New Folder Name Preliminary Estimate of Beam Tube Motion Induced by wind Noise

HYTEC, INC.

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May 9 , 1995

Dr. G. Sanders
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102 East Bridge Laboratory
Pasadena, Calif. 91125

Dear Gary:

I have enclosed a preliminary copy of the beam tube analysis that was not available earlier. I have also included a full size copy of the displacement response predictions, in the event that someone wants to present the results. The entire document was shipped to Mike Gamble at Florida yesterday.

Please call if you have any questions regarding the material.

Sincerely,

Bill

William O. Miller

LIGO
Beam Tube Dynamic Analysis

April 28, 1994

T. Thompson/W. O. Miller **HYTEC, INC**

Preliminary Estimate of Beam Tube Motion Induced by Wind Noise
T. Thompson May 7, 1995

Background: Wind induced vibration of the beam tube enclosure is an extremely complicated phenomenon. This note will address a simplified approach for estimating the beam tube motion induced by wind noise. We view this as an opportunity to quantify the motion of the beam tube before one proceeds into a more elaborate and detailed prediction using a refined FEM.

The fluctuating forces and loads are due to the turbulence, vortex shedding and eddies. Under the extremely tight time constraints some simplifying assumptions were made in order to bound this problem. In the note from R.Weiss he gives some basis for estimating wind loading on structures similar to those proposed for LIGO. It is this author's understanding that the loading presented by Weiss is for an idealized half-cylinder in cross flow, not for an elliptical structure currently being shown by CBI. These equations were used to make some intelligent assumptions about what could be expected in the way of wind coupling into the LIGO enclosure and then into the beam tube itself.

Analysis: The analyses were performed to estimate the beam tube motion were more complicated than what was originally anticipated. Two finite element models ultimately were employed to get the frequency range desired by LIGO. The first finite element model, shown in Figure 1, consisted of shell, solid, and pipe elements to represent the elliptical beam tube enclosure, the concrete slab, the beam tube, and the soil surrounding the sides of the enclosure (10 meters deep by 15 meters wide). The beam tube enclosure will be fabricated from of an elliptical precast 5 inch concrete shell. The enclosure will sit on a concrete foundation which most likely will be 6 inches in thickness. For our model, the beam tube support was placed close to what is currently shown in the CBI plans, which shows the tube offset approximately 1 meter from the centerline of the enclosure. The second finite element model is a subset of the first and it has only the beam tube modeled (pipe elements), with a boundary condition simulating a rigid connection to the floor.

Footing not included

In the large finite element model the low frequency soil response tends to dominate the calculation of mode shapes. In this low frequency range, the modal extraction process generates a large number of modes solely associated with soil response. For this reason, it was impractical to use just one large model to obtain the beam tube response over the frequency range of interest.

For the foregoing reason, we chose to determine the beam tube response in two steps. The approach of using two models afforded an opportunity to determine coupled soil/slab/tube modes which could not be identified with the idealized tube used in the large model. This approximate analysis approach bounded many aspects of the problem, while providing valuable insight into this problem. It should be emphasized that the primary objective was to "scope" the problem and determine the magnitude of vibration in the beam tube induced by wind loading.

Figure 2 shows the application of boundary conditions representing the wind load on the enclosure. This approximation to the wind loading as two discrete line loads, represent the drag and lift forces. This first order approximation cannot hope to capture the true pressure distribution on the structure which may ultimately be required in detailed simulation for LIGO.

The procedure used in this analysis was to use the equations developed by Weiss to estimate the input forcing function to the detailed model shown in Figure 1. This model because of it's large size captures only the first few beam tube modes. The dynamic results for this model quit at 25 Hz, which represent the first 75 modes of the model. The floor input vibration is captured from this model and transferred into the simpler beam tube model which has been used in prior analyses. This procedure should accurately capture most of the "interesting" vibratory modes. The slope, or roll-off, of the input vibrations decay rapidly with frequency in the larger model and this was also captured for input into the smaller model.

