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Resonance of the Support Structure of the Large Optics Suspension 1 (LOS1) Prototype

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1 ABSTRACT

We measured resonant frequencies and identified modes of the suspension support structure of the Large Optics Suspension 1 (LOS1) prototype. The lowest three modes were at 85 Hz (the first fixed-free bending mode about x axis), 103 Hz (the first fixed-free bending mode about z axis) and 186 Hz (the first fixed-free twist mode about y axis), when the support structure was clamped on an optical bench. It was found that the resonant frequencies were subject to the way the structure was constrained. When the support structure was not constrained, the lowest four modes were at 283 Hz, 286.5 Hz (both the first free-free twist mode about y axis), 450 Hz (the first free-free bending mode about z axis), and 458 Hz (the first free-free bending mode about x axis).

2 INTRODUCTION

The resonant frequencies of the suspension support structure of the Large Optics Suspension 1 (LOS1) are required to be above 160 Hz. The first measurement of the resonant frequencies of the LOS1 prototype revealed, however, that some resonances did not meet the requirement. In order to verify validity of the finite element model analysis on this issue, we decided to perform detailed investigations on the mechanical modes of the suspension support structure.

3 EXPERIMENT

3.1. Coordinate System

The following coordinate system is used. (See Fig. 1)

- x: Horizontal and perpendicular to the direction of the beam propagation
- y: Vertical
- z: Direction of the beam propagation

3.2. Setup of the Support Structure

3.2.1. Constrained Case

The support structure was put upside down on an optical table to simulate the actual setup configuration used in LIGO. Sixteen stainless spacers were inserted between the bottom plate and the table, and sixteen clamps (each clamp right above each spacer) were used to constrain the structure firmly to the table. Six of them were used at the front and back lines and two of them were at each side line. (see Fig. 1(b)).

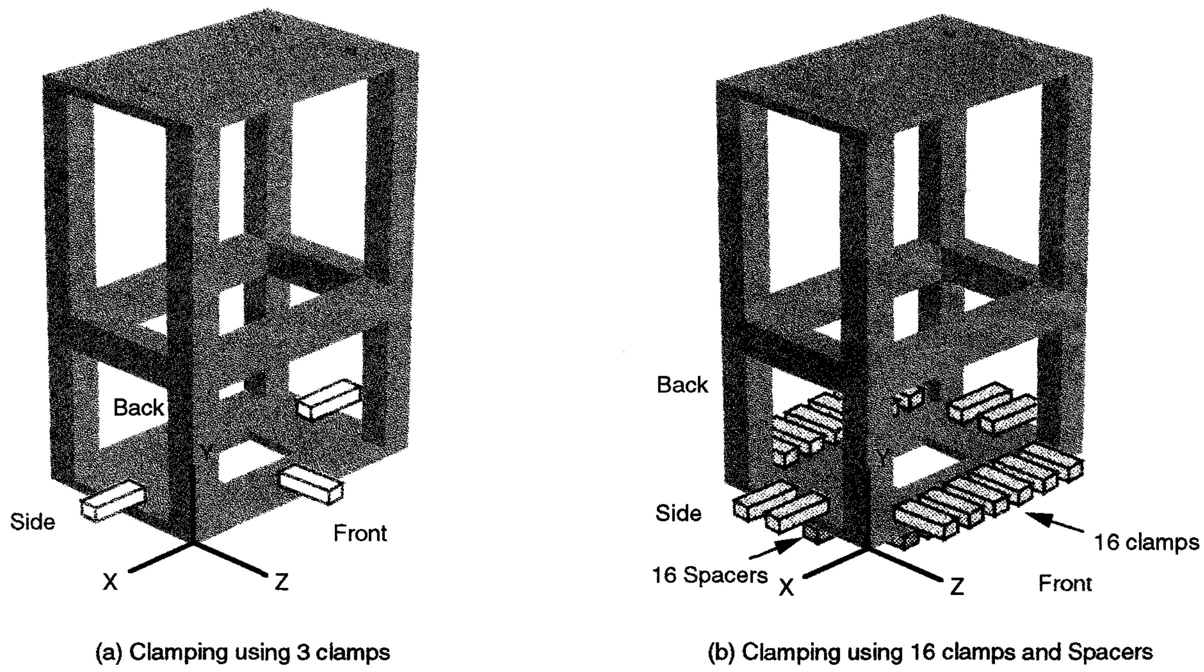


Figure 1: Constrained suspension support structure.

3.2.2. Unconstrained Case

The support structure was put upside down on four pieces of RTV situated at the four corners of the bottom plate (Fig. 2).

