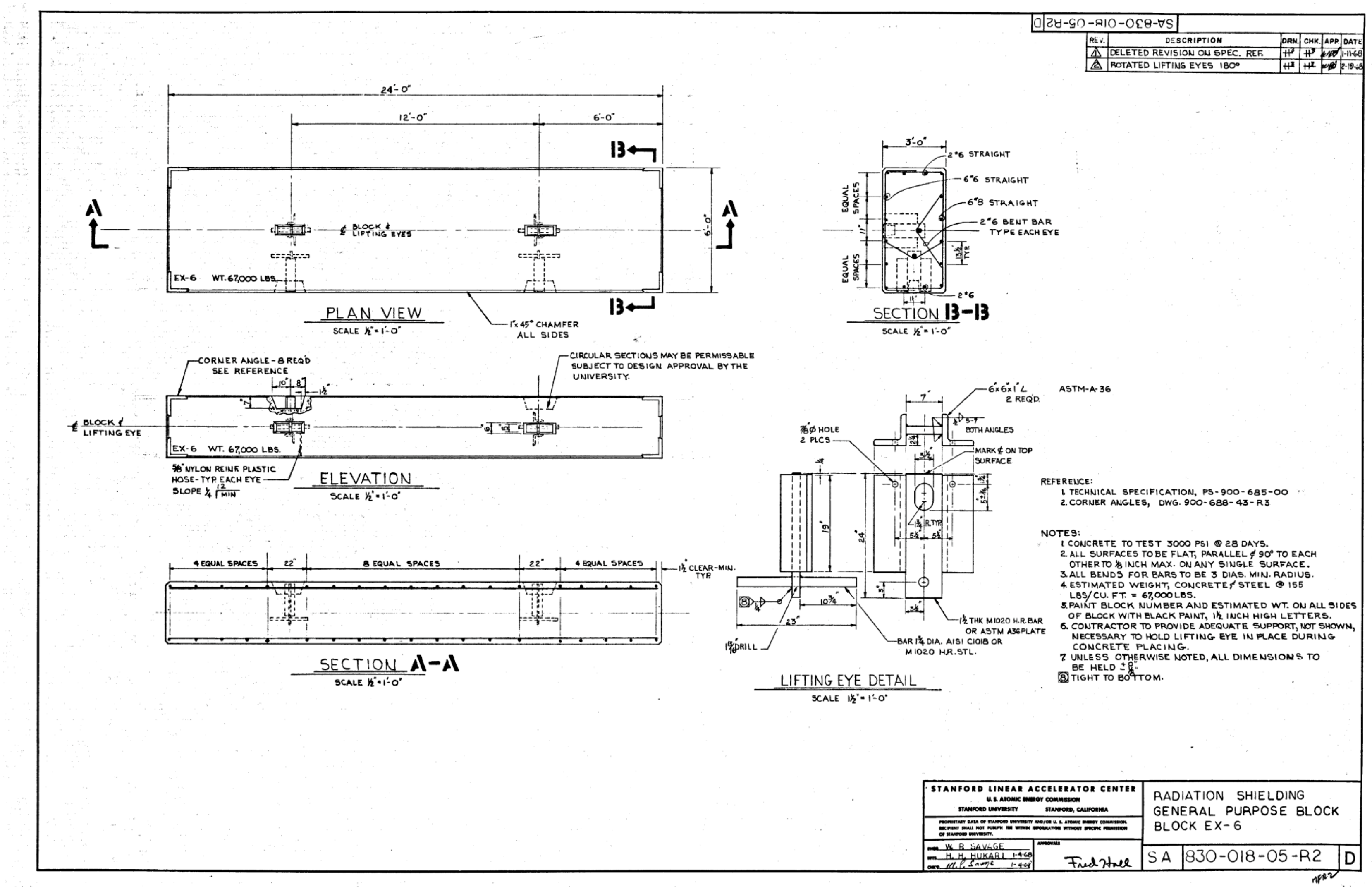
- Door vertical motion:
  - Reaches about 10x larger than ground between 5-200 Hz (~10x at 28 Hz spike)
  - About 5x larger than ground integrated above 5 Hz

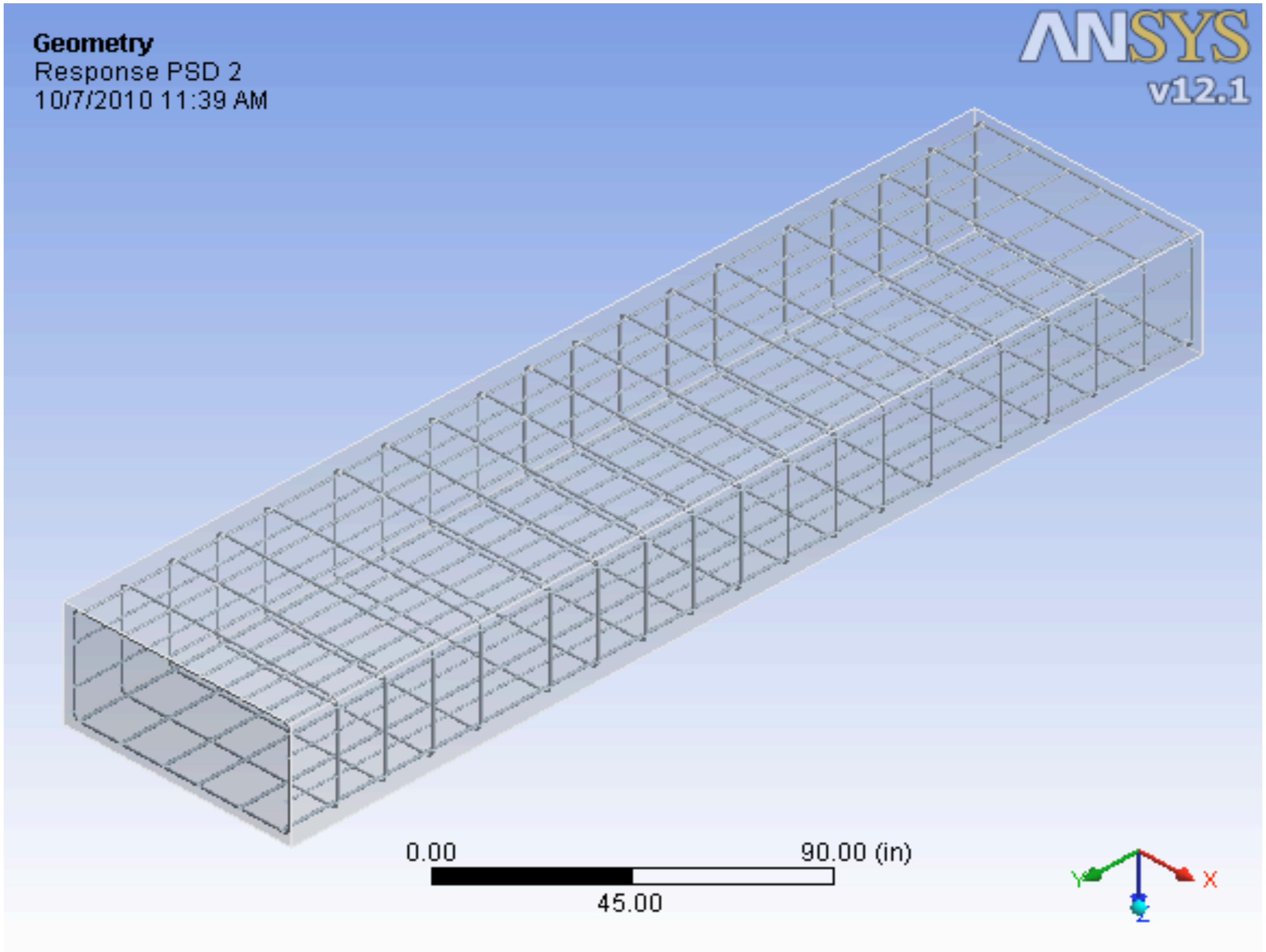
Concrete Model Validation: End Station A

- "Tunnel" constructed of EX-6 shielding blocks
- Geophone positions on floor and second roof block from end
- Variable-frequency vibrator bolted to floor

