LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Simulate about the flex joint of the leg

Yumei Huang , Riccardo DeSalvo

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California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW17-161
175 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

I carried out simulations of the leg Flex Joint, including a study of the maximum stress in bent conditions (leg hitting the range limiting ring, 10 mm bend). Figure1 shows the HAM SAS leg which is constructed from the 1mm thick aluminum.

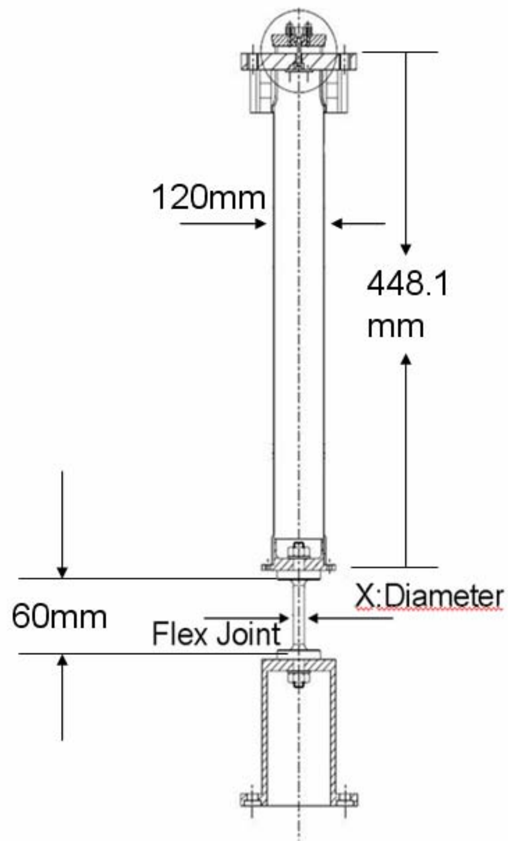

Figure 1: The HAM SAS invert pendulum leg.

I calculated the Flex Joint diameter necessary for critical loads between 500 kg and 1500 kg for the HAM SAS IP leg. The HAM SAS has 4 legs. I simulated one leg carrying one quarter of the total loads on 4 legs. The corresponding loads are between 125 kg and 375 kg.

I started from the model for the Flex Joint diameter of 9.5mm, which has been validated by actual laboratory tests. Then I reduced or increased its diameter in steps of 0.5 mm. I calculated the critical load for 7 Flex Joint diameters with different diameter by fitting the frequency-load curve with a suitable function and evaluating the fit function at 0 Hz frequency.

The critical mass is given by the intercept at 0 Hz frequency of the fit curve.

An example of fit is in figure 2.