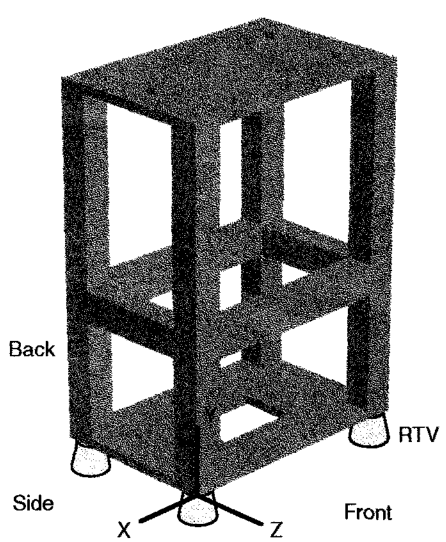


Figure 2: Unconstrained suspension support structure.

3.3. Actuator and Detector

The resonant frequencies and modes were investigated by exciting modes and detecting the motion at various points of the support structure using the following methods:

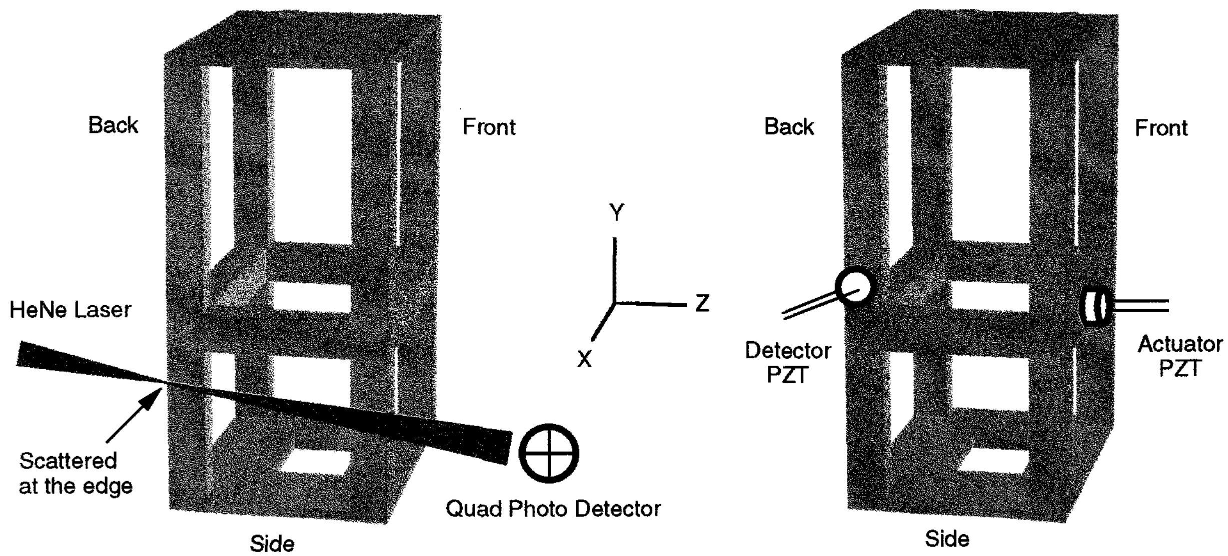
[Actuator]

- Hitting by a small object
- Actuator PZT attached on the support structure (see Fig. 3 (b))

[Detector]

- Laser beam focused on the edge of the support structure and a quadrature photodiode (see Fig. 3 (a))
- Detector PZT attached on the support structure (see Fig. 3 (b))

We measured transfer functions from the voltage applied to the actuator PZT mounted at an appropriate point to the output of the detector PZT mounted at several points to produce phase-sensitive[1] mode maps.



(a) Scattering Detection

(b) PZT Detection

Figure 3: Edge sensor, the actuator PZT, and the detector PZT used to investigate the mechanical modes of the support structure.

1. Although the phase of the transfer function changes rather continuously with positions in the actual measurement, the mode map adopted in this report takes the maximum amplitude and simplifies the phase information to either positive or negative.

4 RESULTS

4.1. Constrained Case

The lowest three resonances were found at 85 Hz, 103 Hz and 186 Hz. In order to verify that they were truly originated from the support structure itself, we loaded a mass (~2kg) on the top plate of the structure; the resonant frequencies decreased by about 10 Hz.[1] We also reinforced the optical table with aluminum bars to increase the stiffness of the table; no frequency shift was observed. Thus we conclude that these resonances come from the support structure.

The 186 Hz mode was analyzed by measuring the motion of the front surface of the top plate along z axis. As shown in Fig. 4, a node of the motion exists at the middle of the front surface of the top plate. This indicates that the 186 Hz resonance is the first fixed-free twist mode about y axis.

We believe that the 85 Hz and 103 Hz resonances are the first fixed-free bending mode about x axis and the first fixed-free bending mode about z axis, respectively, because the 85 Hz resonance was difficult to excite when the structure was hit along x axis, while the 103 Hz resonance was difficult to excite when the structure was hit along z axis (See Fig. 5).

It was also found that these resonance frequencies strongly depend on the way the support structure was clamped. We tried to clamp the support structure with three clamps and three bosses on the bottom plate. The first two resonant frequencies were found at 65 Hz and 158 Hz.

