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Single Stage Platform Experiment Setup and First Results

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Abstract

This report describes a single stage platform experiment constructed at Hytec as a tool for validating spring models and analytical prediction techniques for the LIGO seismic isolation systems. Initial test data is also presented and compared to analytical predictions. Analytical-experimental agreement is shown to be excellent, confirming the validity of the spring models and lumped parameter modeling techniques implemented in MATLAB.

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LIGO PROJECT

Table of Contents

1. Motivation

The single stage platform experiment has two primary goals:

1. provide experimental validation of lumped parameter modeling techniques (Hytec/MATLAB dynamic modeling toolbox[1]).
2. provide independent cross-checking opportunities for semi-empirical models[2] of the coil spring. Those models are obtained by averaging and smoothing of direct stiffness and damping measurements of individual springs on the pendulum apparatus[3].

In addition, it constitutes a first step in preparing hardware and software capabilities which will be used for dynamic characterization of the full-scale BSC first article stacks.

2. Description of Test Setup

The setup (Fig. 1) consists of a single square aluminum platform (32"×32"×3", 300 lb) suspended on 3 damped coil springs and resting on a massive steel/concrete inertial block.

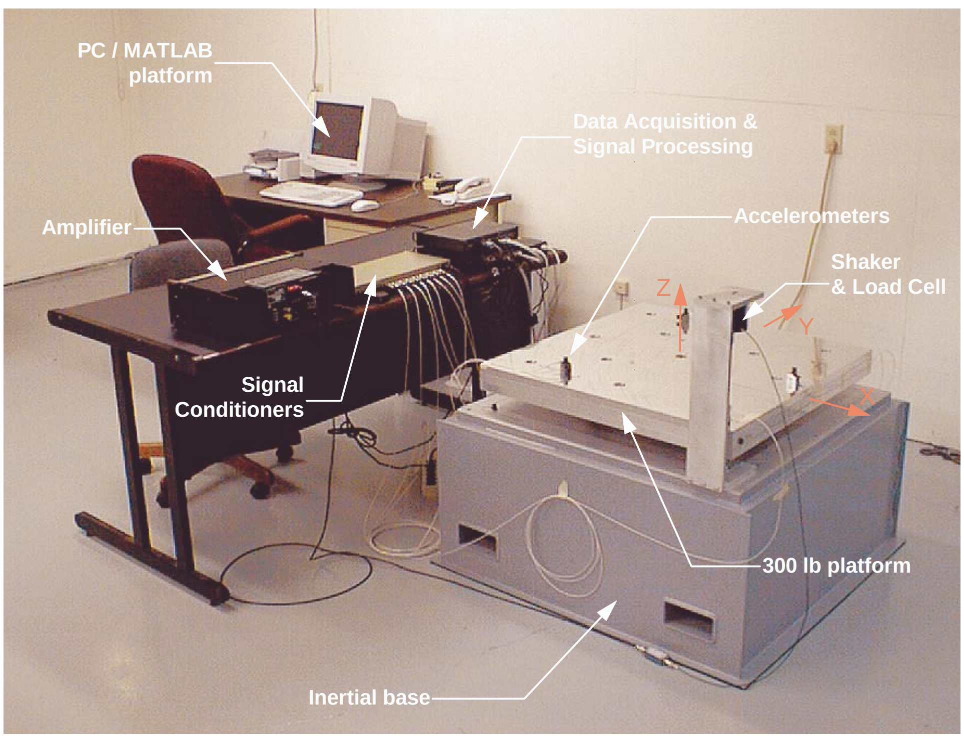

Figure 1: Experimental setup, showing single stage platform on base (with Z shaker), instrumentation electronics, and computer platform.

The springs are located symmetrically under the platform (Fig. 2), so that they are pre-loaded to the nominal 100 lbf each. The radius R can be adjusted to vary natural frequencies and mode shapes.

