M E M O R A N D U M

To:

From:

Date: December 12, 2019

Subject: Calibration of Cantilever Beam Load Cell

Attachments:

1. Table of Calibration Data and Statistical Calculations
2. Calibration Plot
3. Sample Calculations; Determination of Load Cell Accuracy (%FSO)
4. Assessment of Linear Model
5. Original Data Sheet

Results and Discussion

In this experiment, we calibrated a Cantilever Beam Load Cell by adding masses ranging from 0 to 2000 grams to a load cell. We used the average nominal voltage readings from a dual strain gauge whetstone bridge setup read by the PolyDAQ system for calculations. This was done for each mass four times in both upscale and downscale directions in order to more accurately expose the hysteresis error. Similarly, the high and low value was determined for multiple trials in order to expose other error potentially created by the load cell.

Table 1 shows the required information for each sample needed to find the calibration equation. This includes the calculated curve fitted mass, residuals, squares of residuals and uncertainty at 95% confidence. Calculations on the process for finding these characteristics can be found in Attachment 3. From this information, we were able to determine the calibration equation for the load cell of $y = 0.7881x - 12.961$ where y is in units of mV and x is in units of g. This linear equation is clearly demonstrated in the plot in Attachment 2. Using the calibration equation determined for the strain gauge, the mass of the rocks Anonymous and Thorny were determined to be (0.391±0.018) g and (2.353±0.019) g respectively. These values can be compared to the actual mass of the samples in order to determine the accuracy of the calibration equation created.

Attachment 1: Table of Calibration Data and Statistical Calculations

Table 1. Measured quantities and Linear Regression

	Mass	Voltage	Measurement Uncertainty		Calibration Line and Calculations:				Uncertainty and 95% Confidence Limits:		
Number	(kg)	(mV)	(kg)	(mV)	(kg)		(kg^2)	(mV^2)	(kg)		
	y_i	x_i			y_c	y_i-y_c	$(y_i-y_c)^2$	$(x_i-\bar{x})^2$	U	Upper CL	Lower CL
1	0	16.441	0	0.036	-0.004	0.0038479	0.000014806	1.620	0.018	0.014	-0.022
2	0.25	16.762	0.0022	0.036	0.249	0.0012619	0.000001592	0.907	0.018	0.267	0.230
3	0.5	17.075	0.0050	0.030	0.496	0.0041925	0.000017577	0.408	0.019	0.514	0.477
4	0.75	17.400	0.0055	0.024	0.752	-0.001546	0.000002390	0.099	0.019	0.770	0.733
5	1	17.725	0.010	0.020	1.008	-0.008073	0.000065165	0.000	0.019	1.027	0.989
6	1.25	18.043	0.010	0.023	1.258	-0.008294	0.000068795	0.108	0.019	1.277	1.239
7	1.5	18.360	0.011	0.030	1.509	-0.008516	0.000072522	0.417	0.019	1.528	1.490
8	1.75	18.685	0.011	0.030	1.765	-0.014649	0.000214579	0.943	0.019	1.784	1.746
9	2	18.973	0.012	0.032	1.991	0.0087728	0.000076961	1.584	0.019	2.010	1.972
10	2	18.979	0.012	0.029	1.996	0.0040442	0.000016355	1.599	0.019	2.015	1.977
11	1.75	18.670	0.011	0.025	1.753	-0.002827	0.000007992	0.914	0.019	1.772	1.734
12	1.5	18.333	0.011	0.032	1.487	0.0131568	0.000173100	0.383	0.019	1.506	1.468
13	1.25	18.019	0.010	0.024	1.240	0.0102261	0.000104573	0.093	0.019	1.259	1.221
14	1	17.698	0.010	0.033	0.986	0.0136003	0.000184967	0.000	0.019	1.005	0.968
15	0.75	17.371	0.0055	0.036	0.729	0.0209149	0.000437433	0.118	0.019	0.748	0.710
16	0.5	17.066	0.0050	0.029	0.489	0.0112854	0.000127360	0.420	0.019	0.507	0.470
17	0.25	16.754	0.0022	0.029	0.243	0.0071726	0.000051446	0.922	0.018	0.261	0.224
18	0	16.433	0	0.027	-0.011	0.0105467	0.000111234	1.642	0.018	0.008	-0.029
19	0	16.444	0	0.024	-0.001	0.0014836	0.000002201	1.613	0.018	0.017	-0.020
20	0.25	16.774	0.0022	0.031	0.258	-0.008195	0.000067164	0.885	0.018	0.277	0.240
21	0.5	17.098	0.0050	0.020	0.514	-0.01354	0.000183325	0.380	0.019	0.532	0.495
22	0.75	17.401	0.0055	0.015	0.752	-0.002334	0.000005448	0.098	0.019	0.771	0.734
23	1	17.709	0.010	0.027	0.995	0.0045371	0.000020585	0.000	0.019	1.014	0.977
24	1.25	18.027	0.010	0.024	1.246	0.0043154	0.000018622	0.098	0.019	1.265	1.227
25	1.5	18.332	0.011	0.024	1.486	0.0135508	0.000183624	0.382	0.019	1.505	1.467
26	1.75	18.656	0.011	0.018	1.741	0.0086004	0.000073968	0.886	0.019	1.760	1.722
27	2	18.987	0.012	0.020	2.003	-0.002655	0.000007047	1.621	0.019	2.022	1.983
28	2	18.991	0.012	0.024	2.006	-0.005807	0.000033722	1.631	0.019	2.025	1.987
29	1.75	18.661	0.011	0.034	1.745	0.00466	0.000021715	0.896	0.019	1.764	1.726
30	1.5	18.357	0.011	0.024	1.506	-0.005758	0.000033151	0.413	0.019	1.525	1.487
31	1.25	18.043	0.010	0.032	1.258	-0.008294	0.000068795	0.108	0.019	1.277	1.239
32	1	17.715	0.010	0.030	1.000	-0.000191	0.000000037	0.000	0.019	1.019	0.981
33	0.75	17.413	0.0055	0.018	0.762	-0.011791	0.000139034	0.091	0.019	0.780	0.743
34	0.5	17.091	0.0050	0.028	0.508	-0.008417	0.000070848	0.388	0.019	0.527	0.490
35	0.25	16.778	0.0022	0.027	0.261	-0.011348	0.000128771	0.877	0.018	0.280	0.243
36	0	16.449	0	0.028	0.002	-0.002063	0.000004255	1.601	0.018	0.020	-0.016
Averages		17.714		0.027	Sums		0.002798381	24.144			