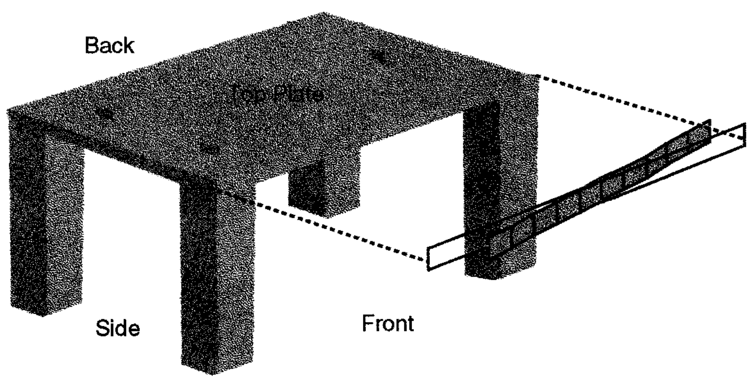


Figure 4: Motion of the front surface of the top plate along z axis at 186 Hz.

1. This experiment was done with only three clams.

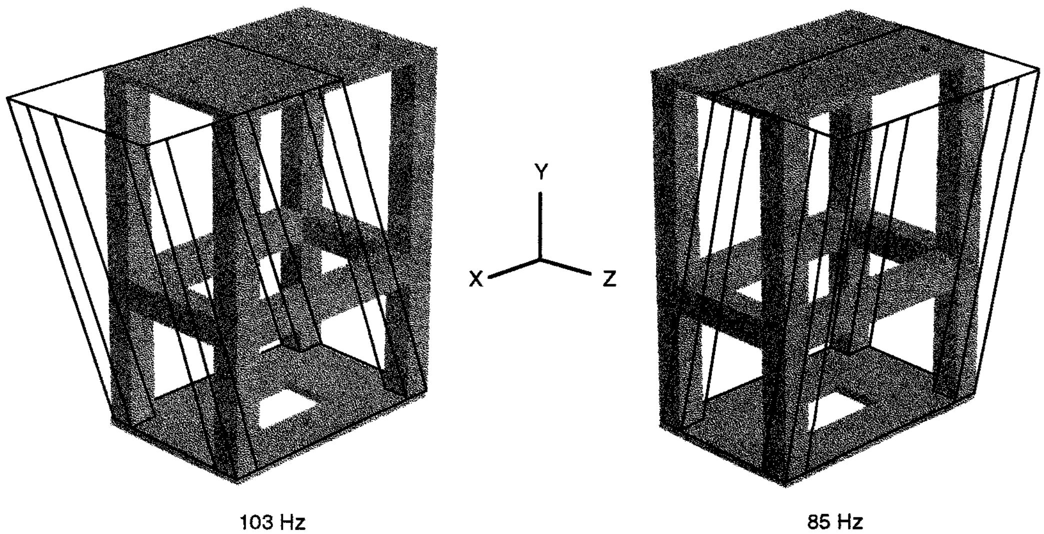


Figure 5: Predicted modes of the 103 Hz and 85 Hz resonances.

4.2. Unconstrained Case

All the resonant frequencies found under 700 Hz are listed in Fig. 6. In order to identify the first four modes, we measured the motion of the four legs along x and z axis with excitation of the legs and the stiffening bars.

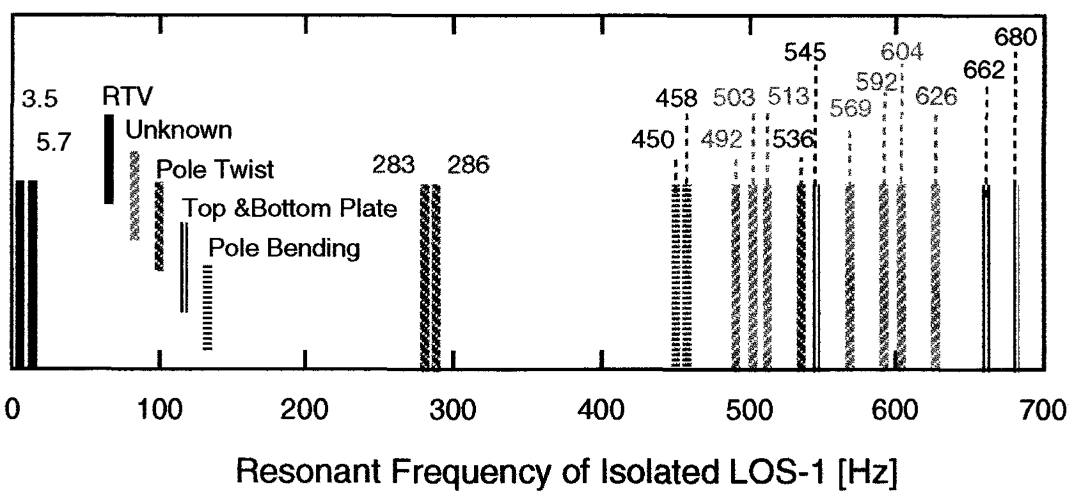


Figure 6: Resonant frequencies of the unconstrained support structure.