Seems unlikely

An assumption was made that the drag and lift force would be equal to one another for this effort. More detailed aerodynamic modeling could be undertaken later if needed in COSMOS to determine accurately the pressure loading around the enclosure. In addition, the point of application for the drag loads were placed approximately 1 meter off the floor, and at the apex of the enclosure for the lift loads. Although these locations are approximate, their placement will serve to quantify the displacement response of the structure.

Why? a stop work

The stop work order placed a time constraint on this task. It was not feasible to get all of the numeric results encompassing the lower wind speeds within the remaining time. We decided to present the "worst case" 50 MPH case. We presume the reader will scale the results to other wind velocities. This approach can be used since the "knee" in the critical frequency curve (f_c) fell well below our starting point of 2 Hz, for all wind speeds considered. The scaling factor is simply the ratio of the wind speeds raised to the 7/2 power. This factor is .0036 for 10 MPH and .021 for 30 MPH.

Results: The linearized displacement results for the beam tube are shown in Figures 3 through 5 for X, Y, and Z directions respectively. It is not apparent from figures, but in the large soil/slab/enclosure model there is a coupled mode at 12.1 Hz. We wish to point out that this coupling represents a factor of 4.5 increase in displacement over the previous "simple" beam tube model presented to LIGO through an earlier transmittal.

The results show that the anticipated maximum displacement of the beam tube is on the order of 25 microns at 12.1 Hz. It is our understanding that this magnitude will potentially pose a problem. The wind driven amplitude of the motions tend to roll off quickly with frequency, hence above 30 Hz the ground noise will tend to be the dominant factor of motion in the beam tube.

Conclusions: The results of this analysis would tend to confirm that wind induced vibrations could be an issue. The beam tube does not sit on an optical floor which would tend to mitigate these forces. The beam tube sits on a relatively thin concrete slab which can be effectively coupled to the wind induced vibrations. Although, the wind induced vibration will roll off quickly, there may be some unacceptable vibrations below 30 Hz.

It may be appropriate to run more detailed solutions of this problems where more realism can be put into studying the affects of soil depth and breadth on their contribution to model results. We would recommend one study variants of design and how they affect the response. Topical examples are:

- enclosure and the slab structural joint
- pressure distribution (center of pressure) on the enclosure
- effect of the actual enclosure geometry on the anticipated coupling to the wind

One could argue that the occurrence of a 50 mph wind may be quite infrequent, and that from operational standpoint the experiment will simply stand down for a period of time. If this philosophy were not adopted, and the vibration of the beam tube remains an issue, some further study implementing clever isolation ideas may be appropriate.

Agreed. Is there data on the frequency dist'n of wind speed at the sites?

References:

1. R. Weiss, *Preliminary Estimates for Wind Noise on the beam Tube Enclosure*, April 11, 1995

How were these wind force PSDs developed?

Constitutive model for soil for ucm motion? Comparison to test data? ⇒ Probably a linear model response