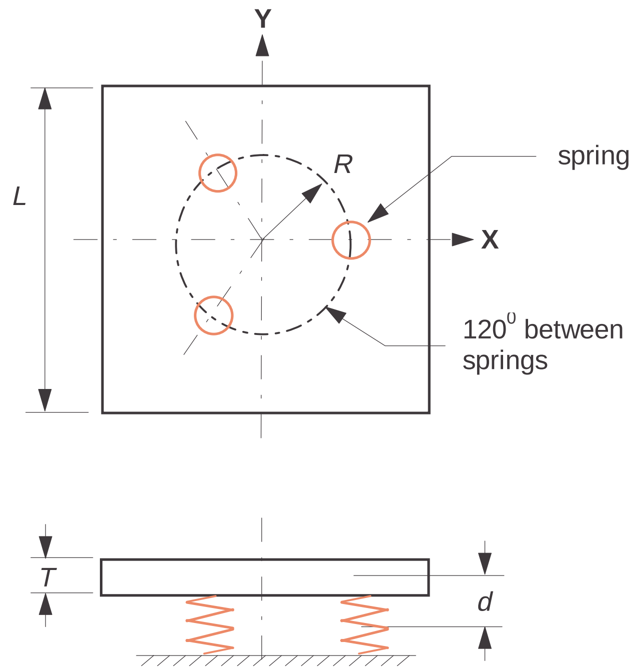

Figure 2: Platform layout showing spring locations (not to scale).

The platform is instrumented for 6 degree of freedom motion measurement (Fig. 3) with 6 piezoelectric accelerometers, placed in groups of 2 at 0, 120, and 240° at a 14" radial offset from the center of the platform (each group consists of 1 vertical accelerometer and 1 horizontal along the tangent to the 14" circle). A shaker is mounted on a stand and excites the front right (+X, -Y) corner of the table; the excitation point is at (14.5, -14.5, 0)" in a reference frame centered at the platform center of mass and shown in Figures 1, 2, and 3. The shaker is connected to the platform through a nylon stinger rod and a piezoelectric load cell.

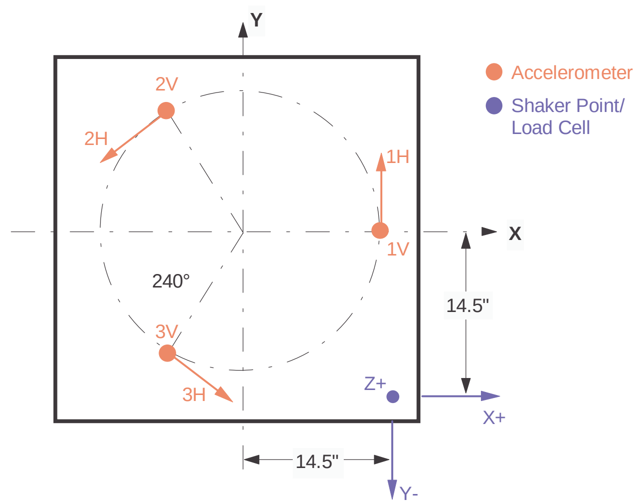

Figure 3: Top view of platform showing accelerometer and shaker / load cell locations.

The accelerometers and the load cell are connected to a signal conditioner and into a digital signal processing unit that performs the data acquisition, windowing, and FFT and transfer function calculations as well as generates excitation signal for the shaker (band limited white noise). The DSP system is controlled by GUI software in the MATLAB environment (Fig. 4). The test is setup to measure 6 complex transfer functions from excitation force to response accelerations; the test data is downloaded from the DSP unit directly into MATLAB for processing and analysis.