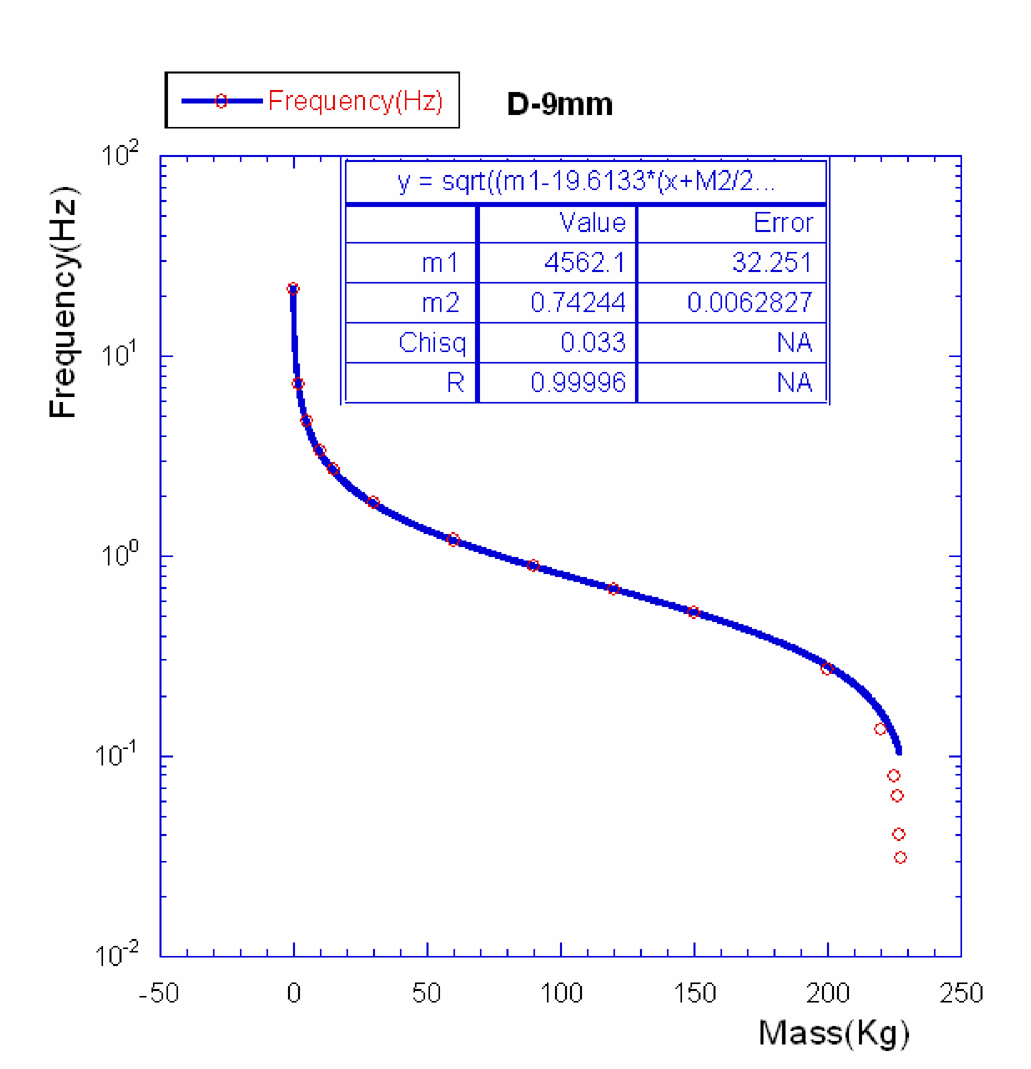

Figure 2: Example of Frequency vs. Mass plot calculated for D = 9 mm

Extracting the critical masses from several plots, and examining them as a function of flex joint diameter, I produced the curve of “Flex Joint diameter to IP load”. We tried to fit the data with a power law and found a best fit for power 3.89, compatible with the fourth power. We assumed that the data follows a fourth power law. The data is shown in figure 3.

I used the fit to the curve and estimated the flex joint diameter needed to yield 0 Hz frequency at 125 kg and 375 kg, simulations were then performed using these loads and diameters. I added these two points to the plot, as shown in figure 4.

Diameter(mm)	Mass at 0frequency (Kg)
7.5000	113.60
8.5000	183.70
9.5000	288.00
10.000	338.00
10.500	415.00
8.0000	143.00
9.0000	227.50
7.7000	125.30
10.230	365.60