EX-6 Shielding Block



Solid Model for FEA



Modal Analysis Results

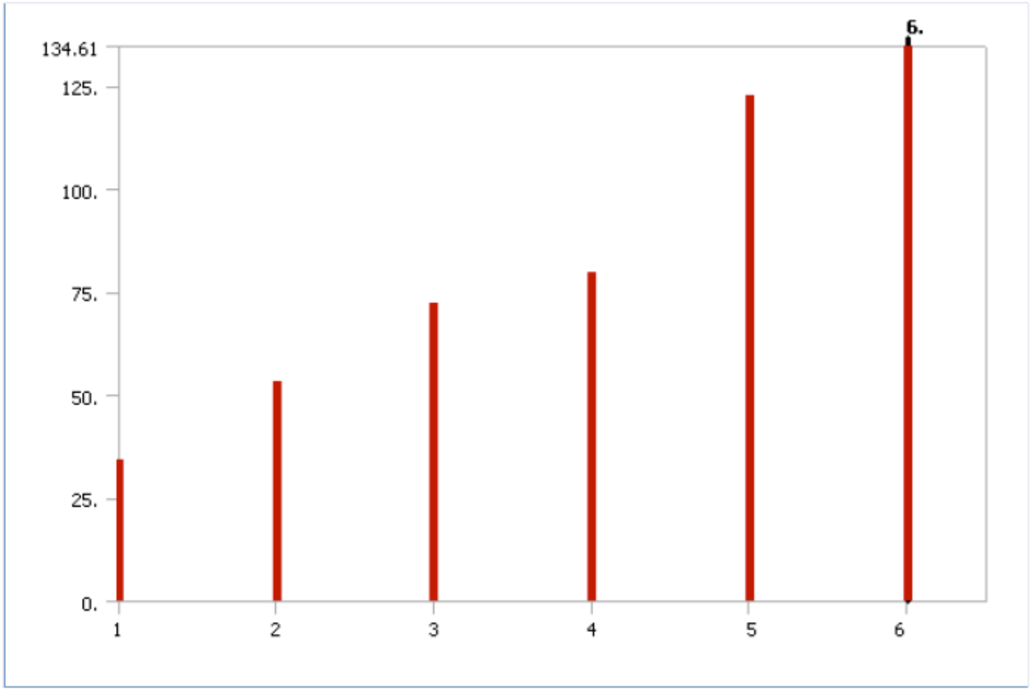
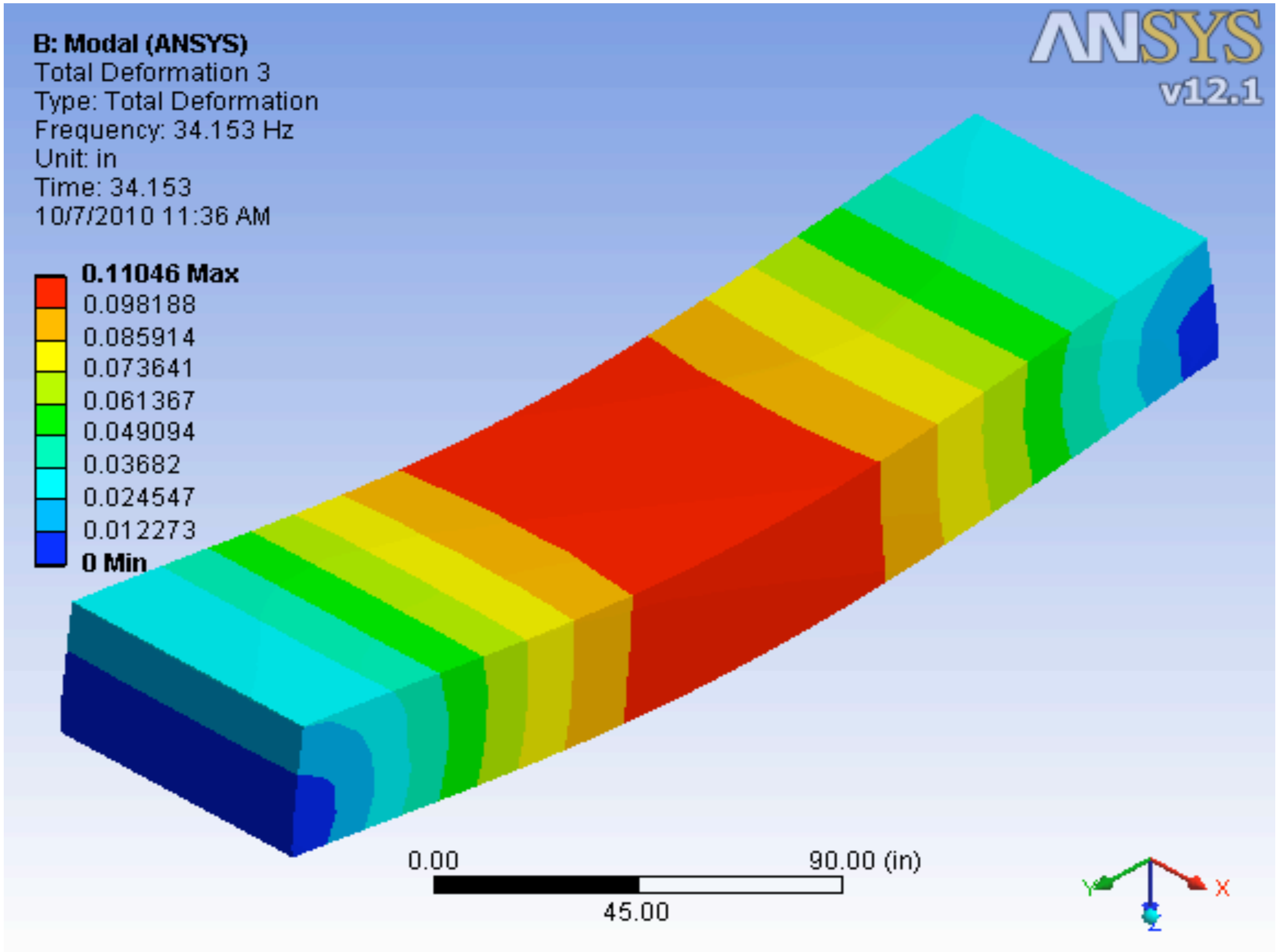


TABLE 20
Model (A4, B4, C4) > Modal (B5) > Solution (B6)

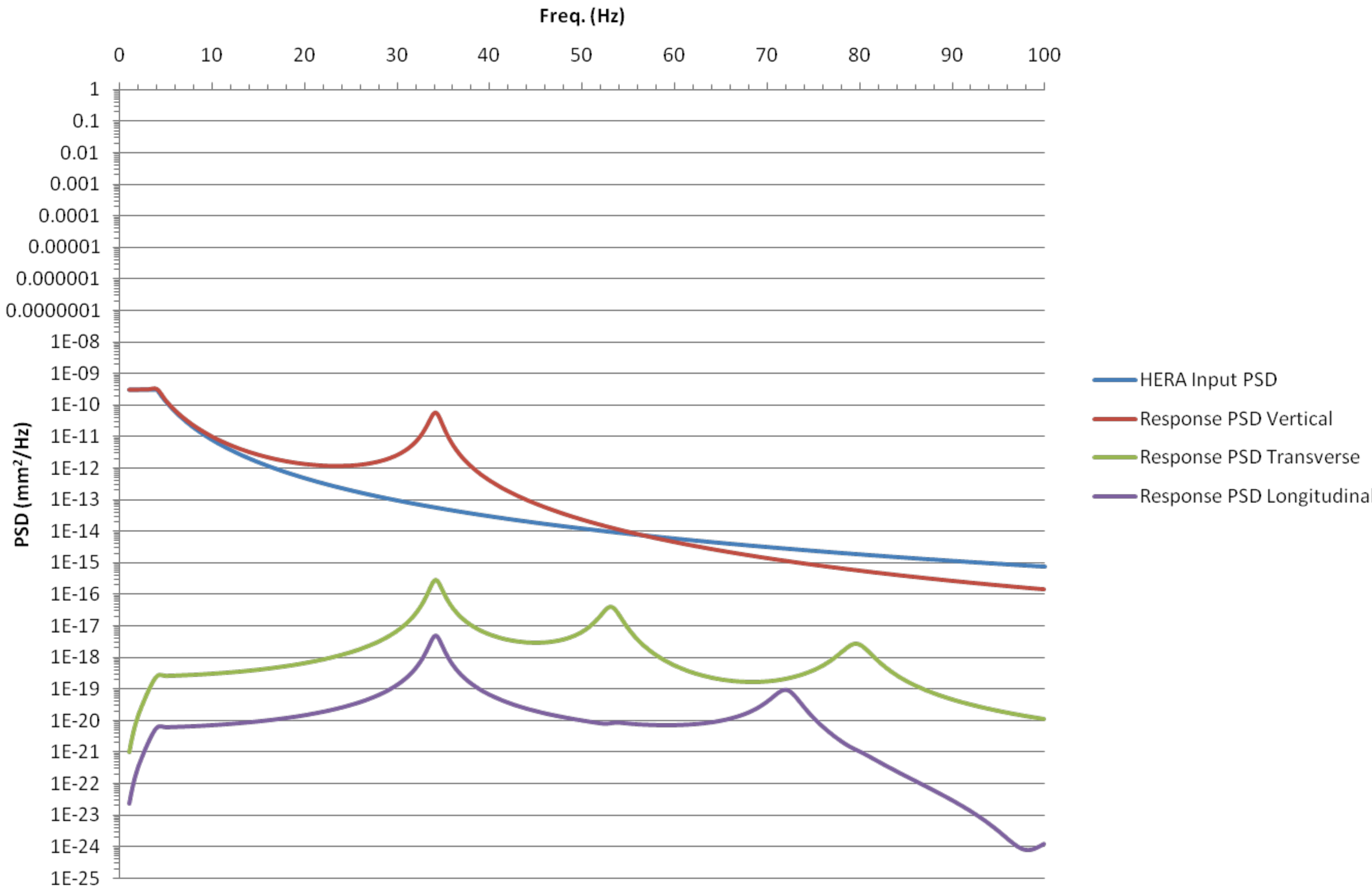
Mode	Frequency [Hz]
1.	34.153
2.	53.163
3.	72.144
4.	79.687
5.	122.84
6.	134.61