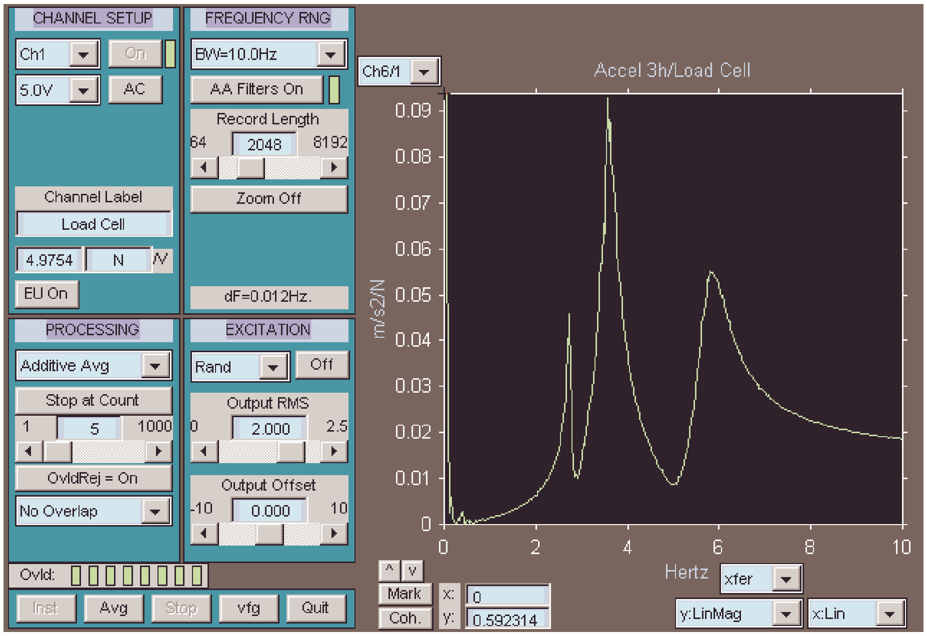

Figure 4: Typical measurement GUI of the Virtual Network Analyzer.

The transfer functions can then be used in two ways to confirm analytical models: direct comparison of transfer function curves or extraction of modal parameters/spring properties via numerical modal identification techniques. The *Structural Dynamics Toolbox* for MATLAB is available for that purpose.

3. Analytical Model

3.1 Model Geometry

Mode shapes, natural frequencies, and transfer functions are calculated using our MATLAB lumped parameter modeling toolbox. Figure 5 shows the six degrees of freedom (DOF) of the platform (the colors in Fig. 5 correspond to those used in subsequent frequency plots).

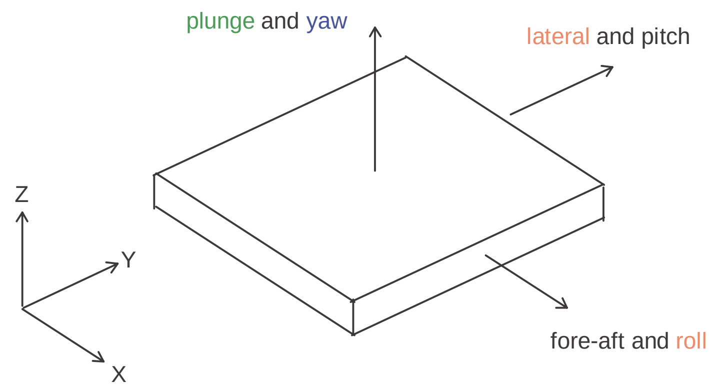

Figure 5: Rigid mass plate showing six degrees of freedom.

Fore-aft, lateral, and plunge are linear DOF along X, Y, and Z axes, respectively; while roll, pitch, and yaw are rotation DOF about the X, Y, and Z axes. The spring location radial distance (R) from the center of mass (cg) can be adjusted from 6 inches to 14 inches, in 2 inches increments.

3.2 Spring Properties

Spring stiffness and loss factors are obtained from measured data reported in reference [2]. Frequency response functions are computed using frequency dependent spring properties (stiffnesses and loss factors).

3.3 Model Dimensions, Mass, and Moments of Inertia

The rigid plate mass and moments of inertia about the model center of gravity are given by

$$
\begin{aligned}
M &= \rho L^2 T, \\
Ixx &= \frac{M}{12}(L^2 + T^2), \\
Izz &= \frac{M}{12}(L^2 + L^2),
\end{aligned}
\tag{1}
$$

where M, ρ, L, T, Ixx, and Izz are the plate mass, density, length, moment of inertia about the x and y axes; respectively. The plate is square thus the mass moment of inertia Iyy equals Ixx. Dimensions and inertia properties of the platform are listed in Table I.

