BSC Support Assembly
Analytical Design

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Abstract

This note summarizes the analysis of a preliminary design for the BSC support structure. Results are presented for natural frequencies, effect of gravitational loading, and a pseudo earthquake condition. Buckling of the support structure under the load of the stack was also considered.

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LIGO PROJECT

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1. Introduction

The support assembly, shown in Figure 1, consists of a support platform, 2 support beams, and 2 cross beams. The support platform provides support for the BSC seismic isolation stack. The support beams penetrate the BSC chamber through 4 welded diaphragm bellows and hold the support platform. Cross beams on the outside of the chamber connect the ends of the support beams and interface with the coarse and fine actuators.

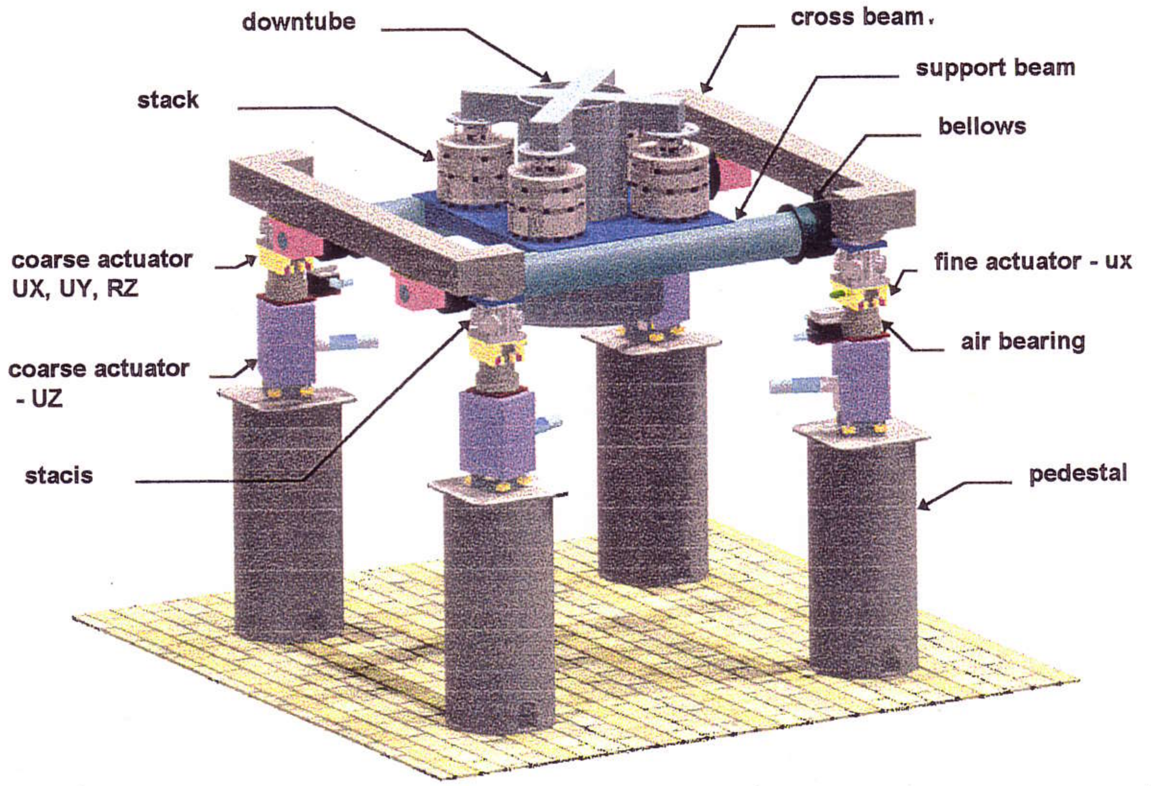

Figure 1. BSC support system, stack, and downtube

2. Description

Overall dimensions of the support structure are shown in Figure 2. The support platform is a welded aluminum sandwich structure with a 12.7 mm (.5") thick upper face, a 9.5 mm (.375") lower face, and a grid of 6.4 mm (.25") rib plates for the core. Aluminum is used to minimize weight at the center of the support beam span. (Analysis shows that the weight of the support platform is a major factor in determining the lowest resonant frequency.)