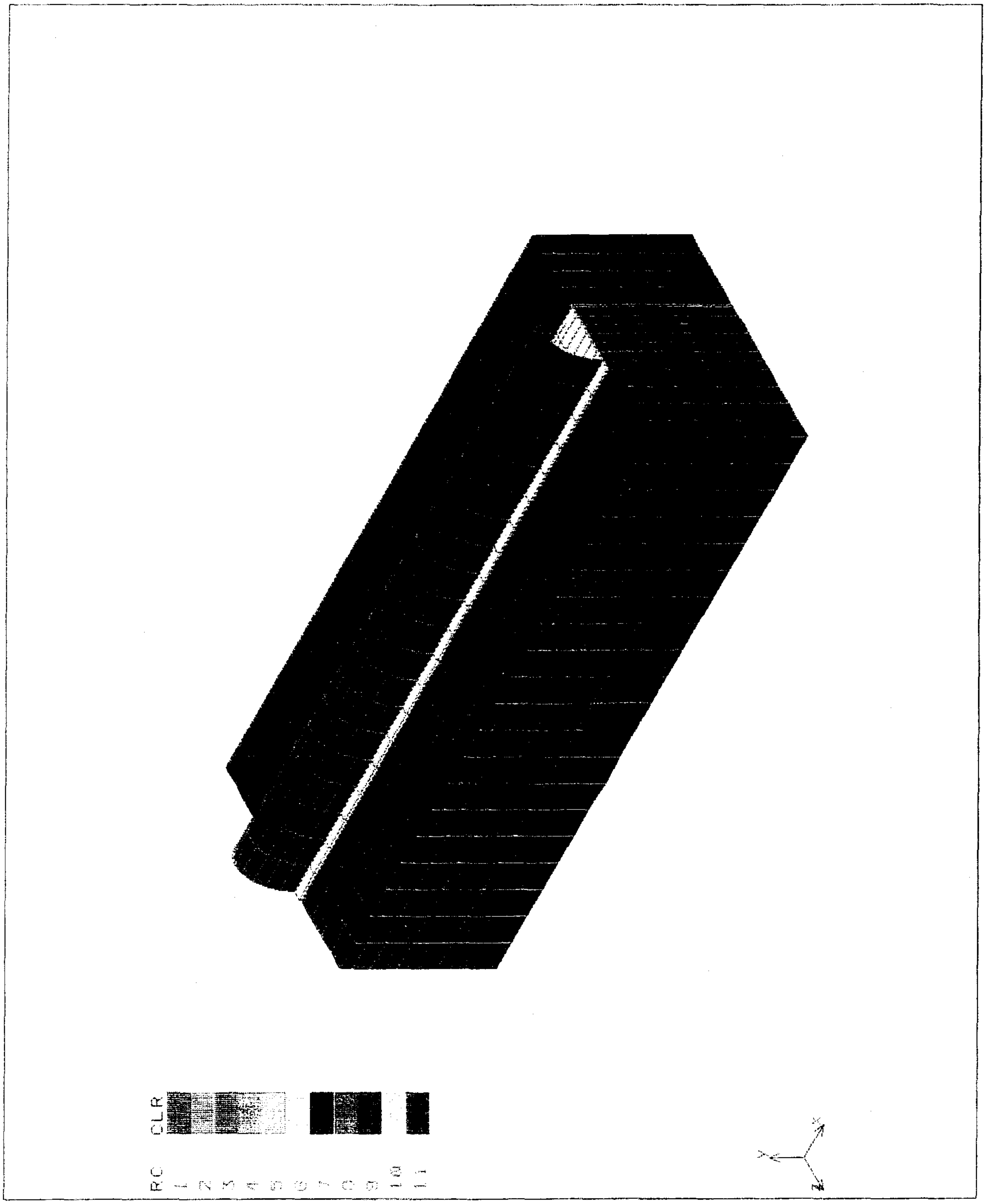


Figure 1. LIGO Soil/Slab/Enclosure and Beam Tube Finite Element Model.