- 458Hz
  Fig. 7 shows the motion of the four legs along z axis at 458 Hz when the front stiffening bar was excited along z axis. We also found that It was difficult to excite motion along x axis at 458 Hz. According to these results, we believe that this mode is the first free-free bending mode about x axis.

- 450Hz
  Fig. 8 shows the motion of the four legs along x axis at 450 Hz when the side stiffening bar was excited along x axis. We also found that It was difficult to excite motion along z axis at 458 Hz. According to these results, we believe that this mode is the first free-free bending mode about z axis.
- 283 Hz and 286 Hz
  Fig. 9 shows the motion of the two legs at 283 Hz and 286 Hz. We believe that these modes are the first free-free twist modes about y axis, which are slightly different in frequency due to asymmetry in the mechanical structure.

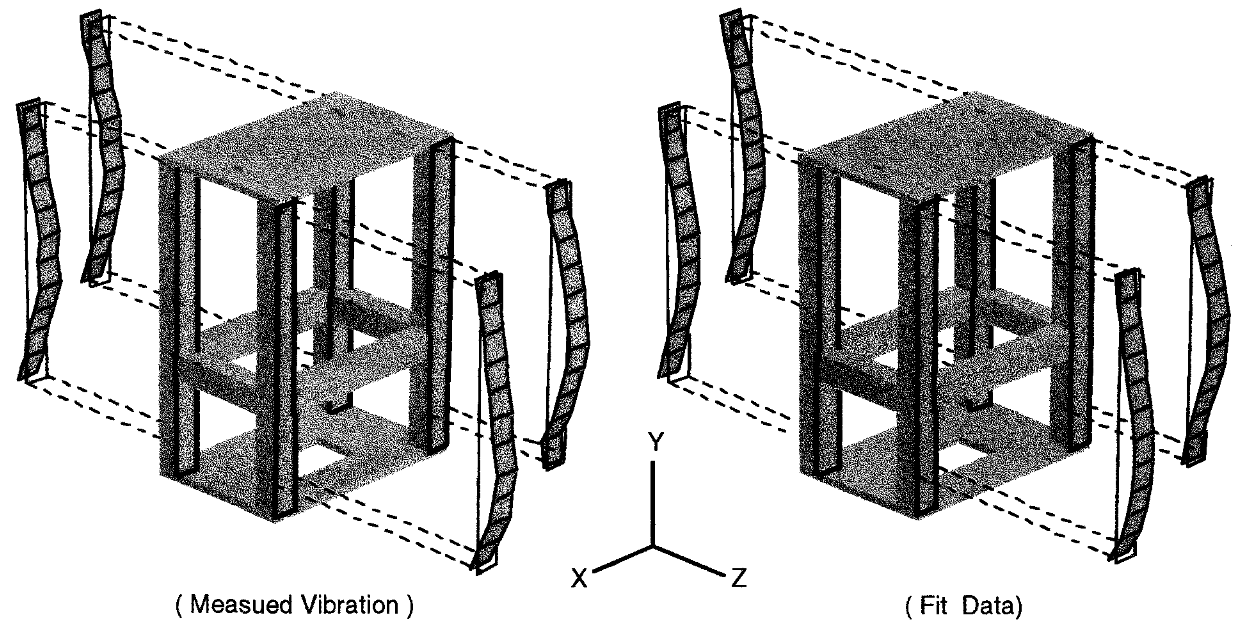


Figure 7: Motion of the four legs along z axis at 458 Hz.