Mode 1

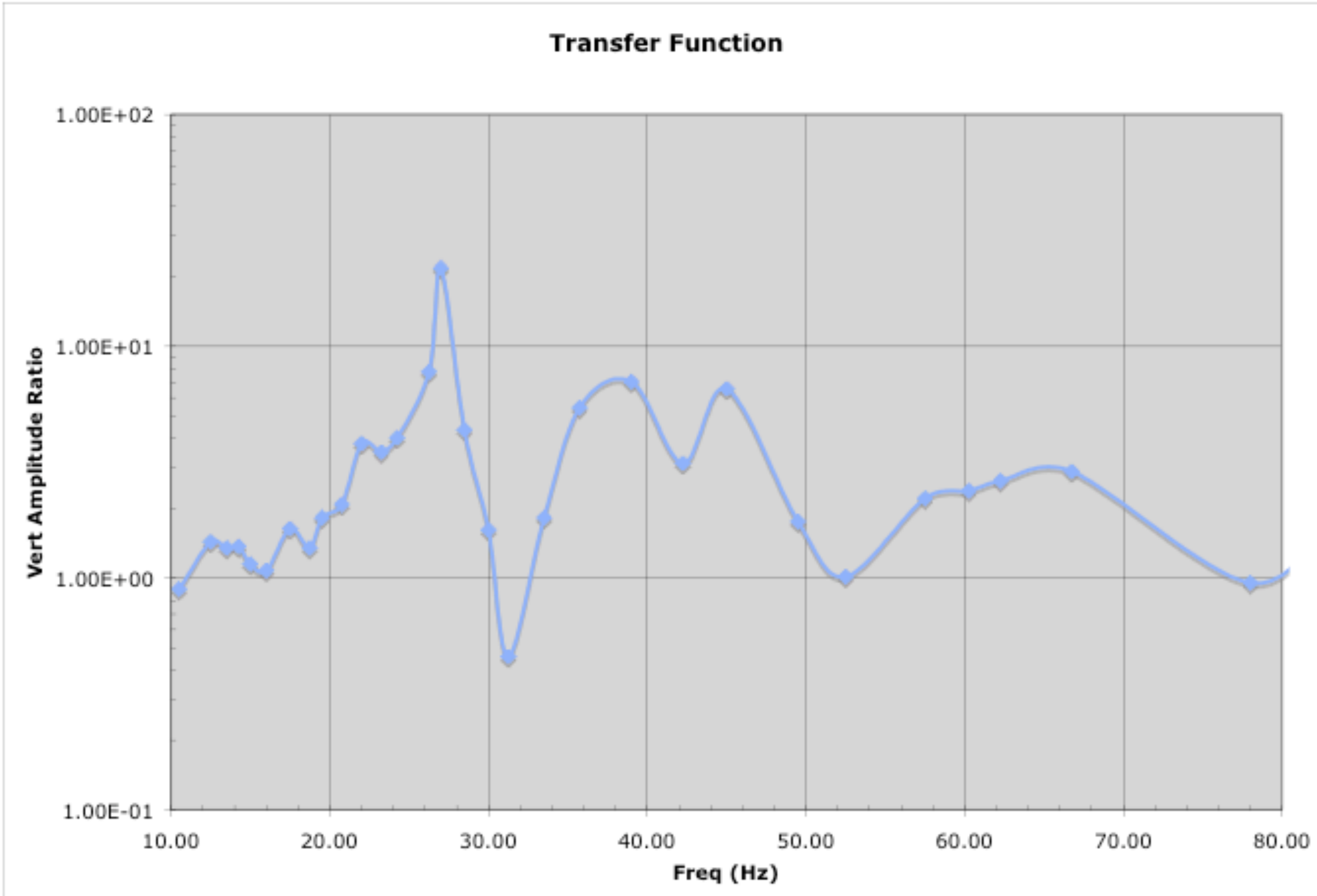


B: Modal (ANSYS)
Total Deformation 3
Type: Total Deformation
Frequency: 34.153 Hz
Unit: in
Time: 34.153
10/7/2010 11:36 AM
0.11046 Max
0.098188
0.085914
0.073641
0.061367
0.049094
0.03682
0.024547
0.012273
0 Min
ANSYS
v12.1
0.00
90.00 (in)
45.00
Y
X
Z

Pre-stress and Damping Added



Transfer Function from Vibrator; ESA Roof/Floor

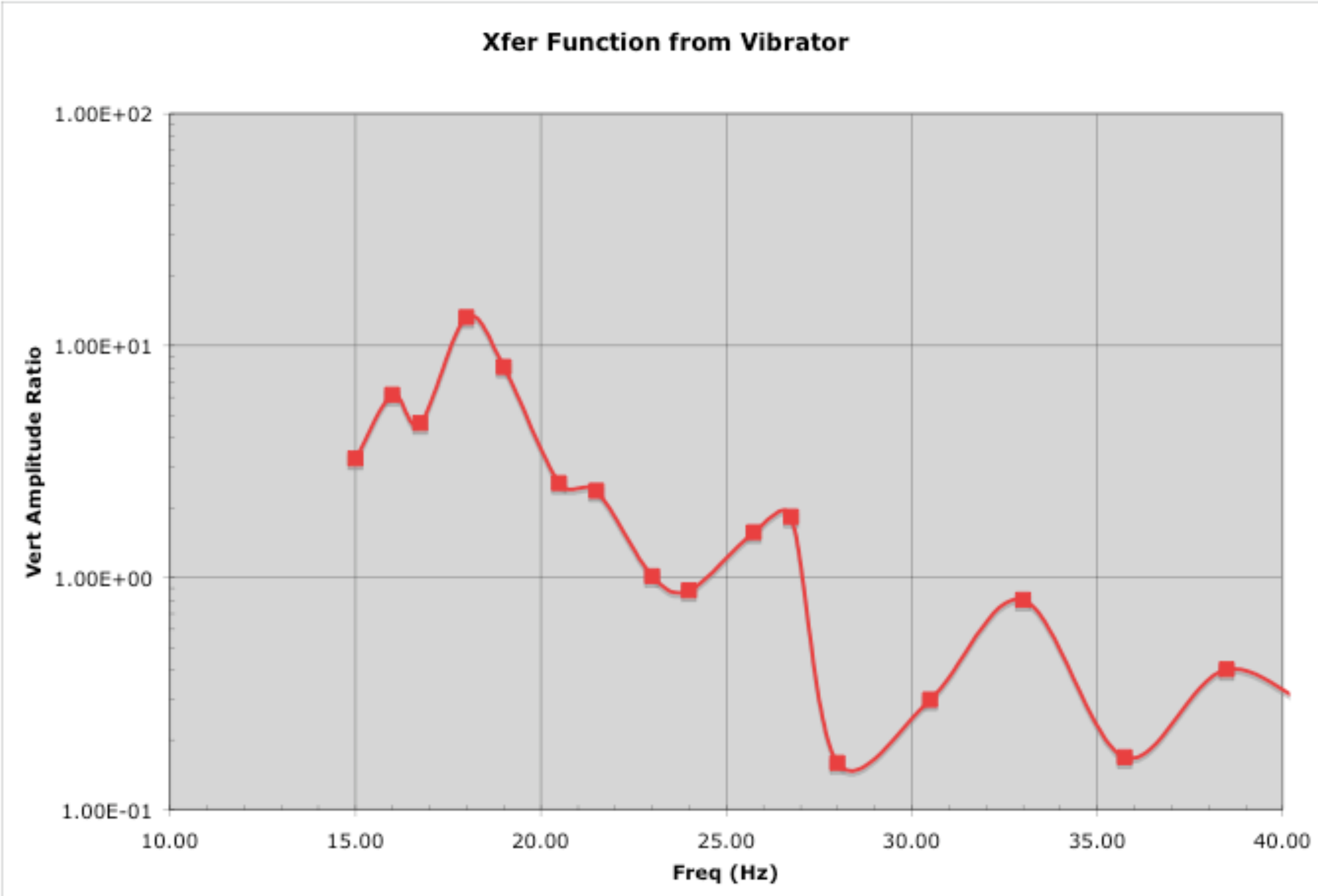


- Fundamental resonance measured at ~27 Hz; higher modes involve floor or sides
- Simulations give fundamental ~34 Hz (~20% difference)