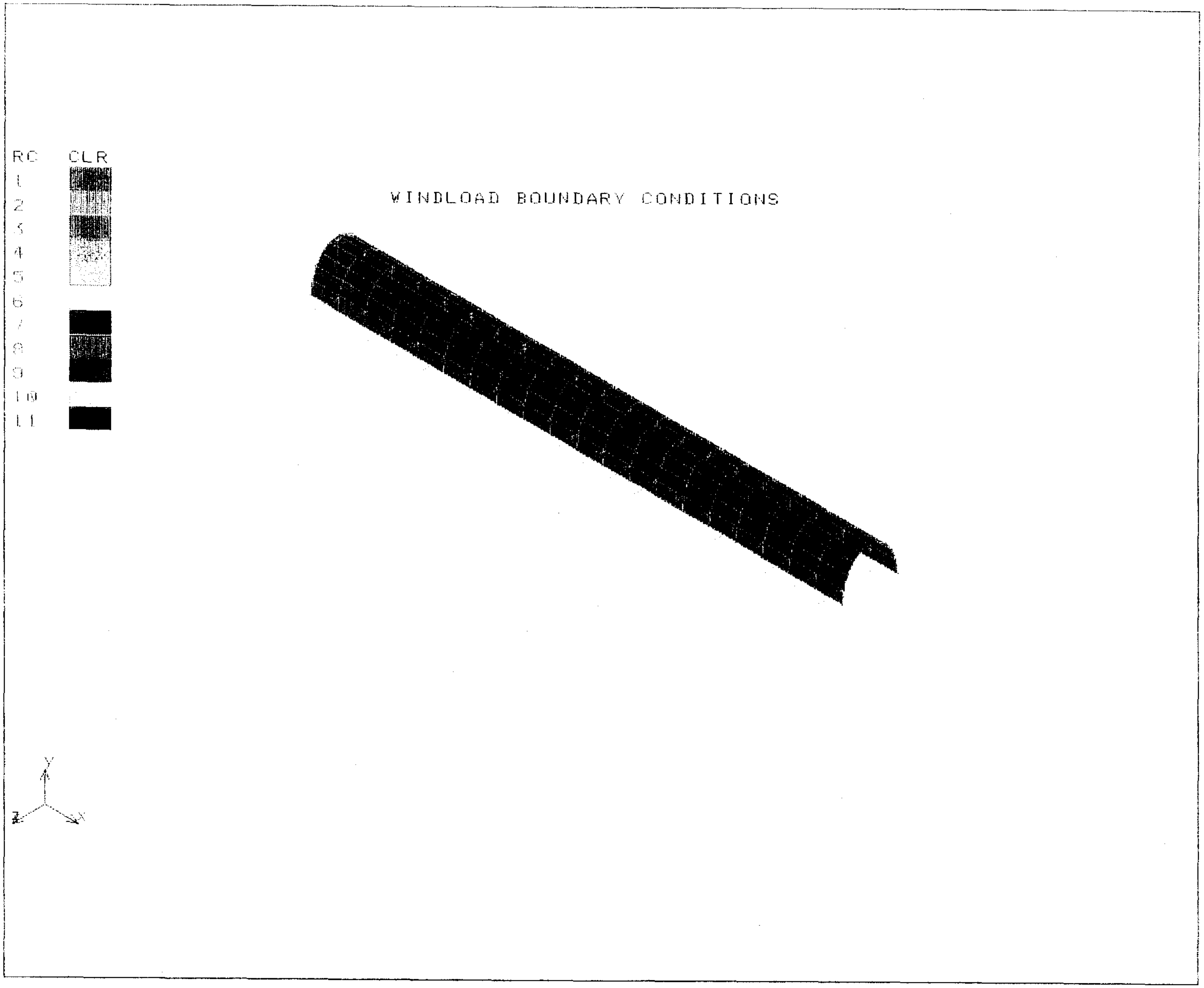


Figure 2. Wind Load Boundary Conditions on LIGO Enclosure.