Property	Value
Length or width (L) m	0.812
Thickness (T) m	0.0762
Density (ρ) kg/m^3	2700
Mass (M) kg	135.65
Moment-of-inertia (Ixx or Iyy) kg-m^2	7.519
Moment-of-inertia (Izz) kg-m^2	14.907

Table I: Platform dimensions, mass and inertia values.

3.4 Calculated Model Frequencies, Damping and Mode Shapes

Natural frequencies and damping ratios of the six suspension modes are plotted as a function of the springs radial location in Figures 6 and 7. The different colors denote different mode shapes as indicated in the legend. In Figure 6a, spring properties (stiffness and loss factor) are fixed to their values at 4.5 Hz, while in Figure 6b the spring properties are a function of frequency.

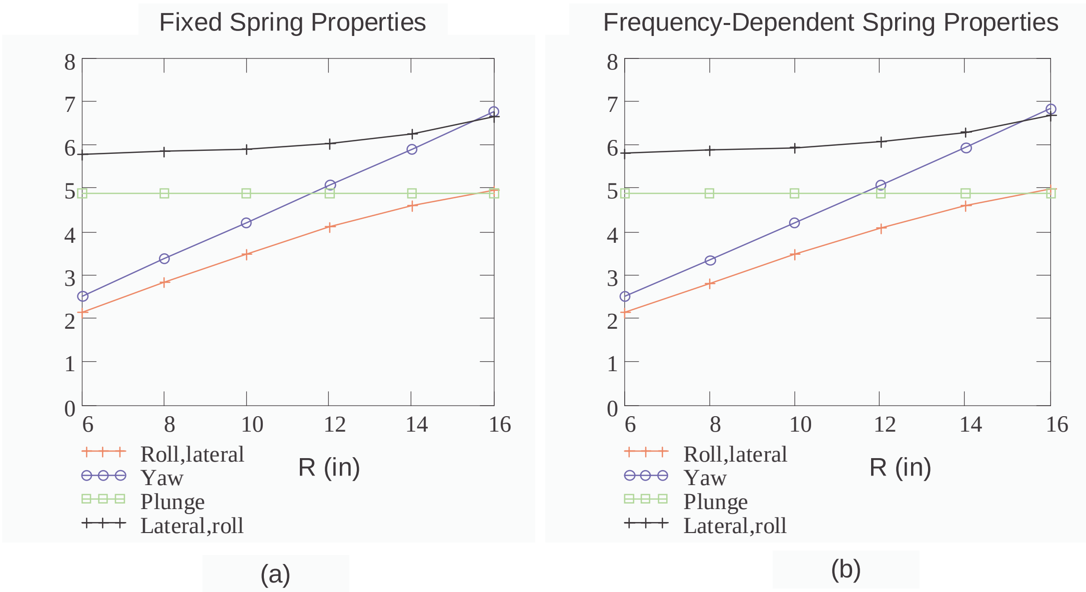

Figure 6: Calculated frequencies for the six mode shapes of the single stage platform; (a) was obtained with fixed spring properties (4.5 Hz reference); (b) was obtained with frequency dependent spring properties.

Examination of Figure 6 reveals very little difference between the natural frequencies obtained with fixed or frequency-dependent properties (the springs stiffnesses are only weakly frequency dependent between 2 and 8 Hz).

Modal loss factor, however, is more strongly influenced by the frequency-dependence in the spring loss factors as seen in Figure 7.