Table 1: HAM SAS leg; Mass at 0 frequency vs. Diameter

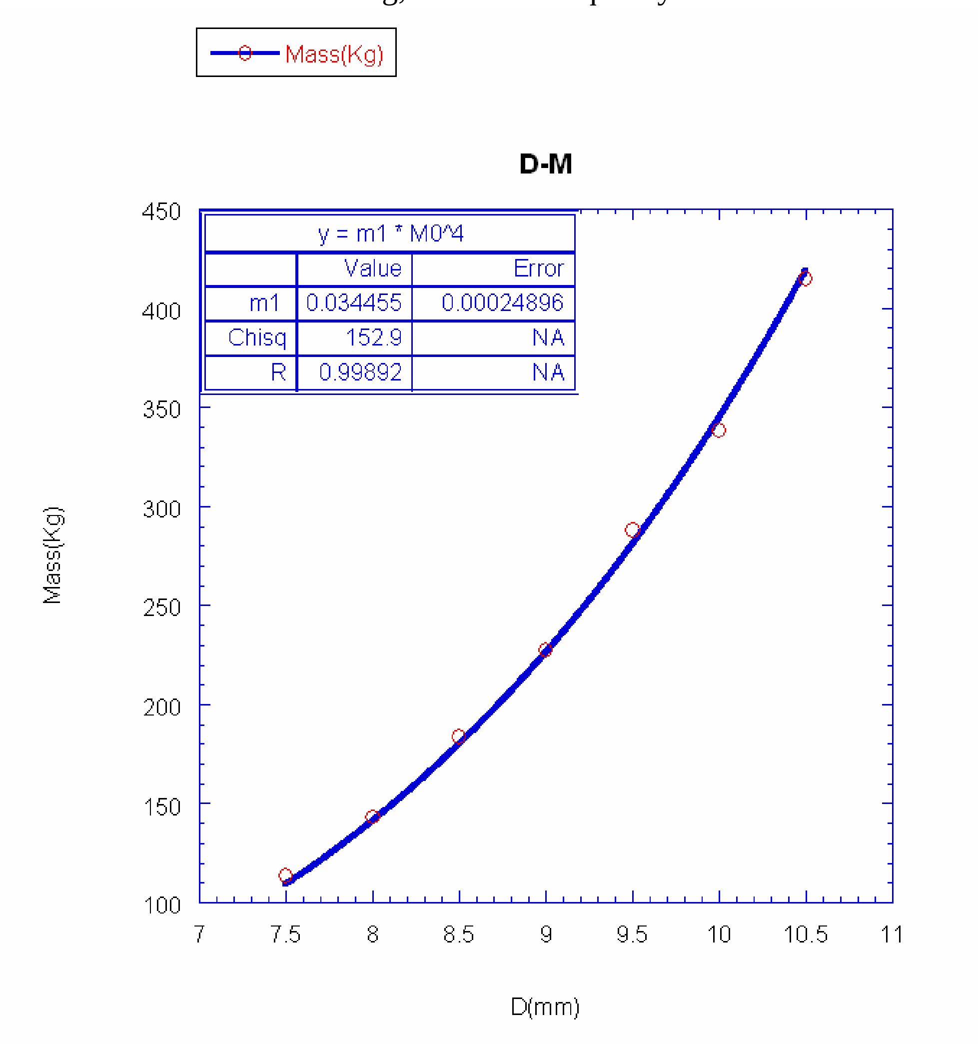

Figure 3: HAM SAS leg, Mass at zero frequency vs. Diameter plot

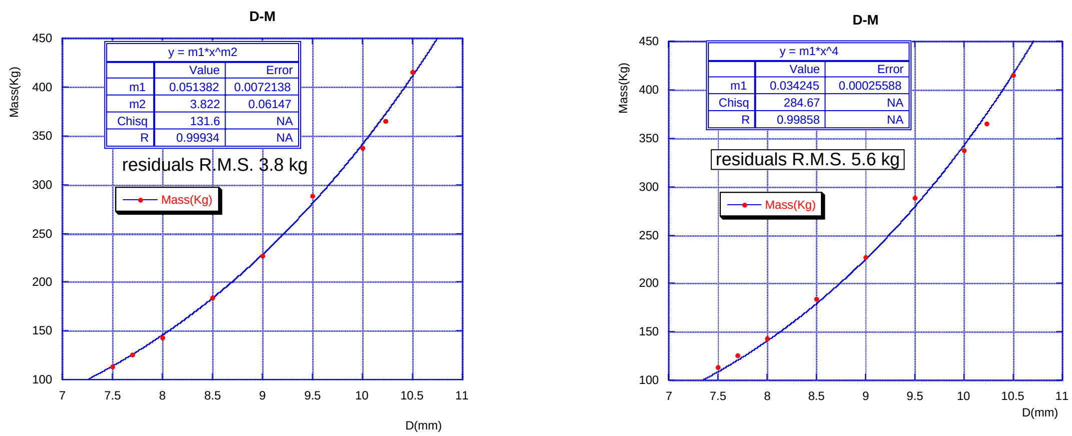

Figure 4: Small leg, two kinds of fit of the Mass at zero frequency vs. Diameter plot.

Both the power law fits exponents of 3.8 & 4 respectively determined the load with similar errors (4 to 6 kg determined from the residuals of the fit). We assumed that the exact relation between load (M) and the diameter (D) is $M \propto D^4$.

For this leg and the 9.5 mm flex joint, we have an experimental measurement of 257.3 kg critical mass to be compared with the 279 to 280 kg found by the two fits. A difference of 8.4%.

We can renormalize the fit to the single measured data point and get the formula

Mass = (0.034245 / 1.0843) (Diameter)^4 = 0.03158 (Diameter)^4

This formula is then used to evaluate the required Flex Joint Diameter for any given load in the HAM-SAS geometry.