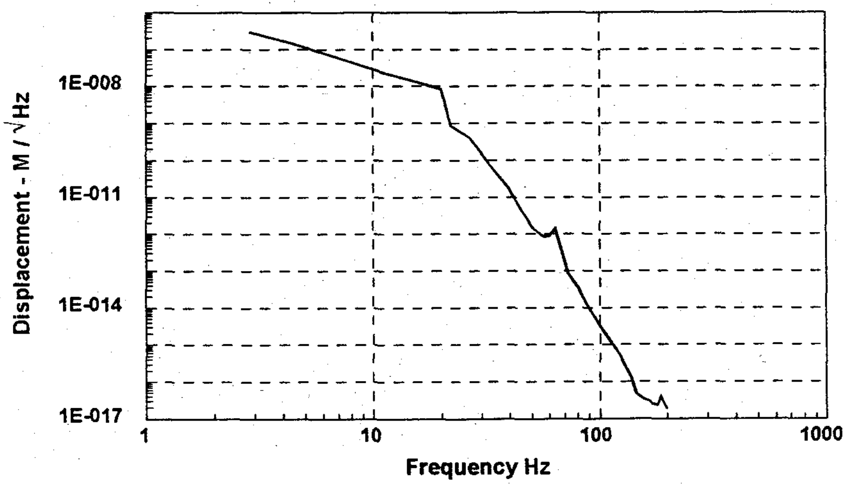


Figure 3. Linearized PSD, X-Direction showing small motions in the beamline direction

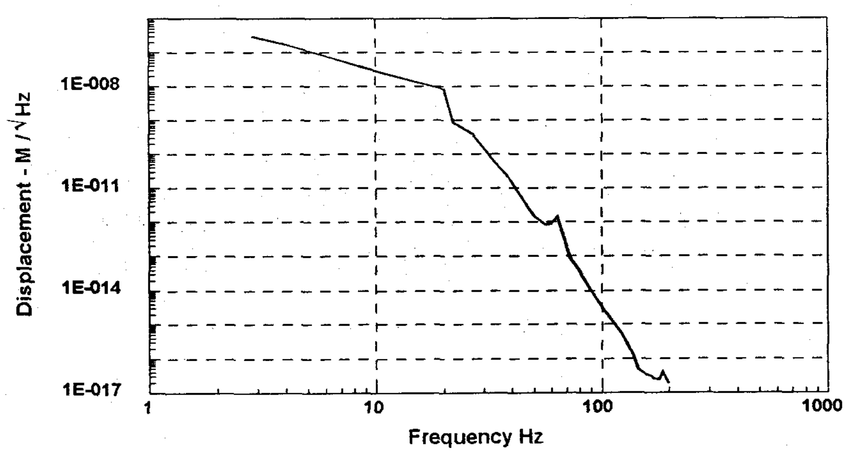


Figure 4. Linearized PSD, Y-Direction showing a peak resonance of 25 microns at 12.1 Hz