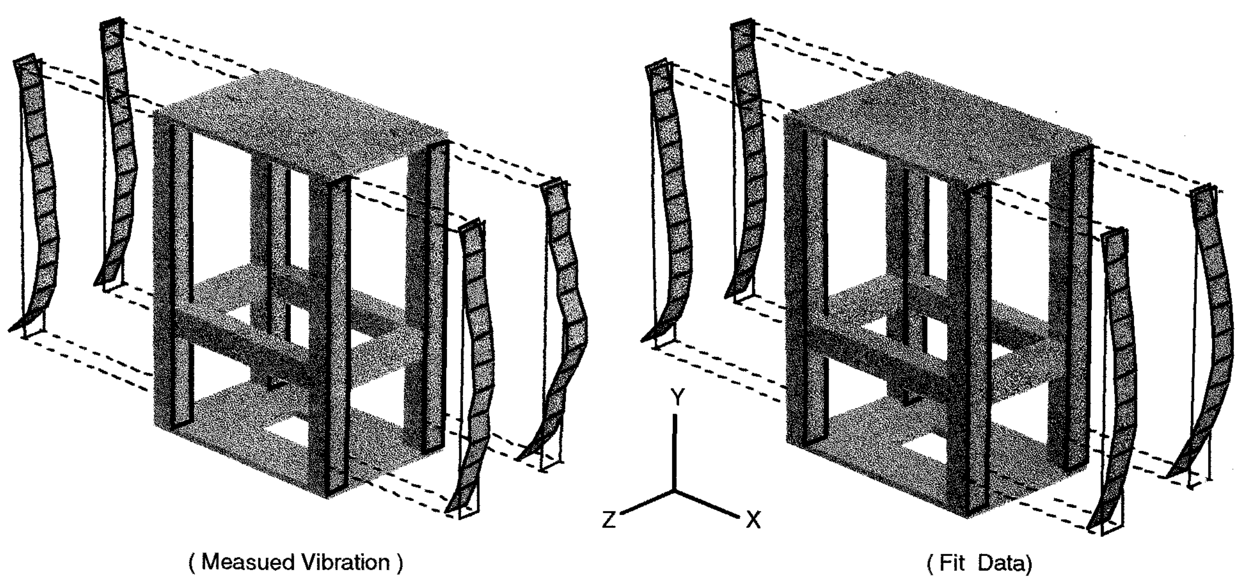


Figure 8: Motion of the four legs along x axis at 450 Hz.

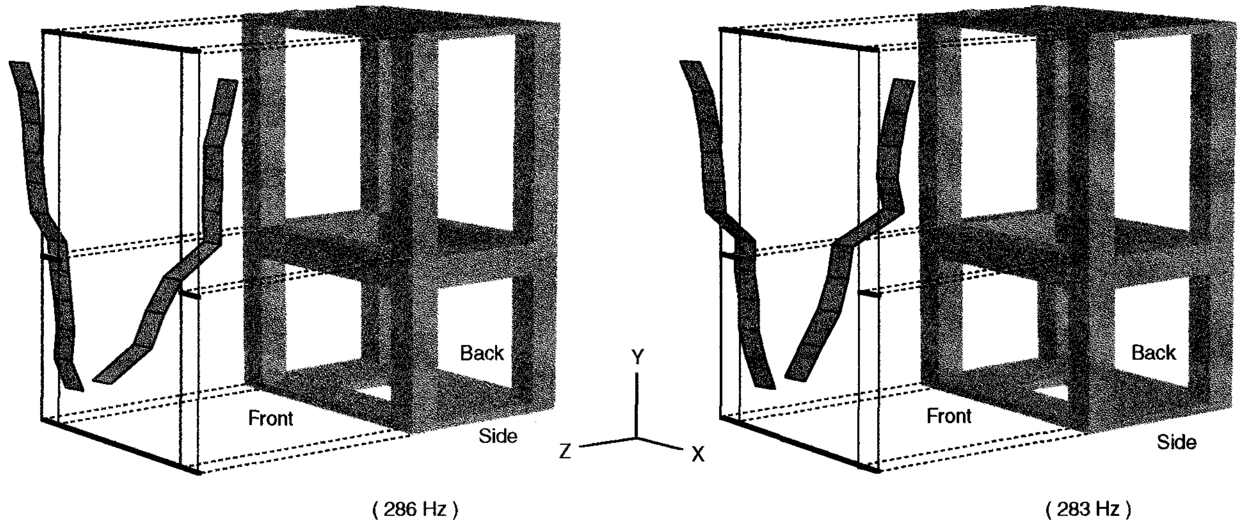


Figure 9: Motion of the two legs along x axis at 283 Hz and 286 Hz.