Concrete Model Validation: Shielding Slab

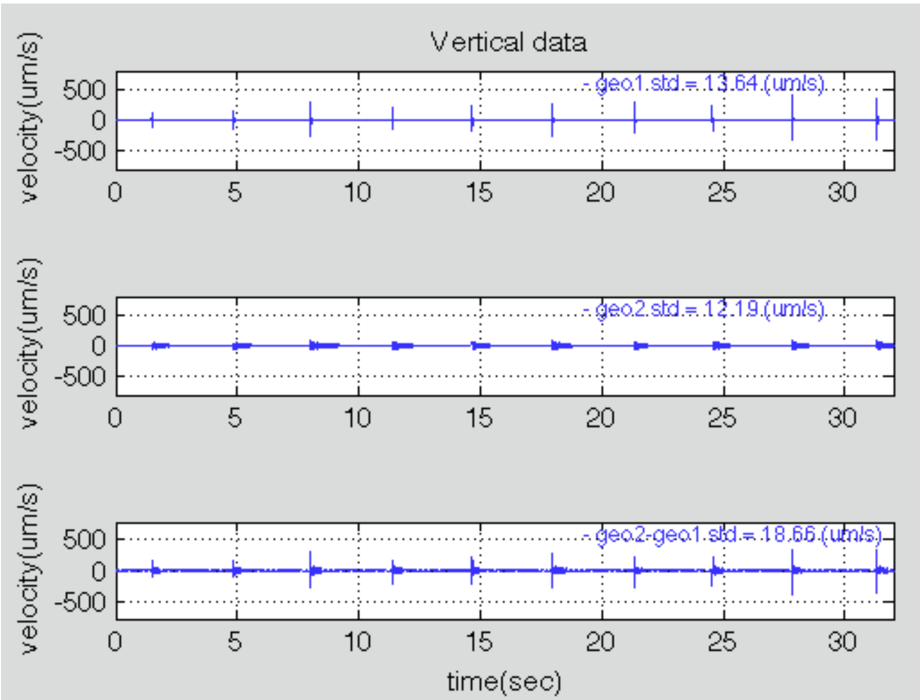
- Concrete slab supported by wooden blocks on concrete pad

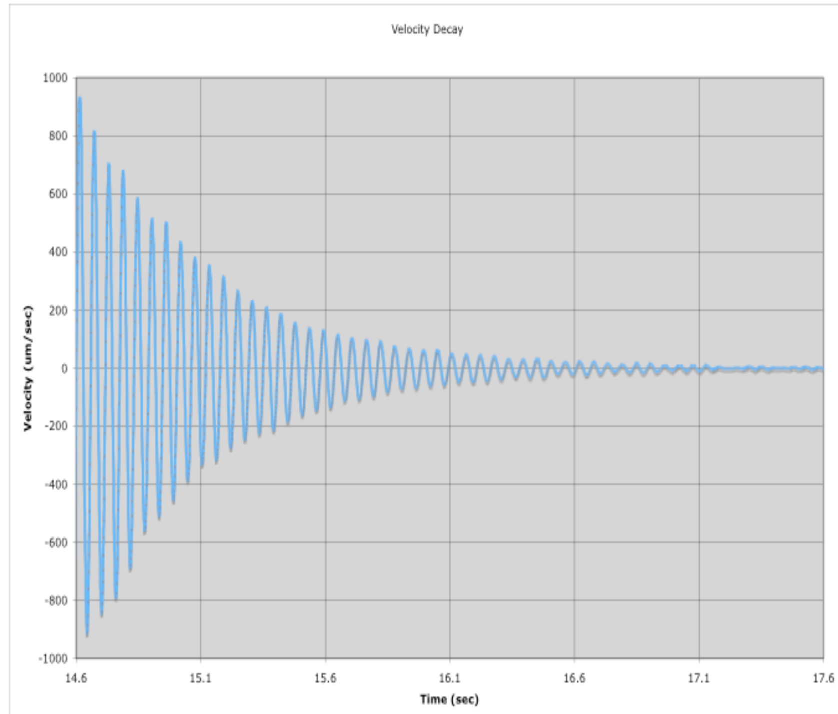
Transfer Function from Vibrator; Slab/Ground



- Modes: ~18 Hz; ~27 Hz; maybe ~33 Hz?
- Simulations give fundamental ~37 Hz

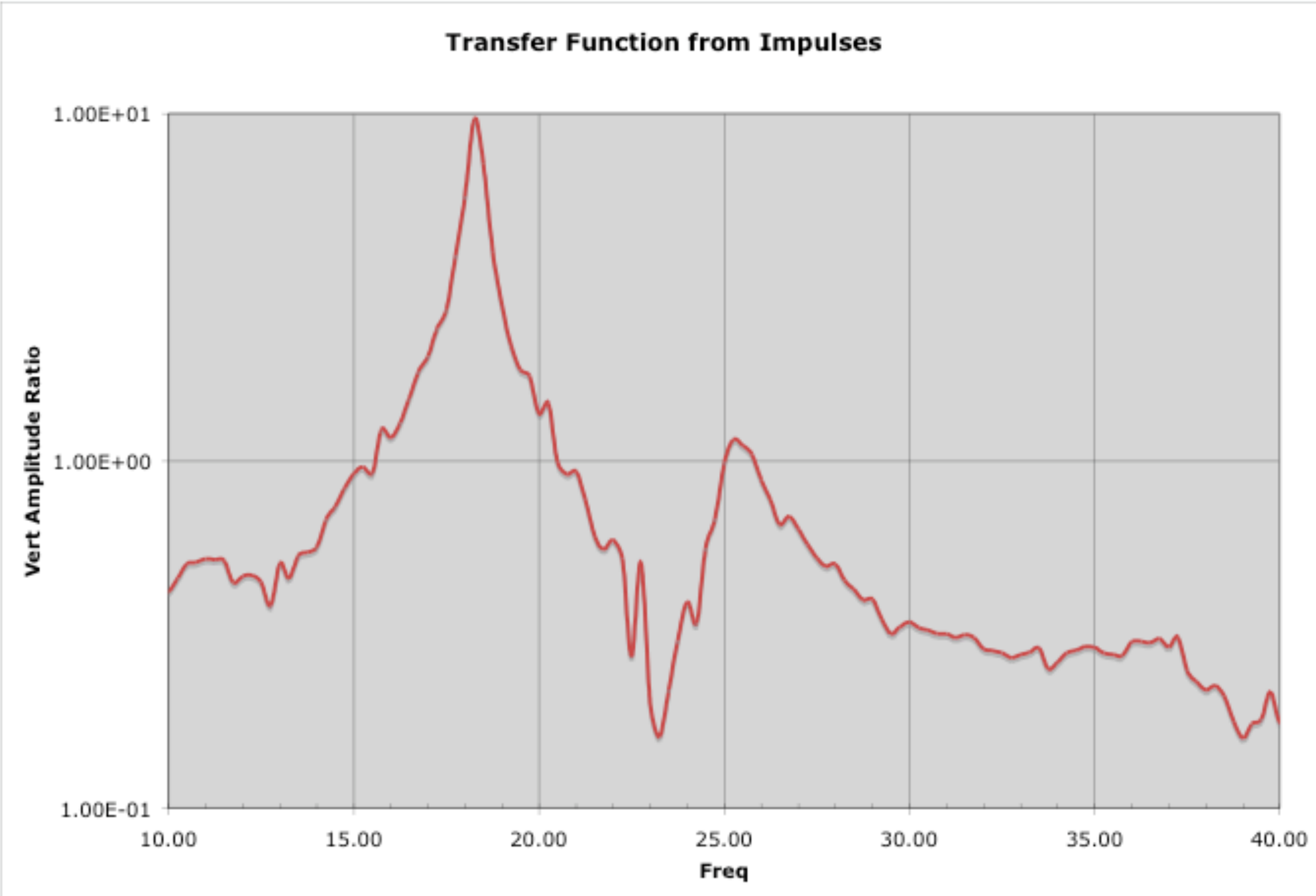
Impulse Response





- Complementary to vibrator data
  - Vibrator emphasizes HF
  - Impulse emphasizes LF
- Allows experimental determination of dominant mode freq and damping factor