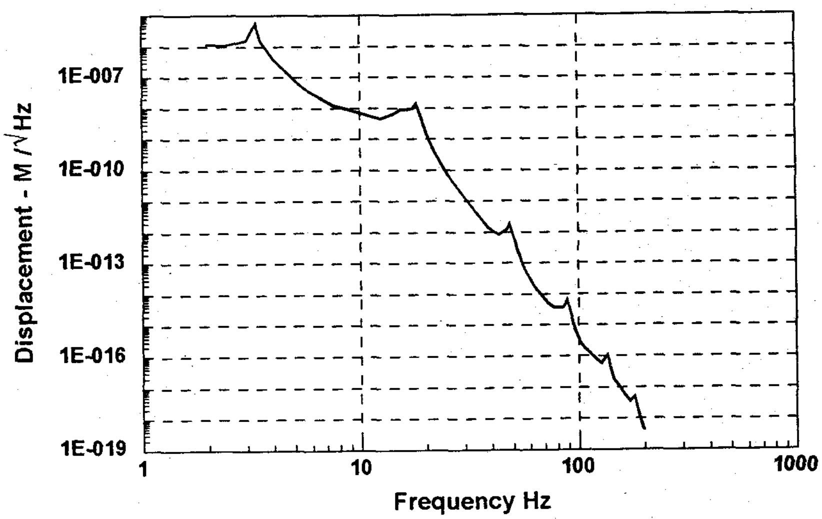
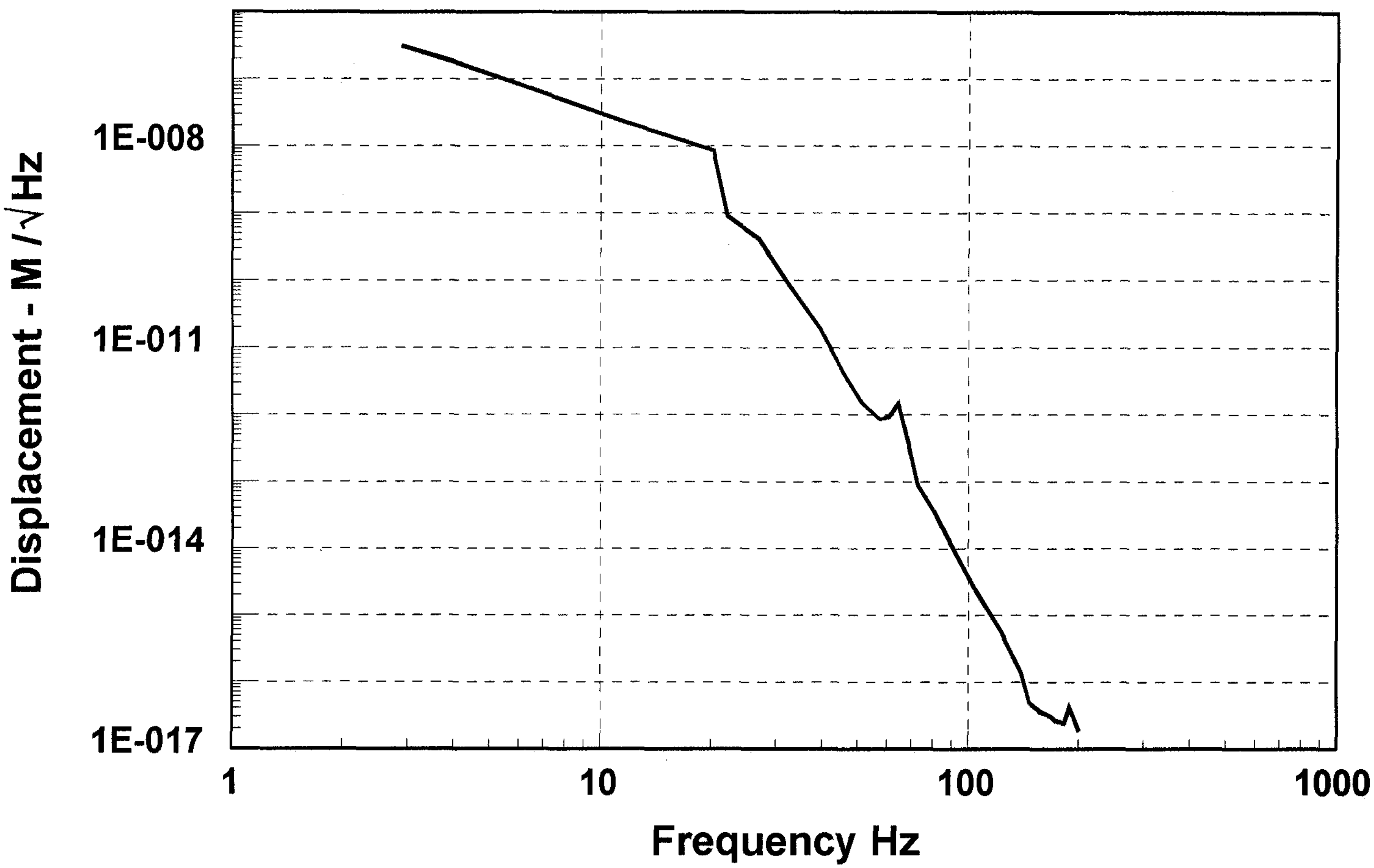