We then calculated the bending stress of the flex joint as a function of movement of the leg’s tip.

The calculated stress includes compressive stress (due to the load) and bending stress.

The stress was calculated both using ANSYS finite element analysis, and by hand.

The two values are compared in table 2 and figure 5.

The numbers are comparable, but the ANSYS data is subject to unexplained large fluctuations.

The Maraging Yield stress is 1.8 GPa.

In no case the stress come close to the Maraging Yield point.

Flex Joint Diameter(m)	Stress (Pa/cm) by hand	Stress (Pa/cm) in computer
0.009	2.8500e+08	3.0590e+08
0.0095	3.0083e+08	5.0900e+08
0.0102	3.2300e+08	3.1600e+08
0.008	2.5333e+08	2.7000e+08

Table 2: HAM SAS leg flex-joint bending stress test.

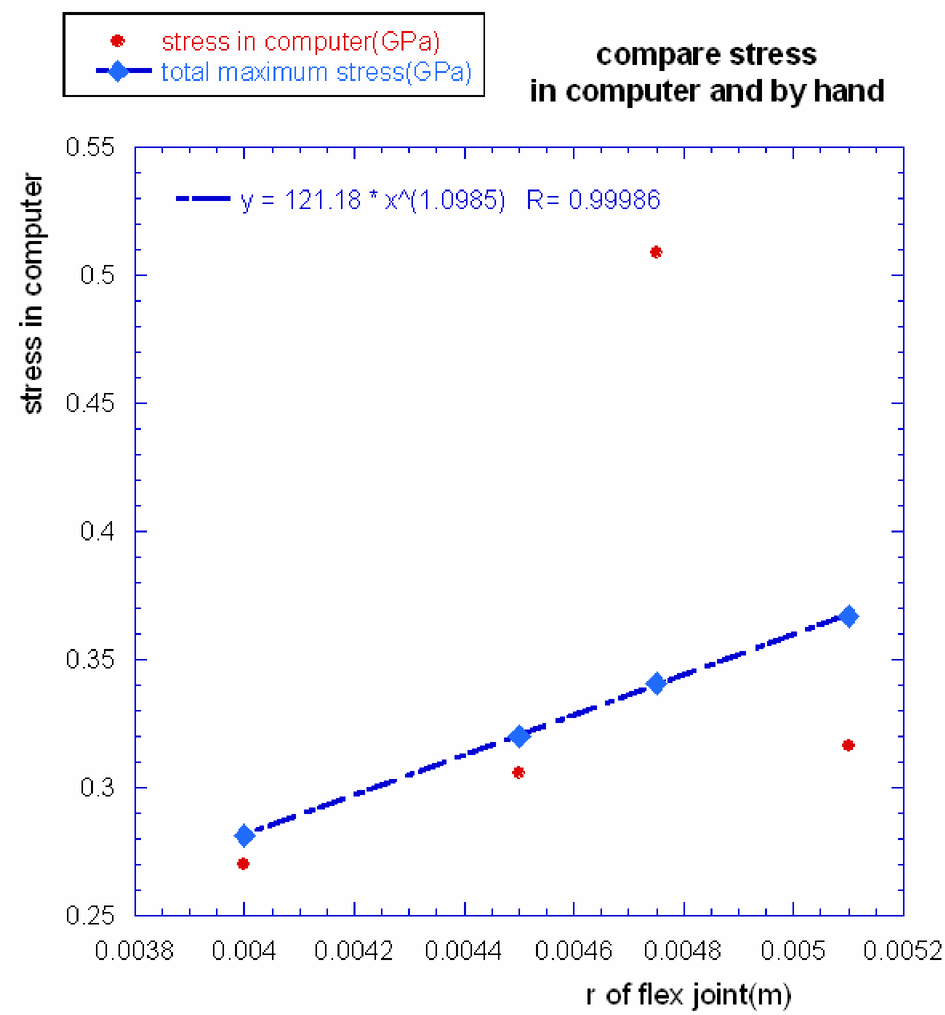

Figure5: the stress in computer and stress by hand

As a further exercise, we calculated the same stress test for a tentative BSC-SAS geometry. This leg geometry uses the same flex joint. The thickness of the aluminum pendulum new leg is increased to 1.5 mm.