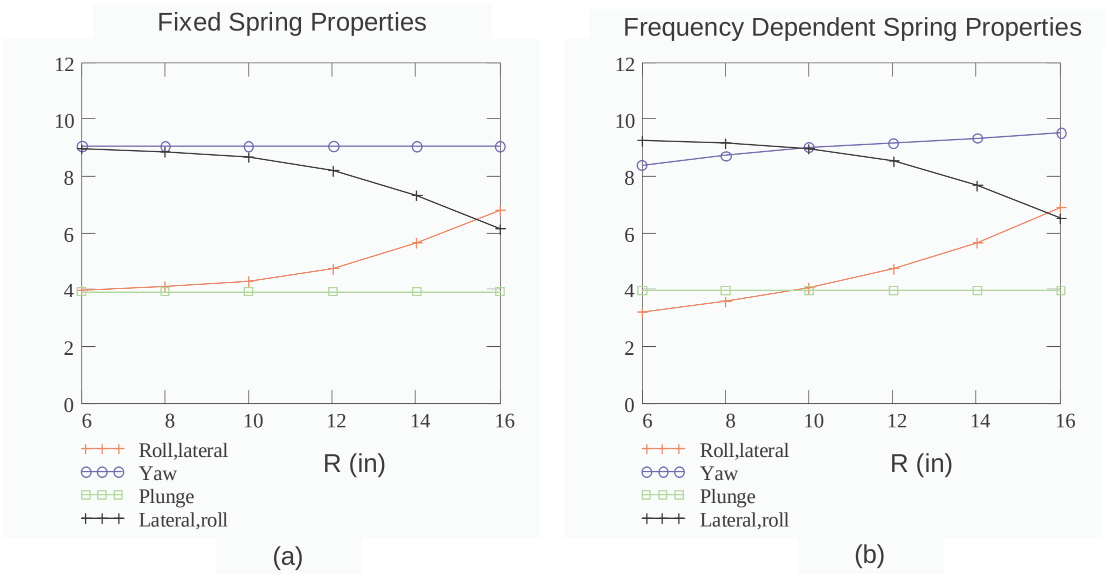

Figure 7: Calculated loss factors for the six mode shapes of the single stage platform; (a) was obtained with fixed spring properties (4.5 Hz reference); (b) was obtained with frequency dependent spring properties.

Figure 7 shows that all but the plunge mode exhibit a frequency dependence effect for loss factor. Because the plunge mode frequency remains constant with spring position and because the fixed frequency (4.5 Hz) is close to actual plunge frequency the effect of frequency dependent properties is negligible on that mode's loss factor.

4. Sample Measured Data

Preliminary data was acquired to confirm the proper operation of the experimental setup and instrumentation. The 3 springs were placed at a R=10" offset form the center of the platform and transfer functions were measured for three excitation directions (X+, Y-, and Z+ as shown in Fig. 3). For each excitation direction, frequency response functions were measured from the excitation force (N) to each accelerometer response (m/s^2). The excitation signal was a band limited white noise from 0 to 10 Hz. For each excitation direction, five samples were averaged to filter out noise; the excitation level during these initial measurements was such that the largest peak-to-peak motions on the platform were of the order of 2 mm.

The measured transfer functions were downloaded into MATLAB and are compared to analytical predictions in Figures 8, 9, and 10 for X+, Y-, and Z+ excitations, respectively.

Analytical-experimental agreement is clearly excellent and was obtained without any adjustments in the models. In particular, note the excellent agreement in peak amplitudes which confirms the spring loss factor data obtained with the pendulum instrument. Note also that our analysis (solid red curves) almost systematically overestimate resonant amplitudes by a few percent, and should therefore provide conservative estimates of the Q's of the LIGO stacks.