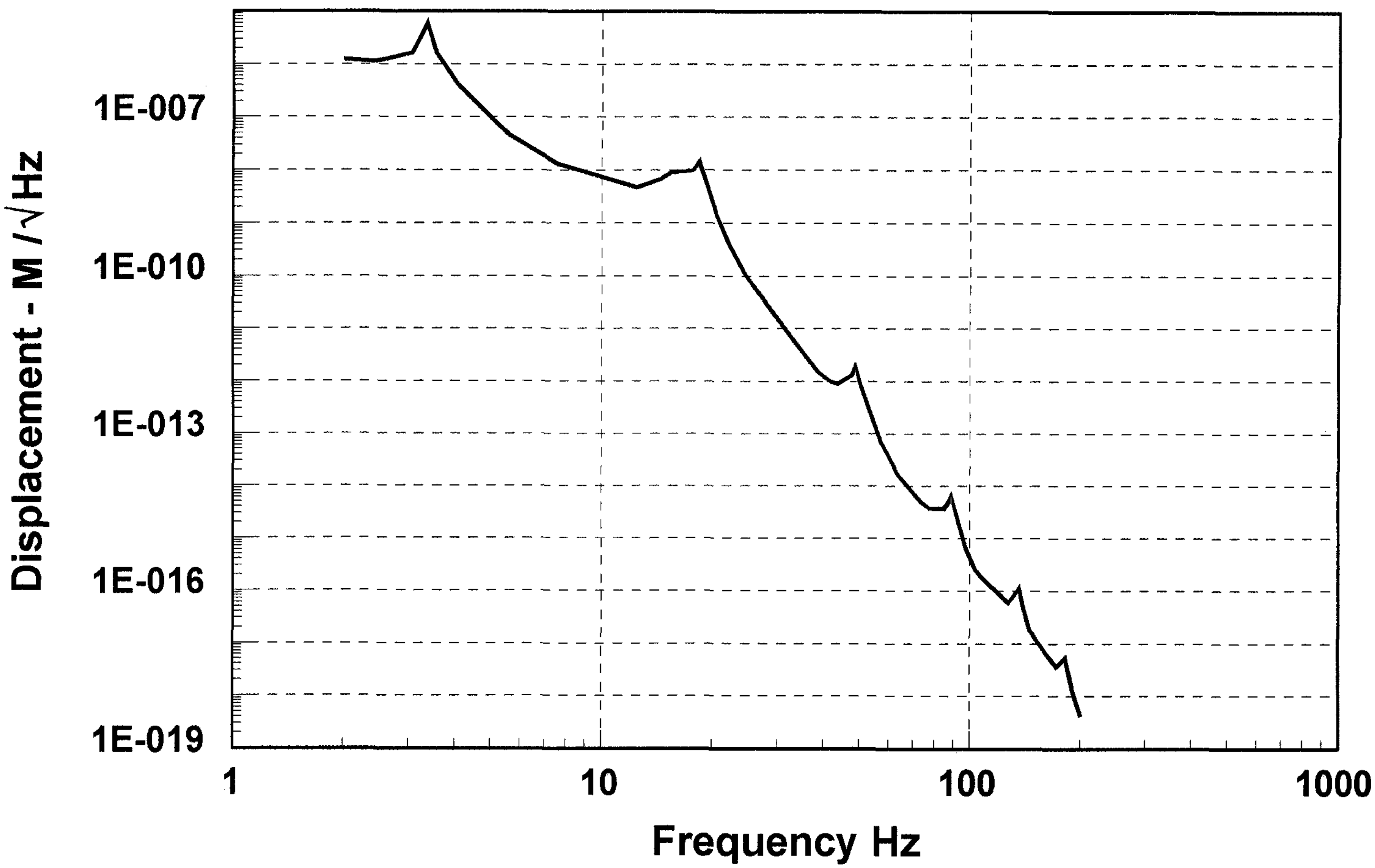