The support beams are made of stainless steel tubing 305 mm (12") in diameter with a wall of 13 mm (.5"). Solid stainless steel plugs with a diameter of 140 mm (5.5"), FEM model, these blocks are represented as solid steel connections from the support beam plugs to the upper walls of the cross beams (Fig. 2). Low carbon steel square tubing 152 x 152 x 9.5 mm (6 x 6 x .375") form the crossbeams that carry the load to the actuators.

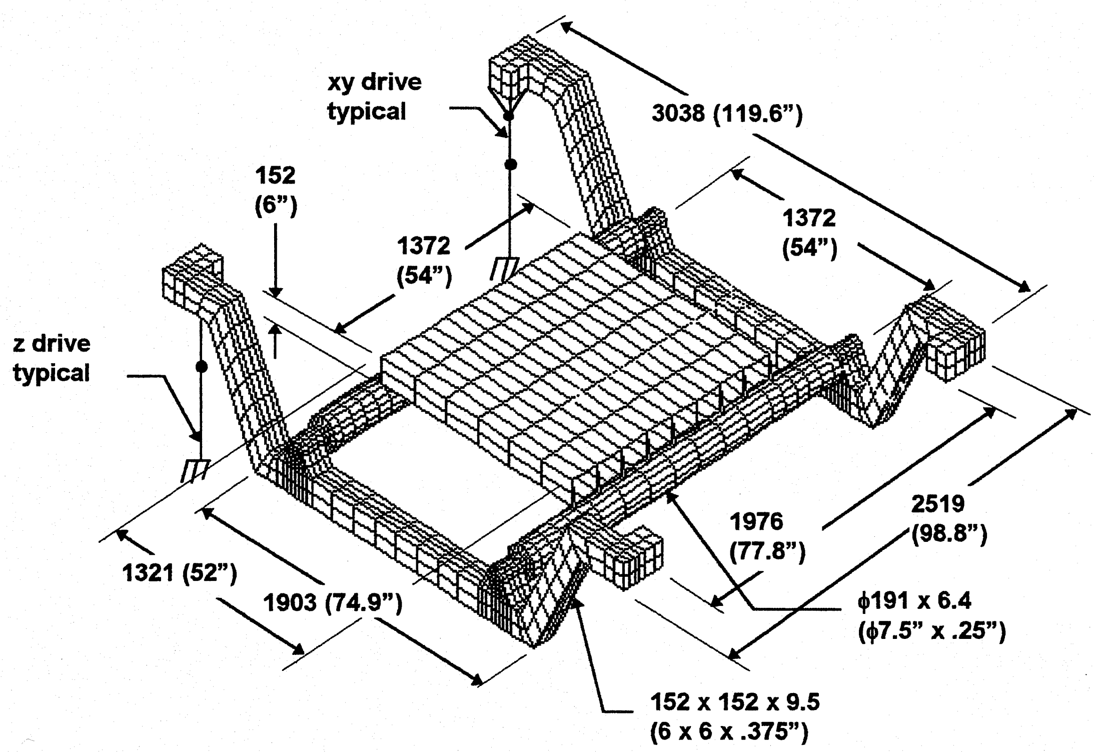

Figure 2. HAM Support Assembly

3. Performance

3.1 Resonant frequencies

Figure 3 shows the first 6 resonances of the support assembly. The assembly rests on 4 rigid beams that connect to another rigid beam representing the coarse x/y actuator. The function of the 4 beams is to spread the load more realistically. This rests on a simulated beam whose properties were adjusted to represent the compliance of the Z actuator within 3% of the 3 directional spring constants and the angular compliance about the 2 horizontal axes.