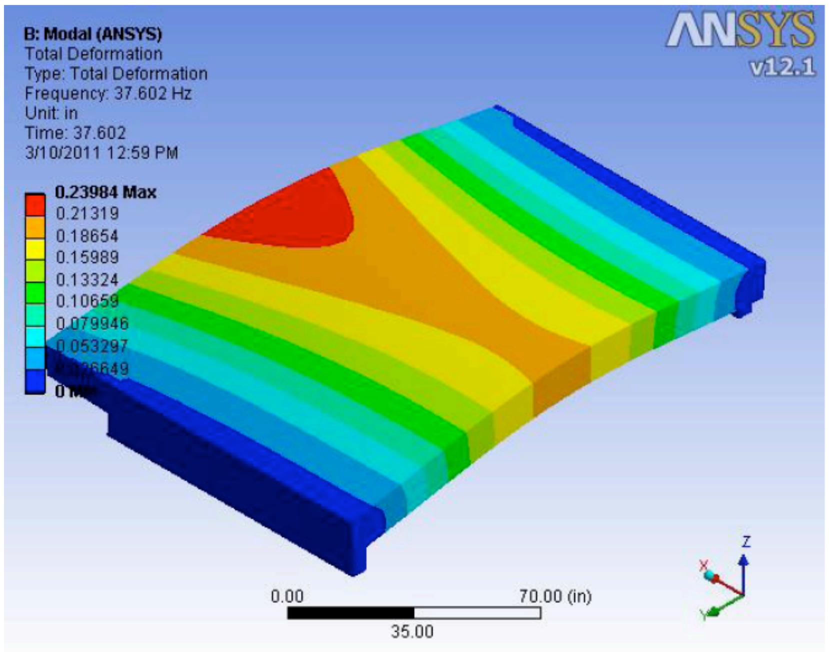
Transfer Function from Impulses; Slab/Ground

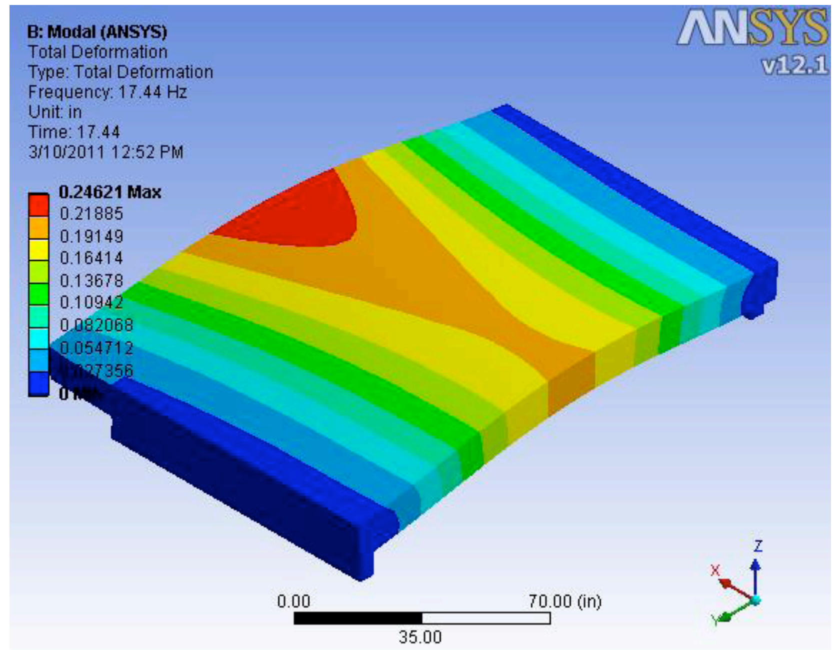


- Modes: ~18 Hz, 1.6% damping; ~25 Hz, 2% damping; maybe ~37 Hz?
- Simulations give fundamental ~37 Hz

1st mode SLAC Concrete

E= (2.4E10 Pa) vs (4e9 Pa)



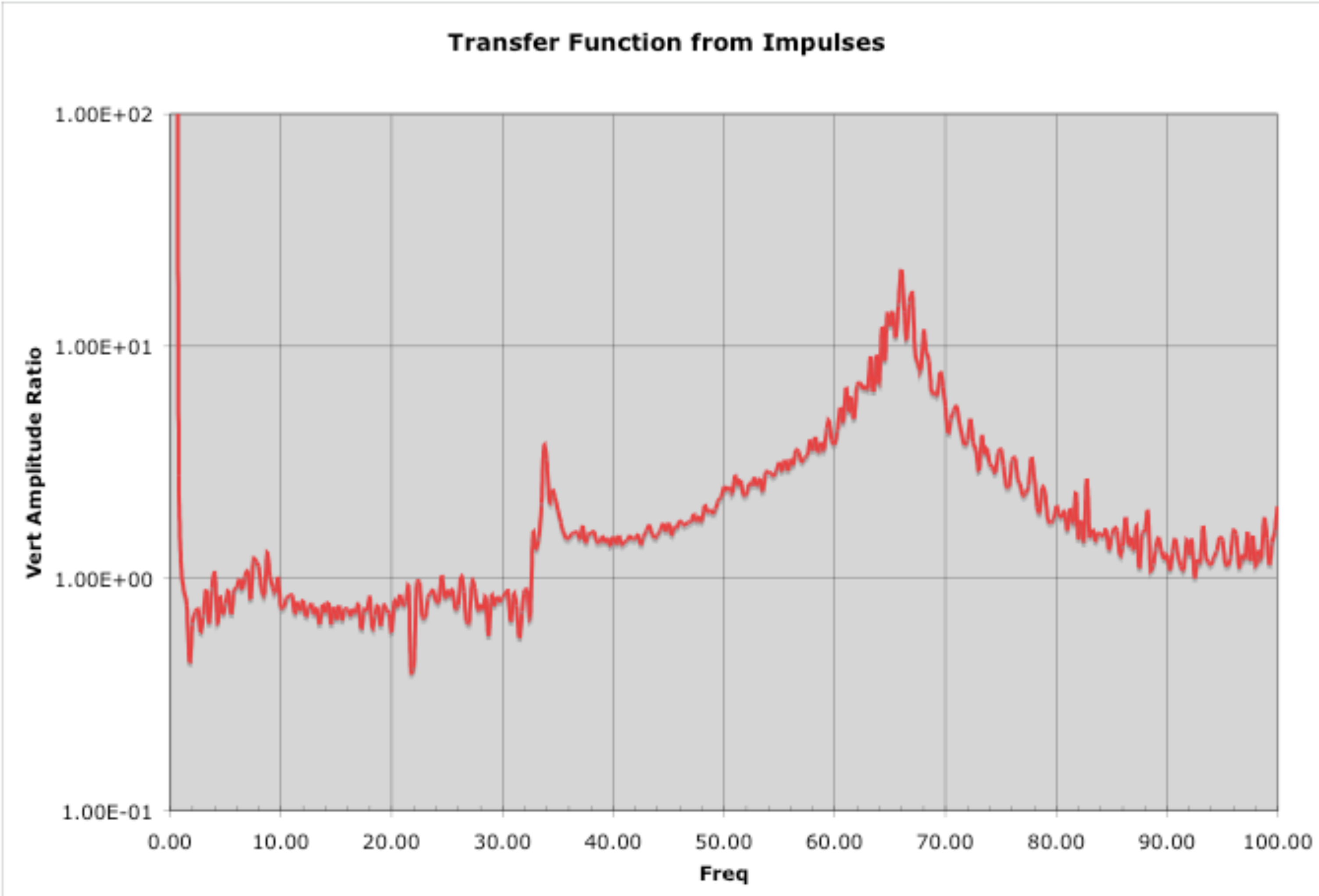


- 37 Hz with “correct” elastic modulus (2.4E10)
- 17 Hz with 5x lower elastic modulus (4E9)
- ~18 Hz measured experimentally