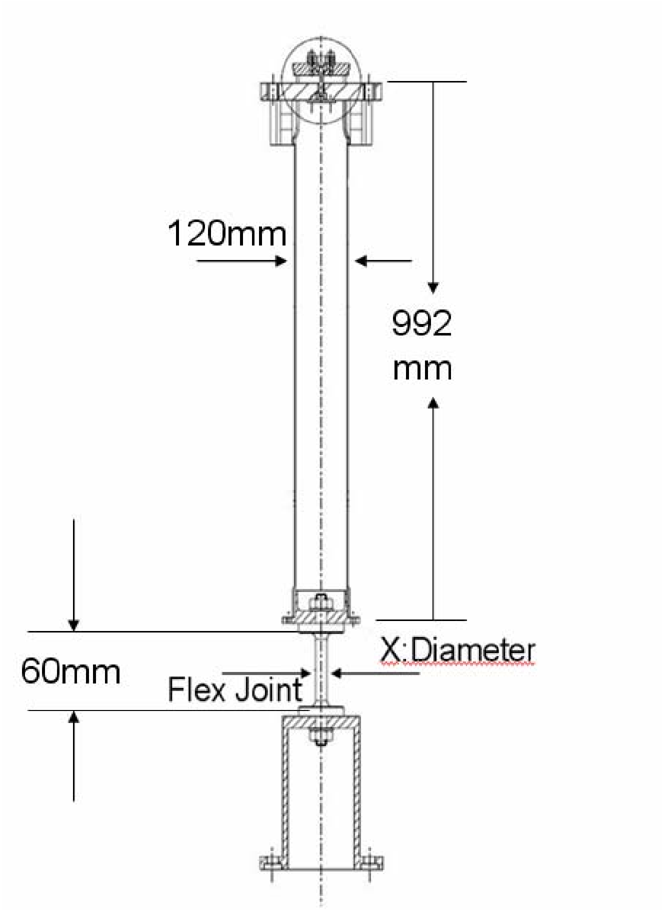

Figure6: Drawing of the BSC SAS invert pendulum leg.

Flex Joint Diameter (mm)	Load at 0 Frequency (Kg)
15.000	763.00
16.000	971.00
10.000	160.00
20.000	2208.0
13.500	500.00
18.000	1488.0

Table 3: BSC SAS leg; Mass at 0 Hz frequency vs. Diameter plot

The exact relation between load (M) and the diameter (D) is also assumed to be $M \propto D^4$.

The BSC calculation uses the same flex joint as the HAM. Since there is more load on the Flex Joint, we calculated its maximum stress as a function of load and as a function of bending.