Initial modeling of the support system was done prior to providing room for the actuators. The cross beam in this analysis was straight. The mode at the lowest frequency was 26 Hz. Once the overall layout was completed, the crossbeam design had to take on a gull wing shape to provide clearance for the actuator column. For this configuration the first mode dropped to 18 Hz. Introducing the flexibility of the Z drive further lowered that frequency to 17 Hz as shown in Figure 3.

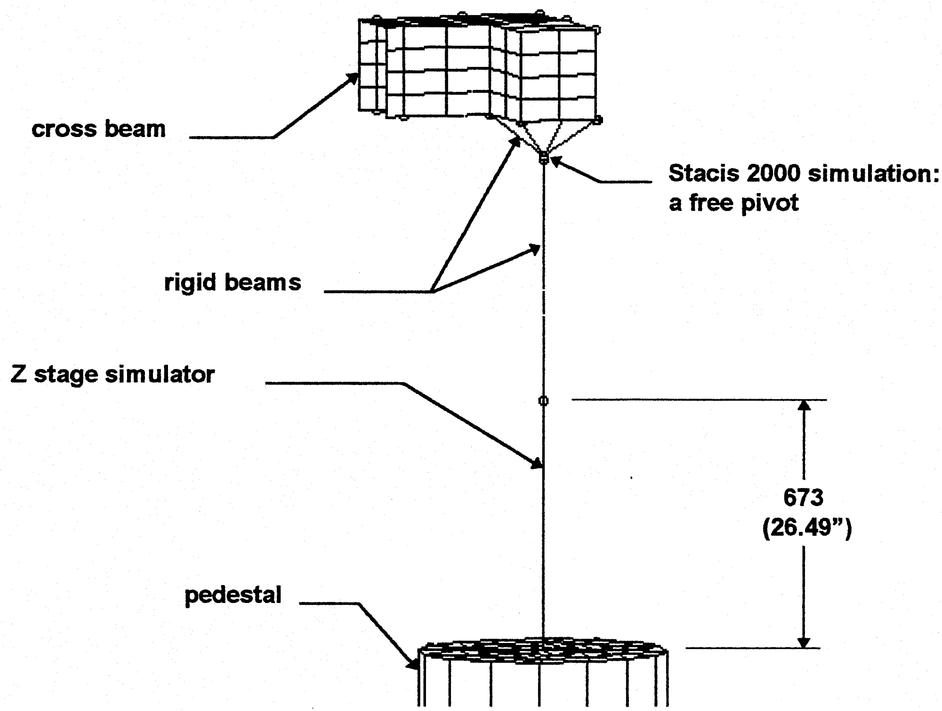

Figure 3. Simulation of Z-stage and stacis

3. Performance

3.1 Resonant frequencies

Figure 4 shows the first 6 resonances of the support assembly. The results are lower than desired, in part because of the low shear stiffness of the actuator's Z-stage.. Modifications in the design of the Z actuator are being considered that should increase its stiffness.. In order to bound the problem the elastic and shear moduli of the material used for the Z actuator were increased by one order of magnitude. The resulting lowest frequency rose to 32 Hz. This is the upper limit of what can be achieved through modification of the Z-stage.

It should be noted that the first 3 modes result from actuator compliance. The first structural mode of the support assembly occurs at 39 Hz.