Concrete Model Validation: Small Shielding Block

- Concrete beam supported by steel I-beams on concrete pad

Transfer Function from Impulses; Beam/Ground



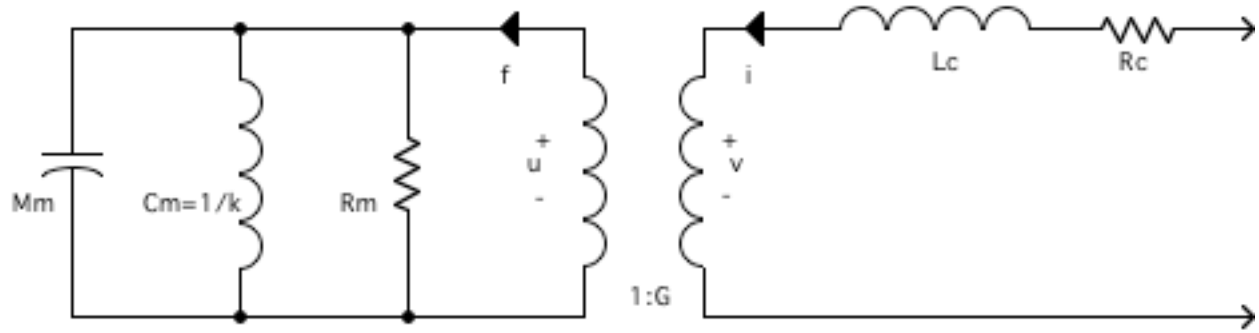
- Fundamental mode: ~34 Hz, 1% damping
- Dominant ~65 Hz peak not fully understood (Node on concrete pad at sensor location? Steel I-beam modes?)

Summary and Conclusions

- Vibration amplification in large, well-designed detector (based on SLD)
  - Expect up to 10x amplification of ground in 5-200 Hz freq band
  - Expect 2-5x amplification integrated above 5 Hz
- Concrete model validation (preliminary)
  - Measured resonant freqs lower than models
    - Microcracking? Nonlinearity?
    - Real elastic modulus lower than model?
  - Measured damping factors ~2x lower than models
  - Experimental setups add complexity not included in models; sims and expts need to be better matched
    - Ground and supports have their own modes
    - Can get "rocking" motion on supports

SLAC NATIONAL ACCELERATOR LABORATORY

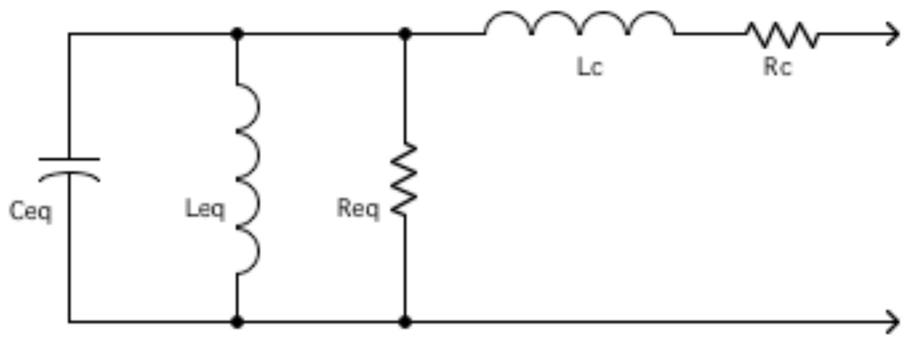
Electro-Mechanical Circuit

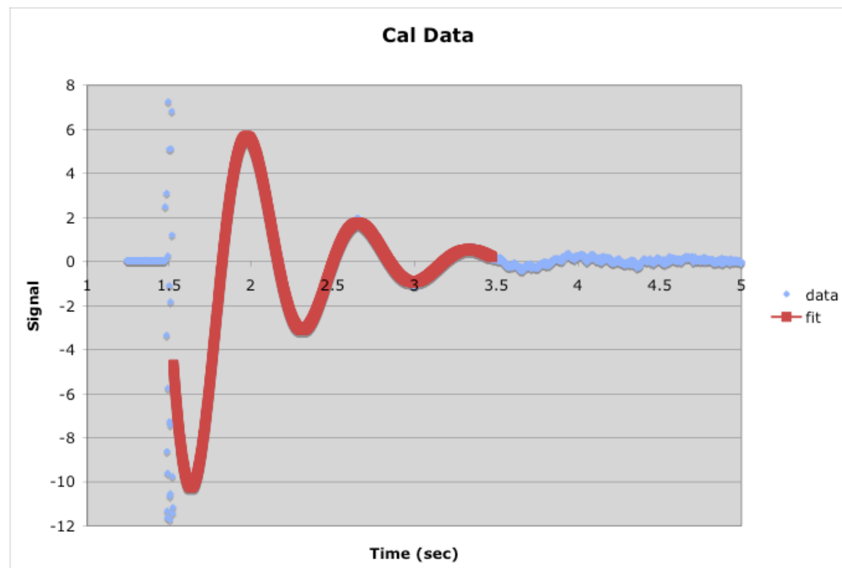


- Mm: mechanical mass [kg]
- Cm: mechanical compliance = 1/k [m/N]
  - k: spring constant [N/m]
- Rm: mechanical resistance = 1/c [m/s/N]
  - c: viscous damping constant [N/(m/s)]
- Lc: voice coil inductance [H]
- Rc: voice coil resistance [Ω]
- Voice coil acts as electro-mechanical transformer
  - "Turns ratio" 1:G G = BL [T m]
  - Current transforms to mechanical force
  - Mechanical velocity transforms to voltage

Geophone Calibration

- Calibration coil method
  - "Normal" calibration method
- Signal coil method
  - Less reliance on mfgr data (only Mm)
  - Proposed by Peter Rodgers et al, Bulletin of the Seismological Society of America, Vol. 85, No. 3, pp. 845-850, June 1995





- Signal coil calibration:
  - Drive current i_0 thru voice coil
  - Switch current off
  - Record transient voltage V(t) at voice coil
  - Fit data to damped sinusoid
  - Find f_0, α (and ζ), G

$$V(t) = Ae^{-\alpha t}\sin(\omega t + \phi) + c$$

$$\omega_0^2 = \omega^2 + \alpha^2 \qquad G^2 = \frac{A\omega_0 M_m}{i_0}$$

$$\zeta \equiv \alpha / \omega$$

Data

- #4723 (Vertical)

	Mfgr	Measured & Calculated
M_m [kg]	0.981	
R_C [Ω]	5500	5575
f_0 [Hz]	1.0	1.496 ± 0.001 (stat)
α [Hz]	~1.76	1.745 ± 0.005 (stat)
$\zeta = \alpha/\omega_0$	~0.28	0.1857 ± 0.0003 (stat)
G [V/(m/s)]	~275	270 ± 1 (stat)

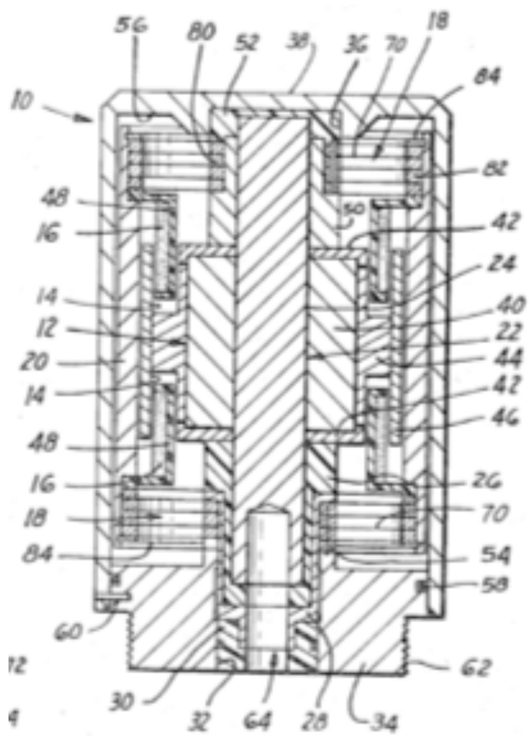
- #L41196 (Horizontal)

	Mfgr	Measured & Calculated
M_m [kg]	0.9677	
R_C [Ω]	5500	5600
f_0 [Hz]	1.0	1.501 ± 0.002 (stat)
α [Hz]	~1.76	1.730 ± 0.002 (stat)
$\zeta = \alpha/\omega_0$	~0.28	0.1836 ± 0.0002 (stat)
G [V/(m/s)]	~275	281.5 ± 0.3 (stat)