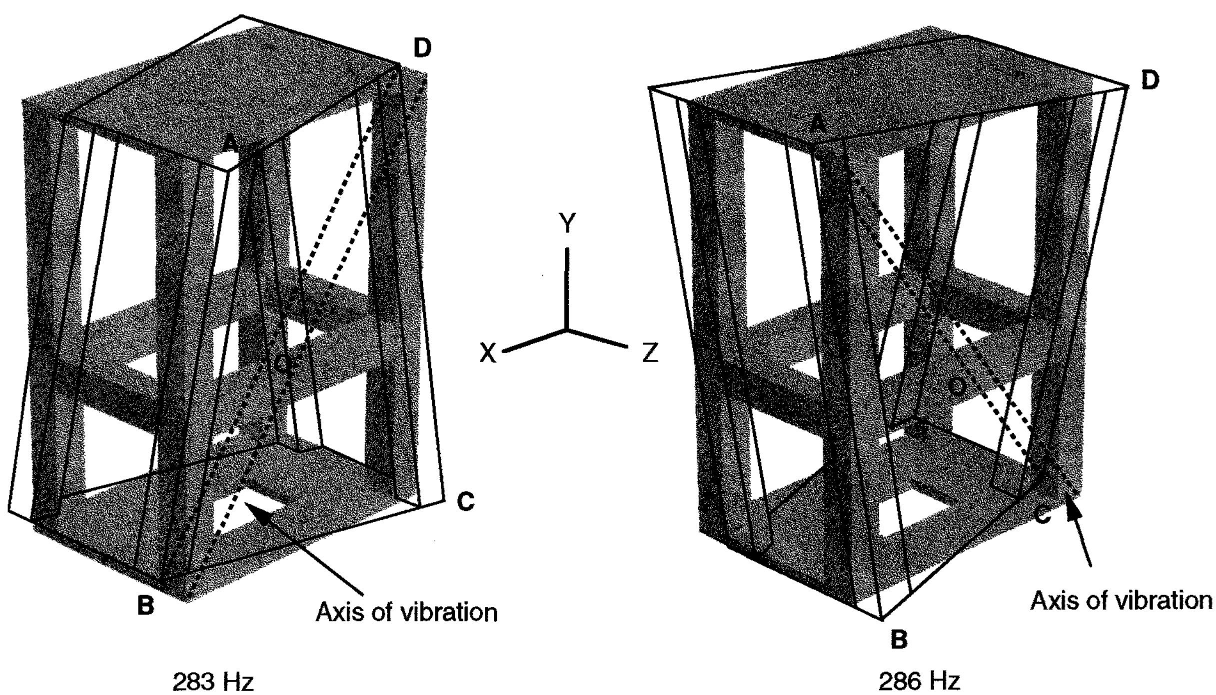


Figure 10: Predicted motion of the 283 Hz and 286 Hz mode.

The 286Hz and 283Hz resonances seemed to be produced due to the slight structural asymmetry of the LOS1. The difference between the 283Hz and 286Hz resonances was estimated as the difference of the axes of vibration denoted by red and black dotted lines. In the case of the 283 Hz, the point A, O and C (which were along the vibration axis) had the same phase, and B and D had the anti-phase compared with them. On the other hand, in the case of 286 Hz, the point B, O and D (which were along the vibration axis) had the same phase, and A and C had anti-phase compared with them.

4.3. Summary

Table 1 shows the summary of the results.

Table 1: Resonant frequencies and modes of the constrained and unconstrained support structure.

Mode	*Constrained Case*	*Unconstrained Case*
Bending mode about x axis	85 Hz	458 Hz
Bending mode about z axis	103 Hz	450 Hz
Twist mode about y axis	186 Hz	283 Hz and 286.5 Hz

5 CONCLUSION

We measured resonant frequencies and identified modes of the suspension support structure of the Large Optics Suspension 1 (LOS1) prototype. We found that two modes did not meet the requirement. These results will be compared with the finite element model analysis to check its validity, and then further finite element model analysis will be performed to establish a possible solution for reinforcement of the structure.

APPENDIX 1 HIGHER-FREQUENCY MODES FOR UNCONSTRAINED CASE

Higher-frequency modes for the unconstrained case were analyzed by measuring the motion of the top and bottom plate along y axis using the detector PZT. The actuator PZT was mounted at the middle of the front stiffening bar to excite the motion along y axis. The results are shown in Fig. 14 to Fig. 17. In each figure the left pictures reflect the measured data and the right ones are the fitted data.

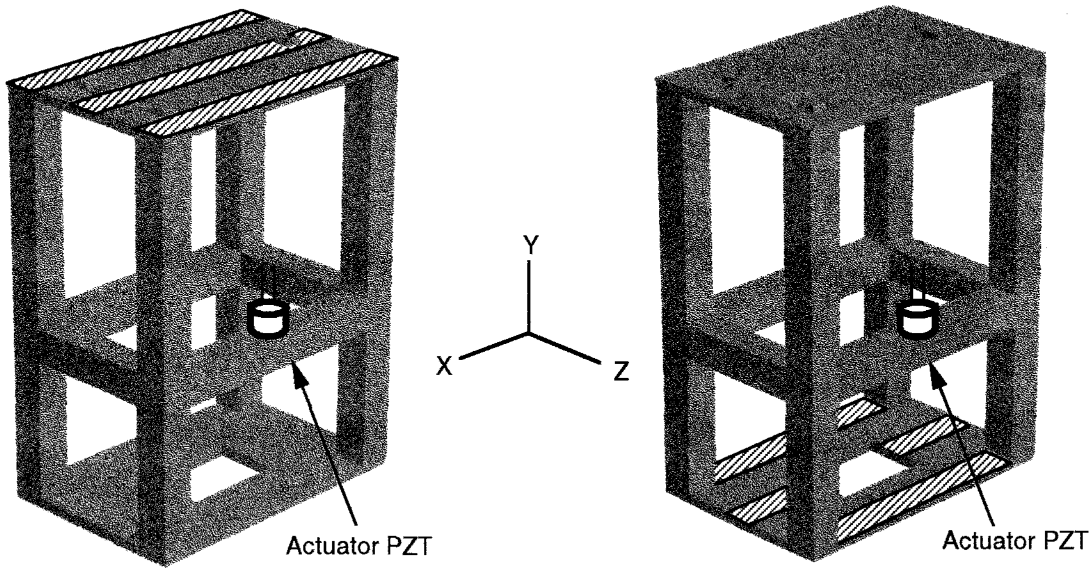


Figure 11: Measurement set-up for the top and bottom plate resonant motion
The each red area was sampled and the transfer function from the actuator PZT to the detector PZT was taken for each sampled points.