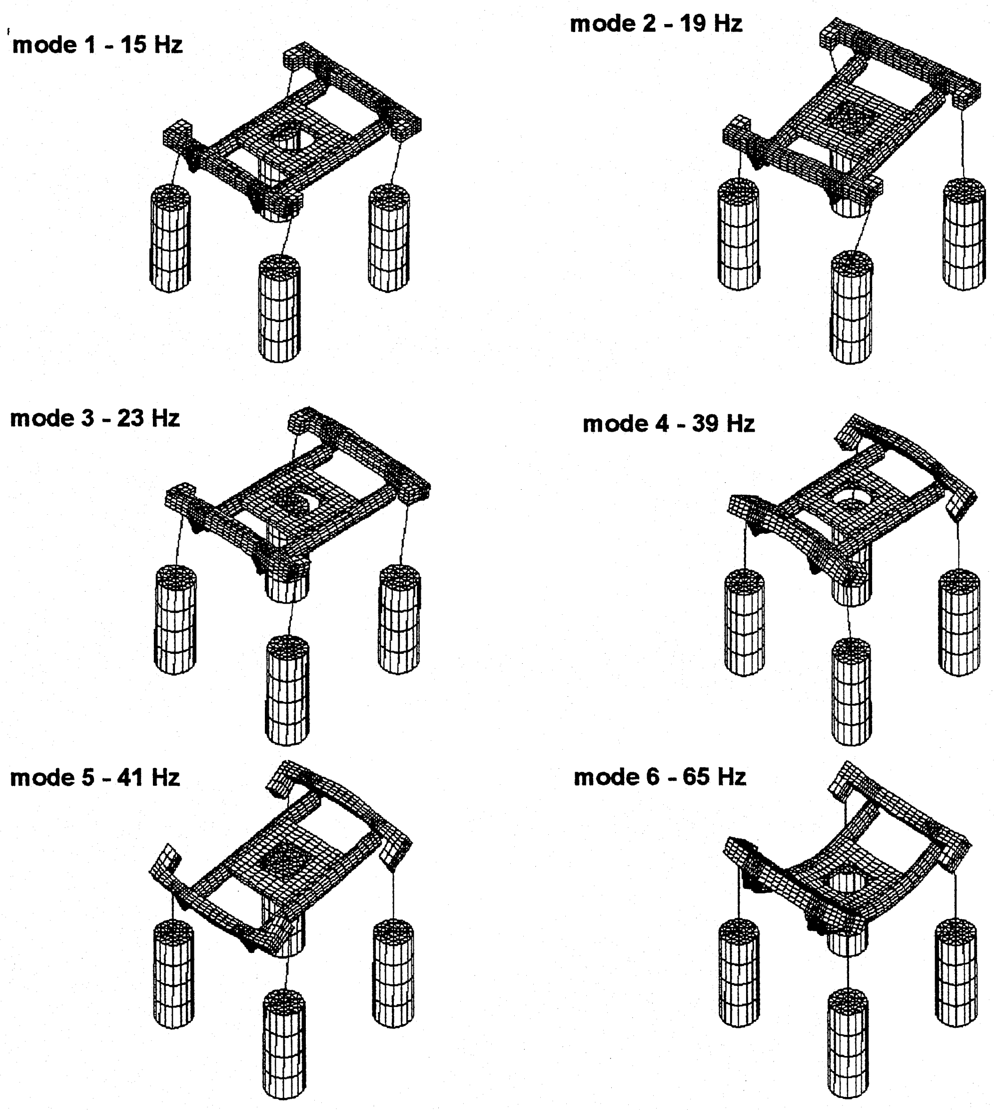

Figure 4. Mode shapes and natural frequencies of the BSC support system.

3.2 Stresses and Deflections

3.2.1 Gravitational Loading

To achieve the desired passive isolation of the stack performance we needed to avoid low frequency structural resonances Consequently, the design of the support system is stiffness driven, and static stresses can be expected to be very low. This is demonstrated in Figure 5. Figure 6 shows the deflections. Gravitational loads are added to the support assembly to simulate the masses of the leg elements, downtube, and payload. Forces equivalent to a mass of 2908 kg (6,411 lbs.) are imposed at nodes underneath the footprints of the leg elements. [651 kg (1,435 lbs.) = downtube and payload; 2908 kg (6,411 lbs.) = stack] The maximum stress is 1.79×10^7 Pa (2,600 psi) occurring on the steel cross beam. The yield stress of the cross beam material is $3.17x10^8$ Pa (46,000 psi). The safety factor is more than 17.