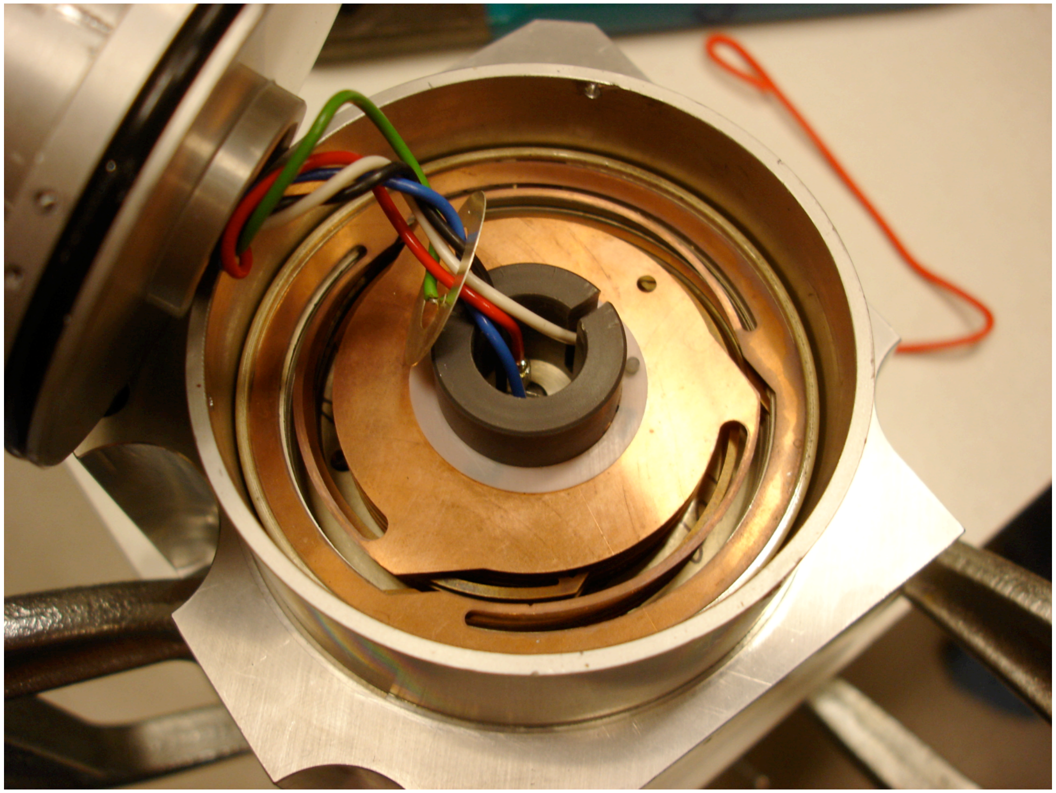
Calculation of f_0 and α should be very robust
Calculation of sensitivity G depends on i_0 and M_m (could have systematics)

Problem

- f_0 wrong by ~50%!
  - Gordon Bowden saw similar problem years ago
  - Consistent with change in spring constant. Mfgr says spring can sag over time; storing upside down may help.
  - Sensor still functional

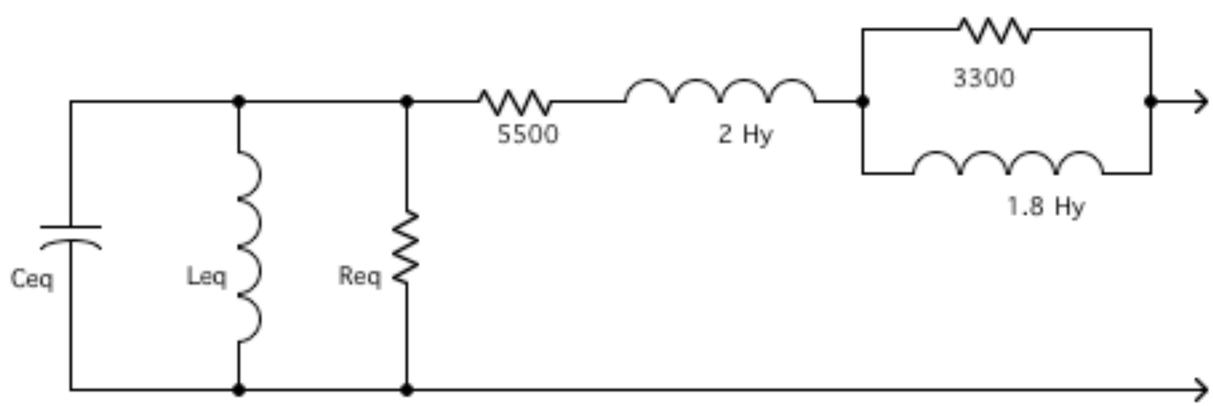


from US Patent #3451040

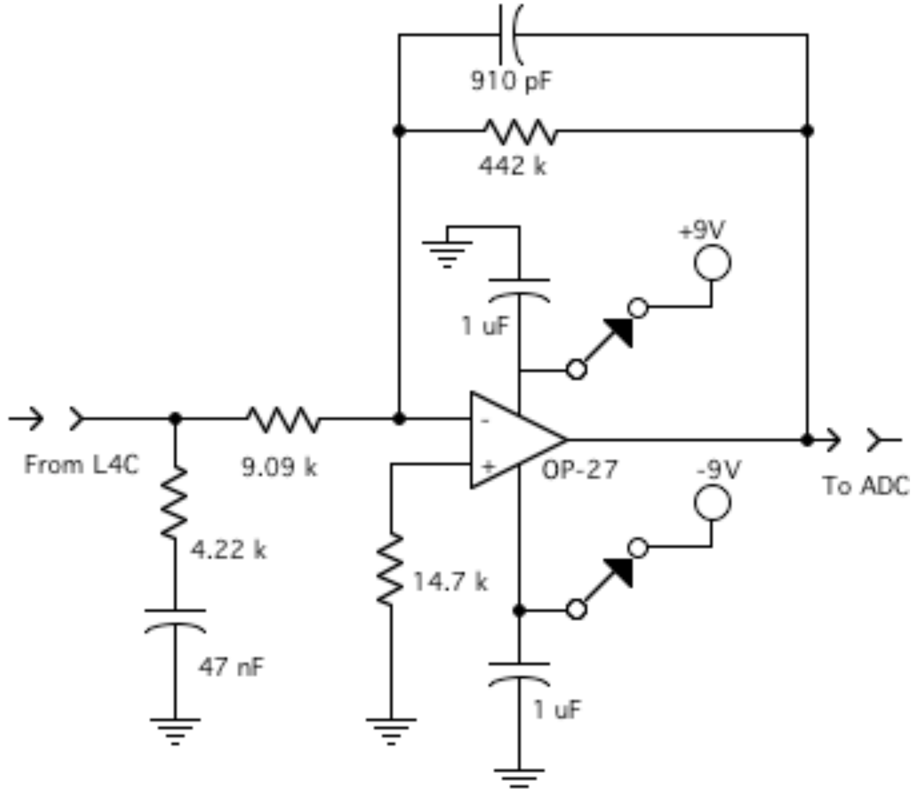


L4C Geophone Equivalent Circuit

- Manufacturer data sheet values
  - Rc = 5500 ohms
  - Lc = 6 Hy
- Voice coil behaves like “lossy” inductor
  - VC inductance is effectively frequency-dependent
  - Well-modeled by circuit below
  - We assume that effective turns ratio G is not frequency-dependent