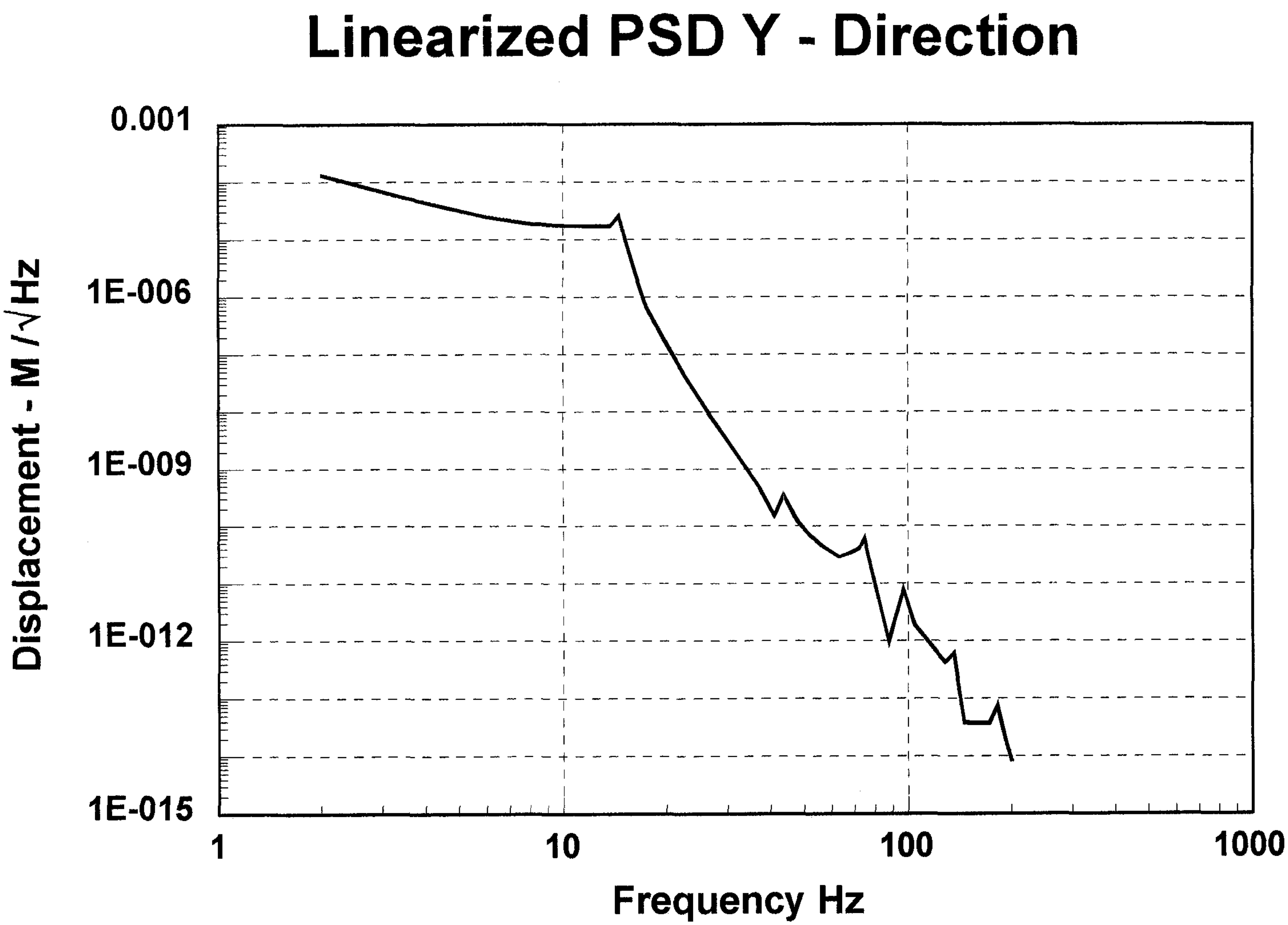
Figure 5. Linearized PSD Z-Direction with peak amplitudes of 25 microns at 3.9 Hz

Linearized PSD X - Direction



Linearized PSD Z- Direction





Linearized PSD Y - Direction
0.001
1E-006
1E-009
1E-012
1E-015
Displacement - M /√Hz
1
10
100
1000
Frequency Hz