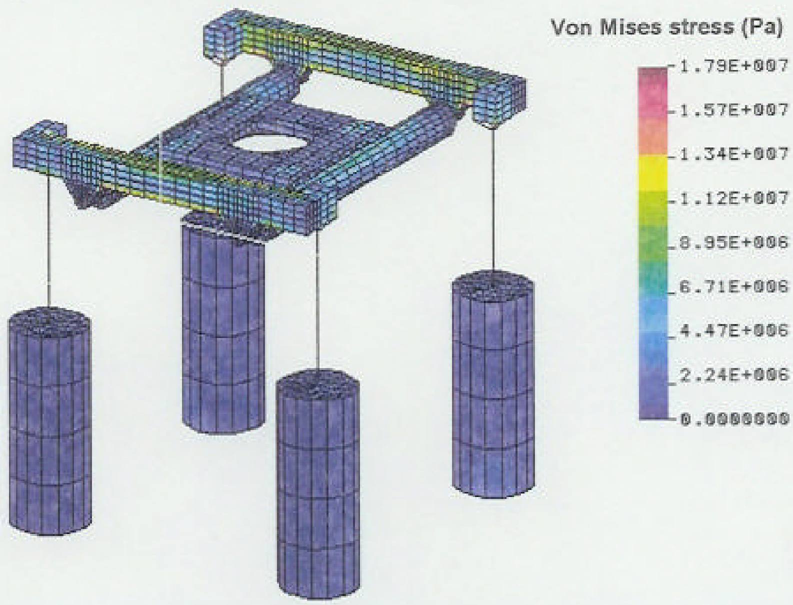

Figure 5. Stresses under gravitational loading.

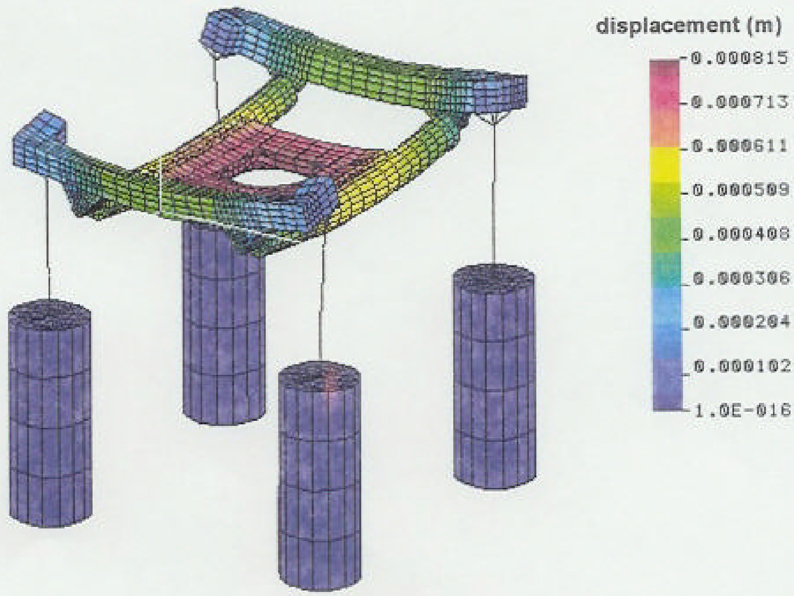

Figure 6. Deflections under gravitational loading.

3.2.2 Pseudo Earthquake Loading

Static loads are imposed on the support assembly to roughly simulate the effects of earthquakes. Forces are applied to the nodes within the footprints of the leg elements. These forces equal 28,517 N (6,410 lbs., 1 g) in the vertical direction and 14,258 N (3,205 lbs., ½ g) in the transverse directions. The 1 g is the equivalent of the sum of the weights of the leg elements, downtube, optics table, and payload. The 14,258 N represents .5 g's of horizontal acceleration, more than equivalent to an earthquake load at the Washington or Louisiana sites.* Figures 7 through 10 show the maximum stresses and deflections for the two load cases. Gravity is also considered in both load cases. Load case 1 has the transverse forces perpendicular to the beamline. In load case 2, they are parallel to the beamline.