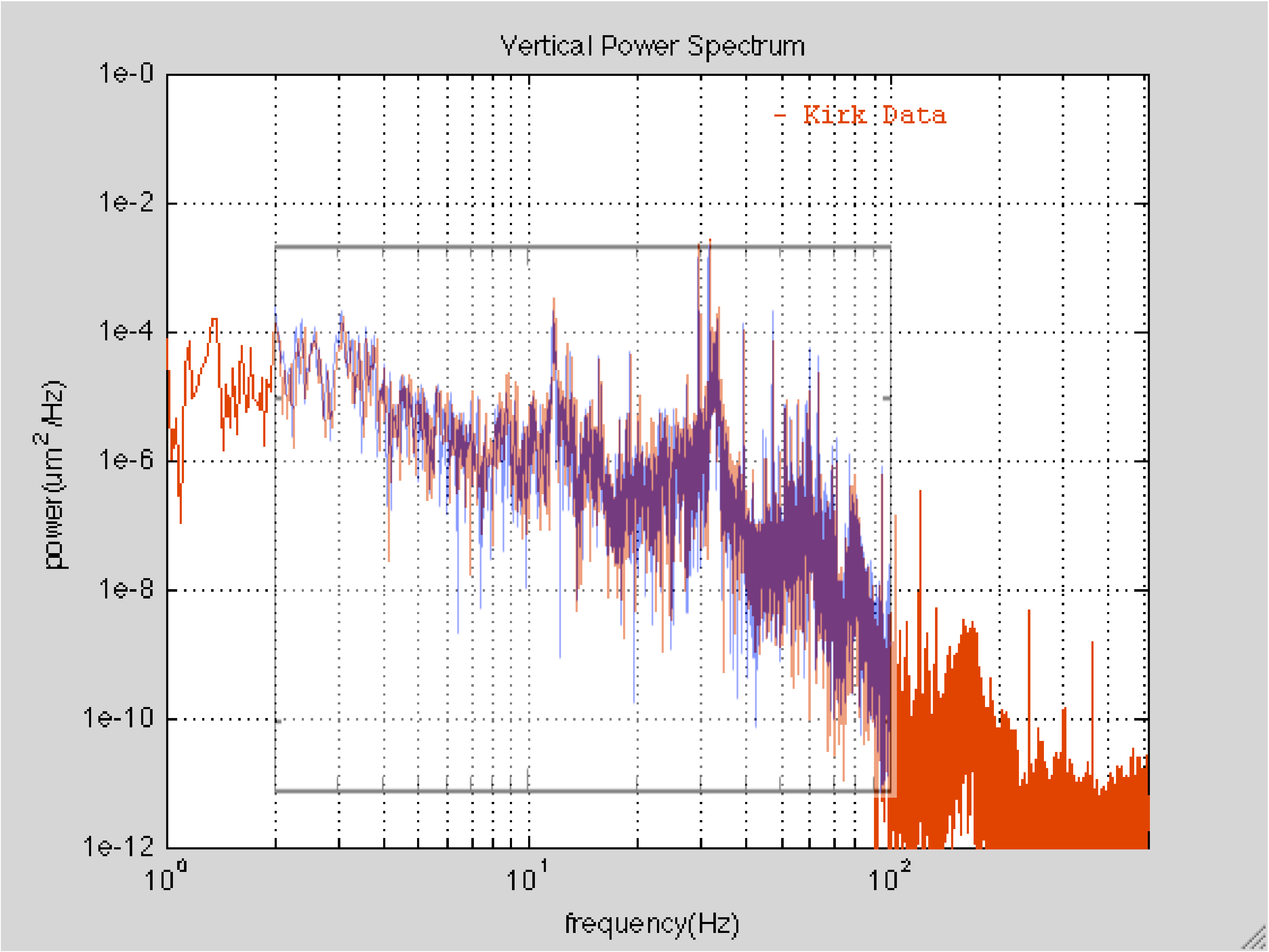


Battery-Powered Preamp



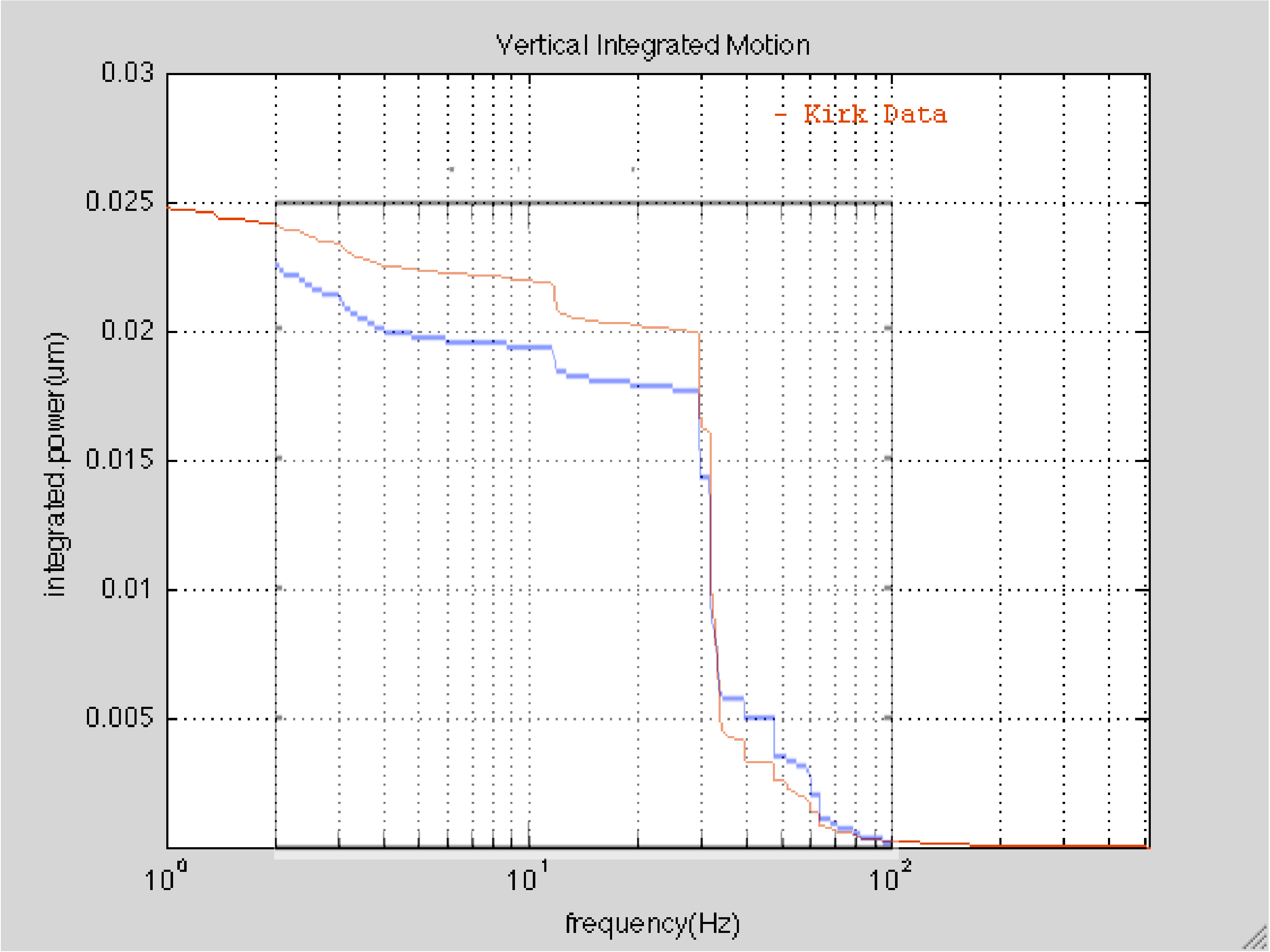
- Gain of -30x with 5500-ohm L4C geophone/seismometer
- Damping of 0.707 with good 5500-ohm L4C
  - 2-pole Butterworth HPF response at ~1 Hz
- Low-pass anti-alias filter
  - 2-pole critically coupled LPF response at ~400 Hz
  - RC network on input corrects for lossy VC behavior

Data Comparison



- Blue: Jim Turner's Data; Red: Kirk's Data (1 x 32 sec, Hanning window)

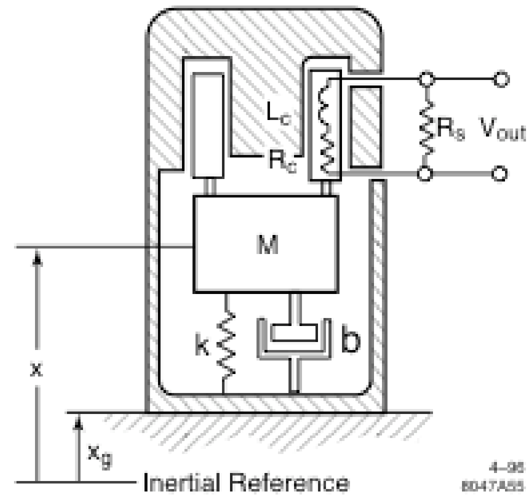
Data Comparison



- Blue: Jim Turner’s Data, 22.6 nm integral; Red: Kirk’s Data, 23.9 nm integral (1 x 32 sec, Hanning window)

Sercel L4C Seismometer/Geophone

- Simple damped mass-spring system
  - ~1 kg mass
  - ~1 Hz resonant frequency; acts as high-pass filter
  - Mechanical damping ~0.2
  - Appropriate Rs increases damping to ~0.707 (smoothest LF response)



from NLC Zeroth-Order Design Report, Snowmass 96

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