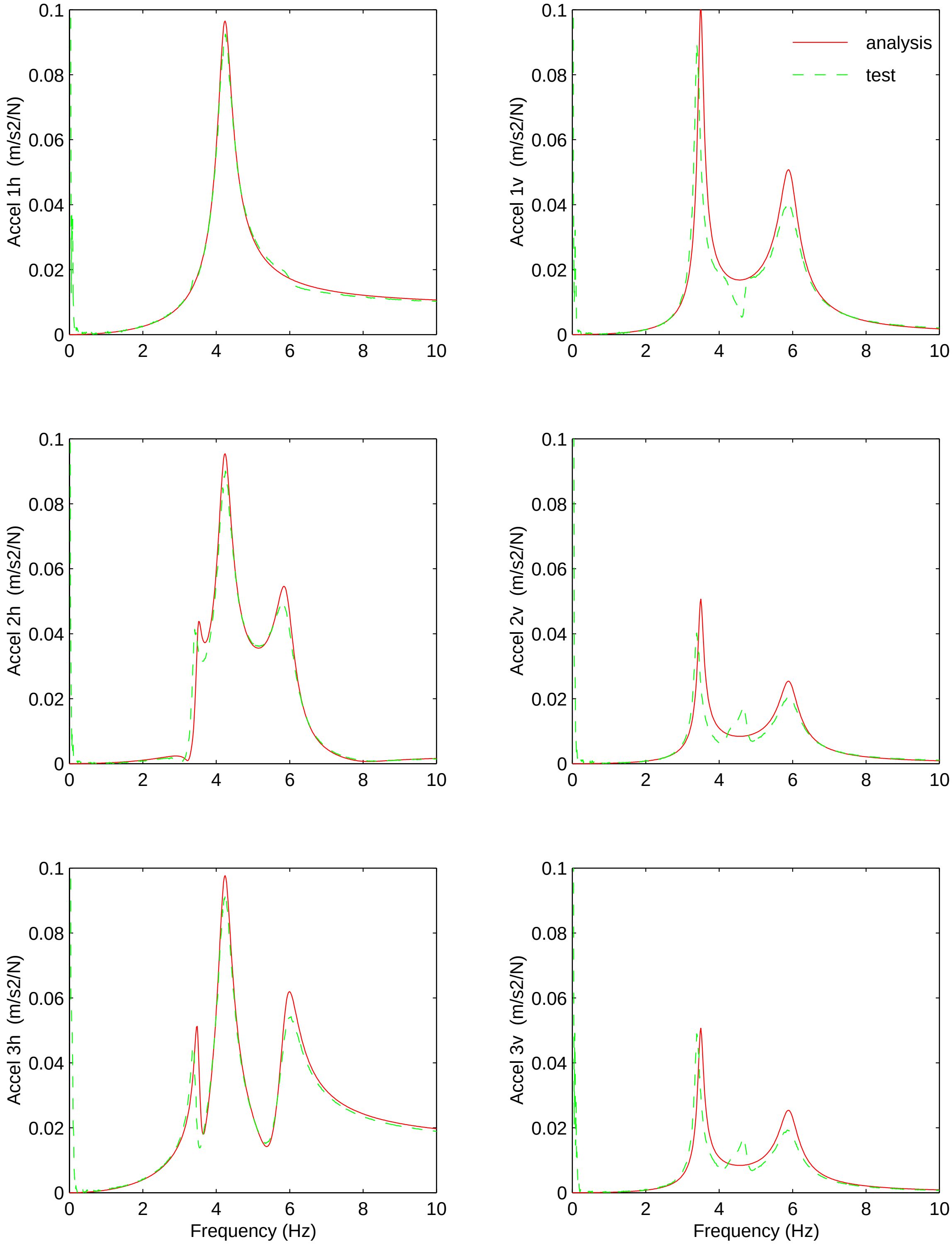

Figure 8: Test and analysis transfer functions for +X input force and 10 inch spring radius (test 091797_10_r_x+).