The highest stress is 2.1 x 10^7 Pa, again occurring in the steel cross beam, which gives a safety factor of 15 over the yield strength of the material.

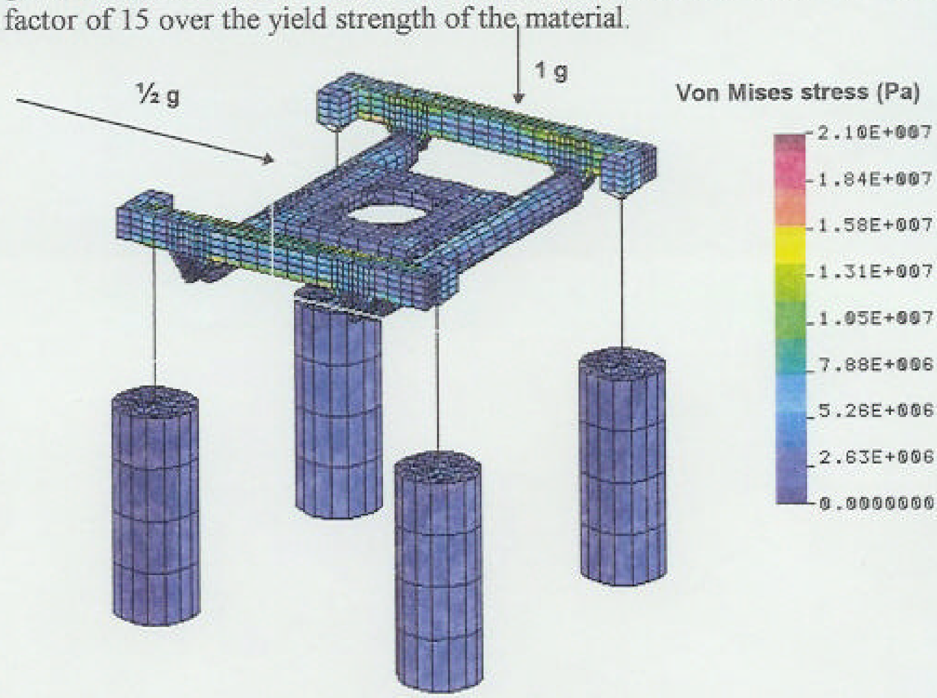

Figure 7. Stresses under pseudo earthquake loading - Case 1*

* pessimistic evaluation of pseudo earthquake equivalent static horizontal accelerations at the Hanford site (zone 2B) lead to 0.1 g to 0.4 g (per calculation procedures defined in the Uniform Building Code)