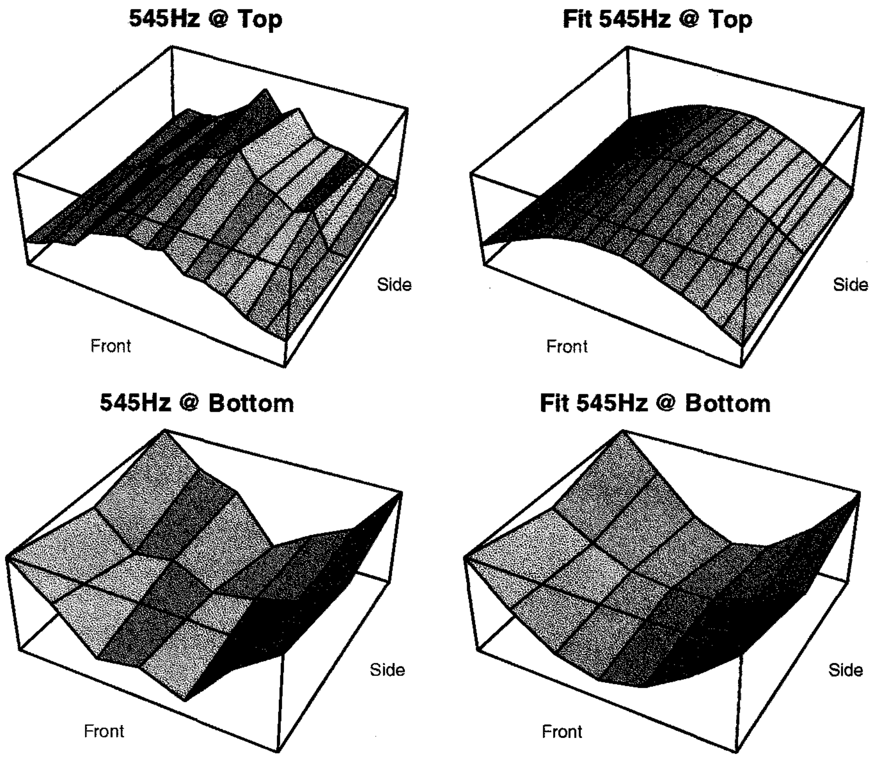


Figure 12: The 545 Hz top and bottom plate vibration

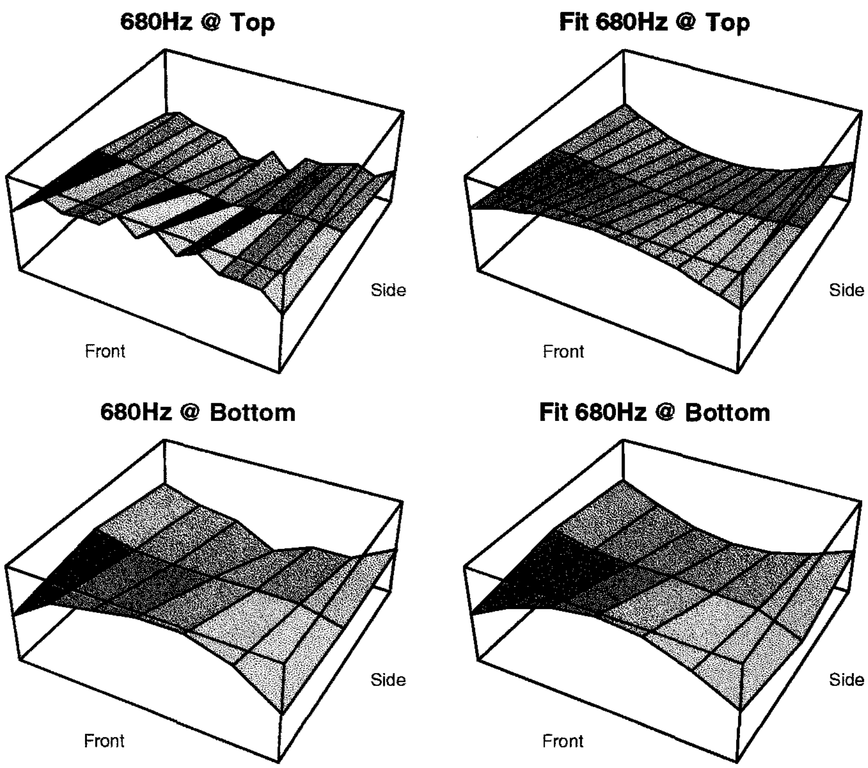


Figure 13: The 680 Hz top and bottom plate vibration