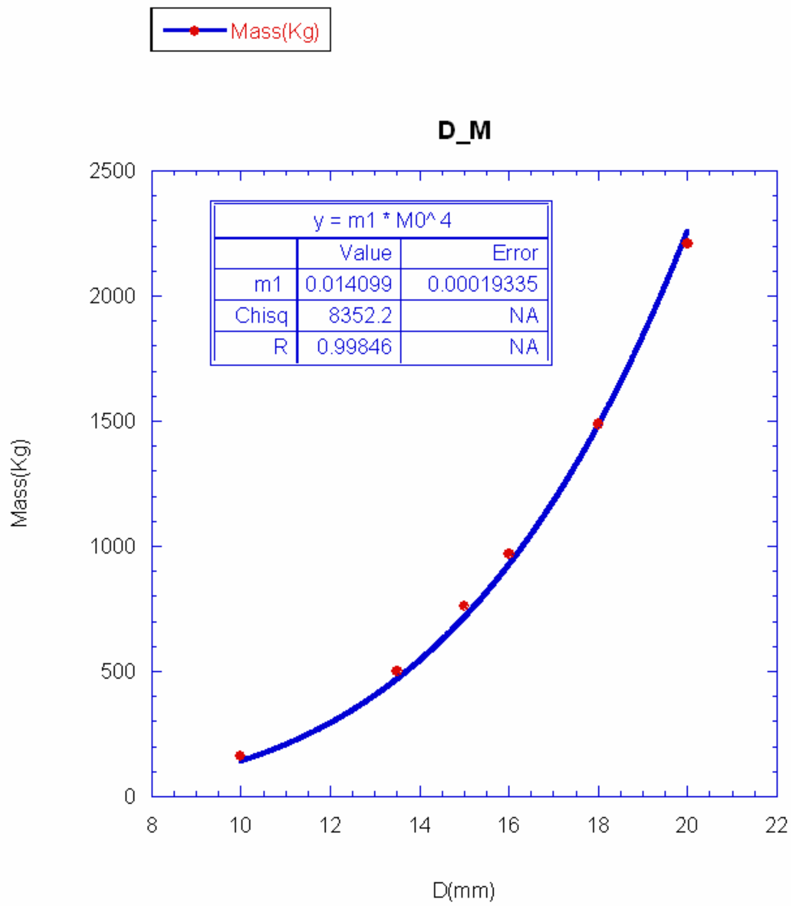

Figure 7: Big leg, Mass at 0 frequency vs. Diameter

Diameter(m)	Stress (Pa/cm) by hand	Stress (Pa/cm) in computer
0.0135	2.1547e+08	2.0350e+08
0.01	1.5961e+08	3.0400e+08
0.018	2.8730e+08	2.4600e+08
0.016	2.5538e+08	3.4100e+08

Table 3: BSC SAS leg flex joint Stress estimation.

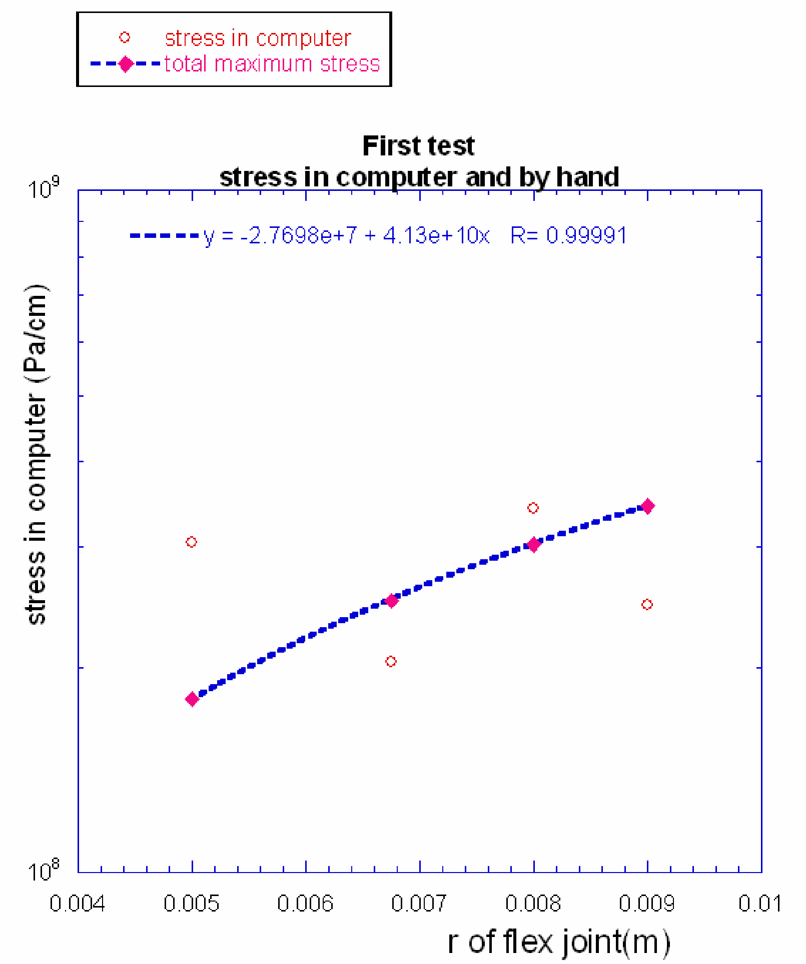

Figure 8: Big leg, Stress vs. r of flex joint

Studying the figure, we can find that the calculated stress obtained from computer is poor, these results are in rough accord with the result we obtained by hand, but with large scattering from the theoretical result. The limit stress per cm is 1.8×10^9 Pa. Given the fact that the range limiters are set to about 10 mm, all the points are largely below the limit. So we conclude that the same flex joint is good also for the BSC higher load (and smaller bending) both stress results of the flex joint are not too big. Now, we can say the flex joint is safe.

The discrepancy between theory and simulation is not well understood.