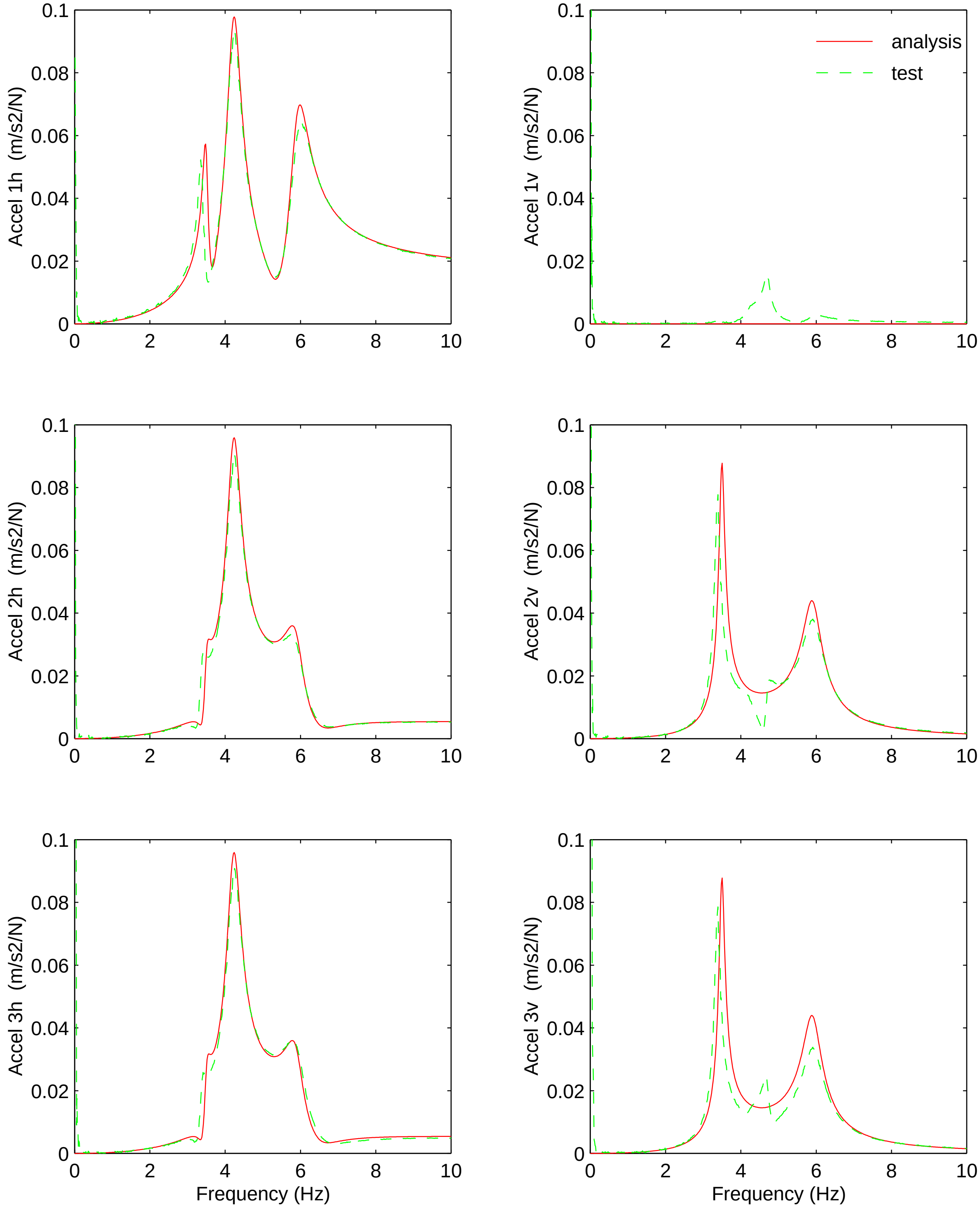

Figure 9: Test and analysis transfer functions for -Y input force and 10 inch spring radius (test 091797_10_r_y-).