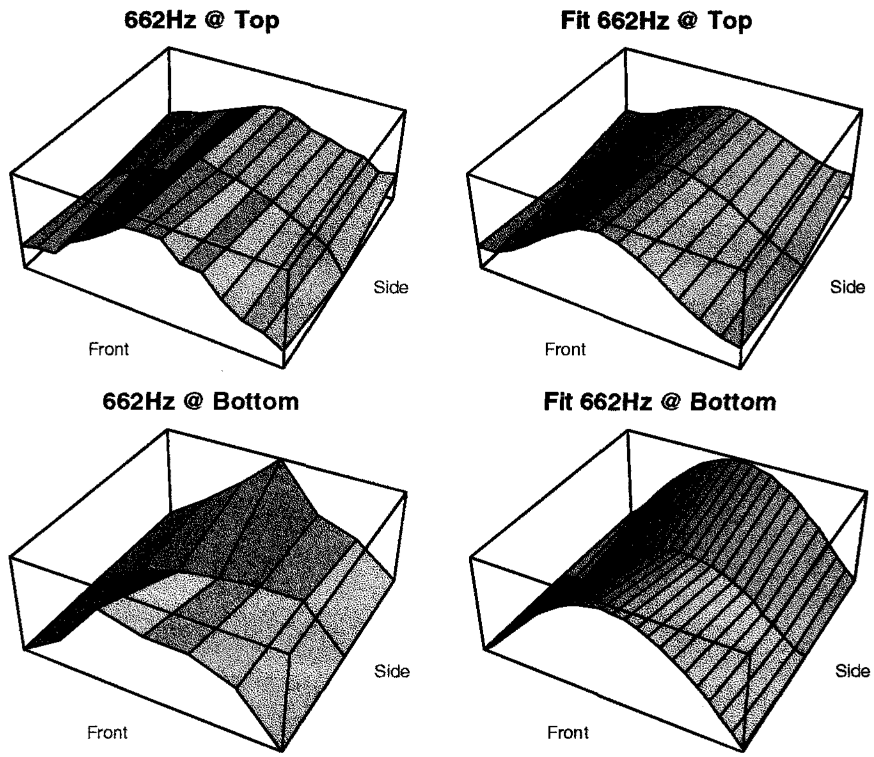


Figure 14: The 662 Hz top and bottom plate vibration

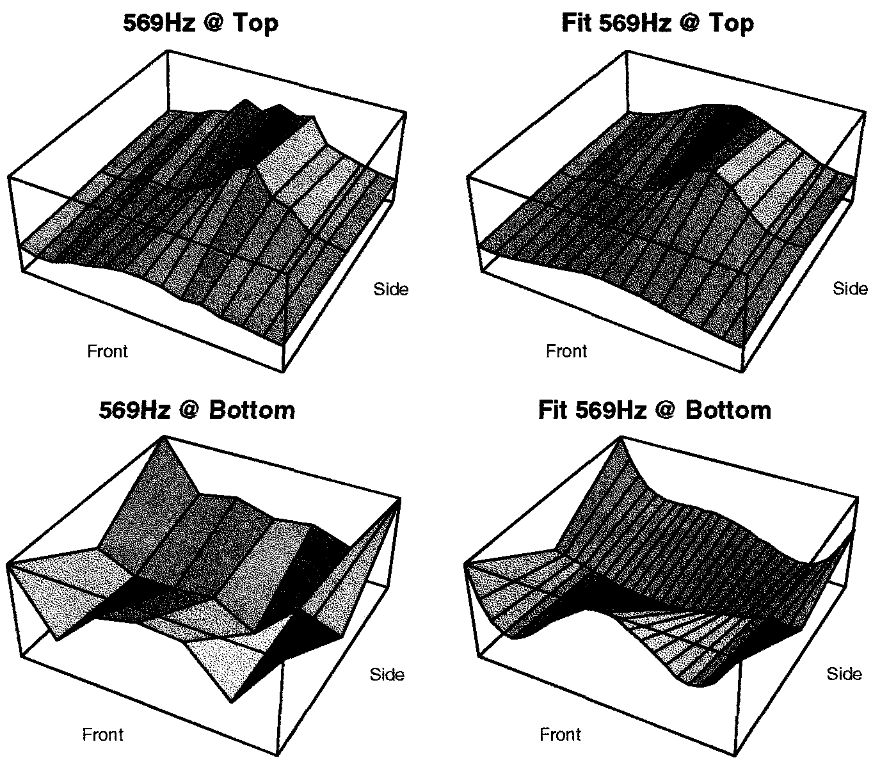


Figure 15: The 569 Hz top and bottom plate vibration