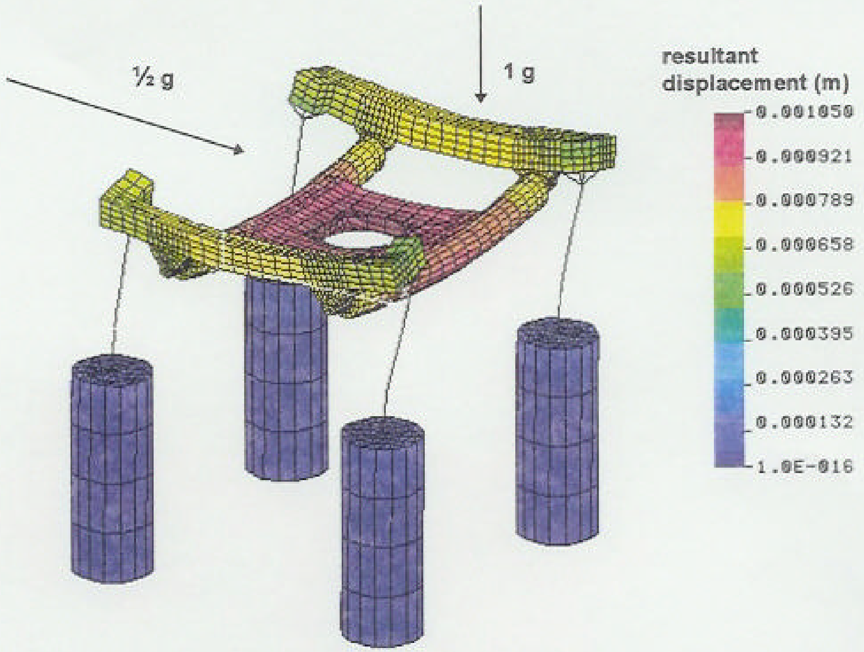

Figure 8. Deflections under pseudo earthquake loading - Case 1

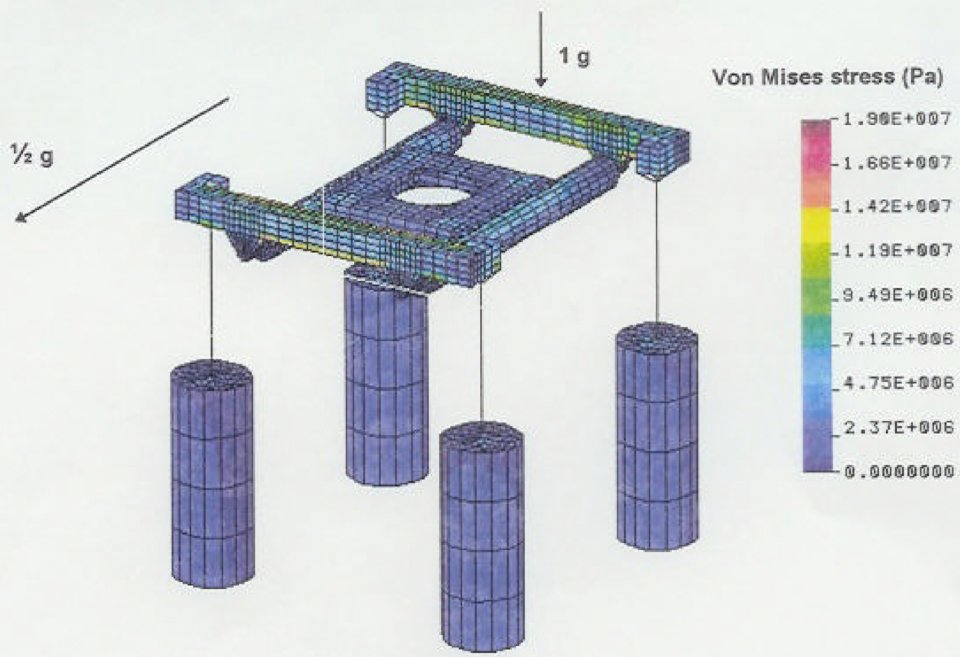

Figure 9. Stresses under pseudo earthquake loading - Case 2

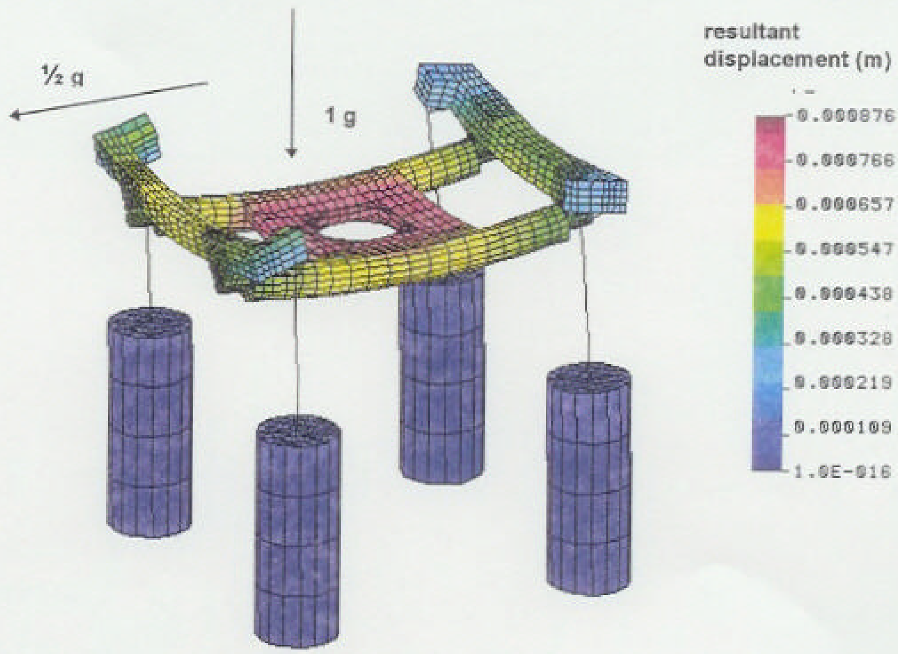

Figure 10. Deflections under pseudo earthquake loading - Case 2

3.3 Buckling

The same 28,517 N (6,410 lbs.) vertical load (stack, downtube, & payload) is applied to the support assembly, and the design is checked for buckling. Buckling occurs in the compressed upper plate of the support table, shown as the enlarged view in Figure 11. The computed safety factor is 220.

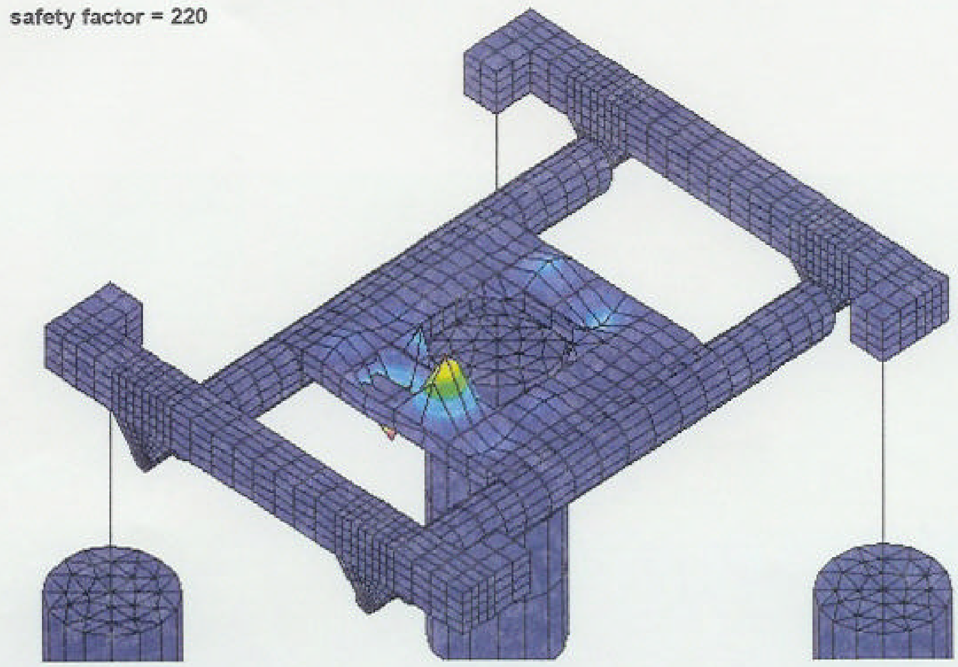

Figure 11. First buckling mode under operational loading.

4. Conclusion

The maximum stress computed under simulated earthquake conditions is 2.1×10^7 Pascal, occurring in the steel cross beam. This is only 5% of the ultimate tensile strength of the low carbon steel material. The safety factor in buckling, under normal gravitation loading, is 220. There is no doubt that the support assembly is structurally sound. The primary resonance of the system is lower than desired. This is due to the compliance of the Z-stage actuator. Efforts will begin immediately to stiffen this actuator and raise the primary resonance above 15 Hz.