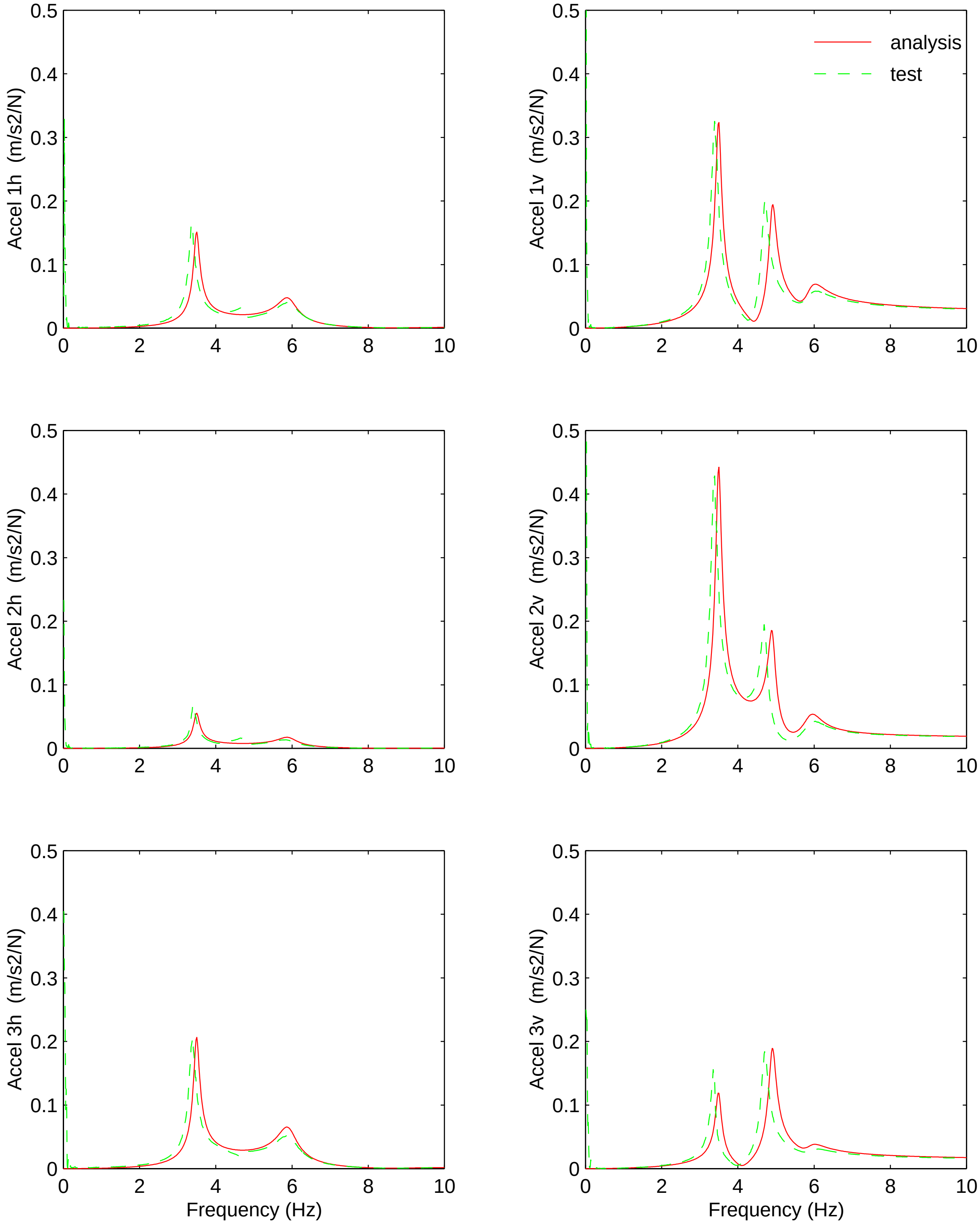

Figure 10: Test and analysis transfer functions for +Z input force and 10 inch spring radius (test 091797_10_r_z+).

5. Conclusions

A single stage platform experiment is now operational at Hytec. It can be used to measure dynamic behavior of a rigid body suspended on LIGO damped coil springs and provide validation of analytical models and techniques. Initial measurements show excellent data quality and almost perfect analytical-experimental fit. Analytically predicted resonant amplitudes (or Q's) tend to be slightly conservative as compared to experimental data.

6. References

1. E. Ponslet, *Isolation Stack Modeling*, HYTEC Inc., Los Alamos, NM, document HYTEC-TN-LIGO-01, January 1996.
2. F. Biehl, *LIGO Damped Coil Spring on Fluorel – Comparison of Mechanical Behavior for Six New Coils*, HYTEC Inc., Los Alamos, NM document HYTEC-TN-LIGO-27, September, 1997.
3. E. Ponslet, *Low Frequency Damping Measurement Setup and First Results*, HYTEC Inc., Los Alamos, NM, document HYTEC-TN-LIGO-17, June 1997.

Note 1, Linda Turner, 09/03/99 02:17:39 PM
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