Attachment 2: Calibration Plot

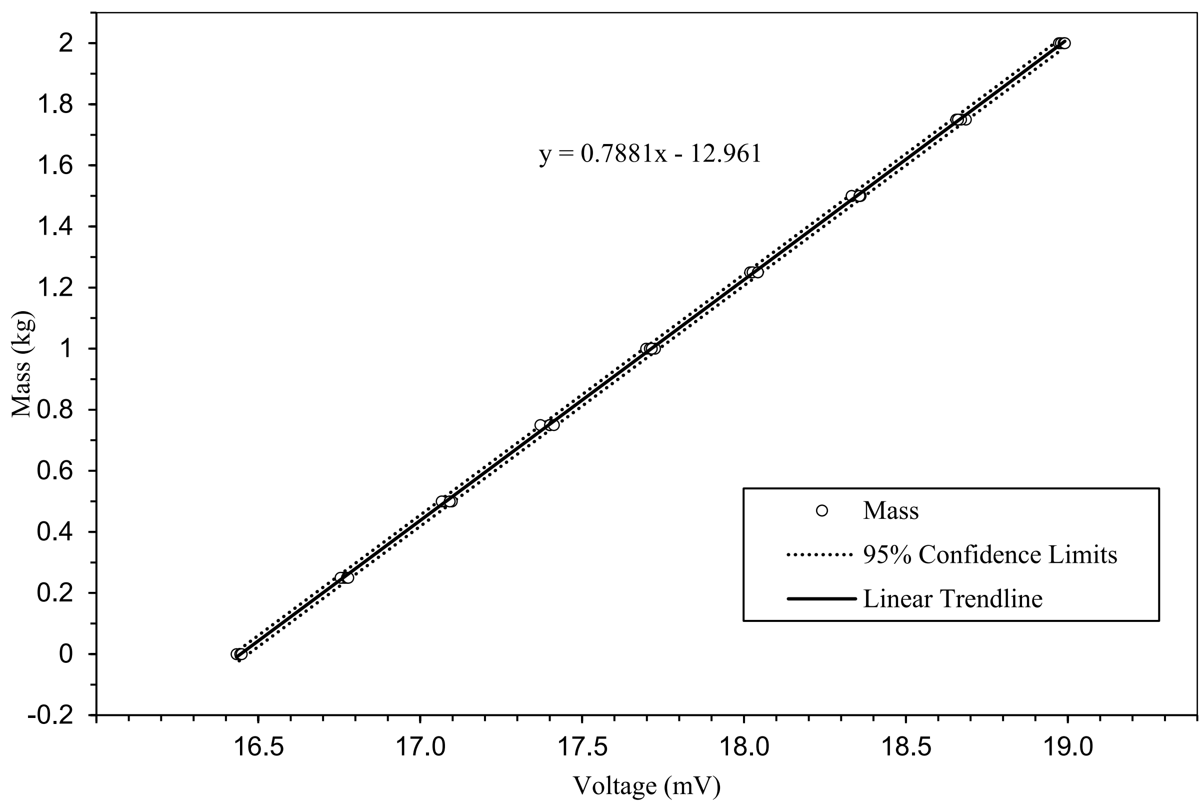

Figure 1. Calibration Plot of Mass vs. Voltage

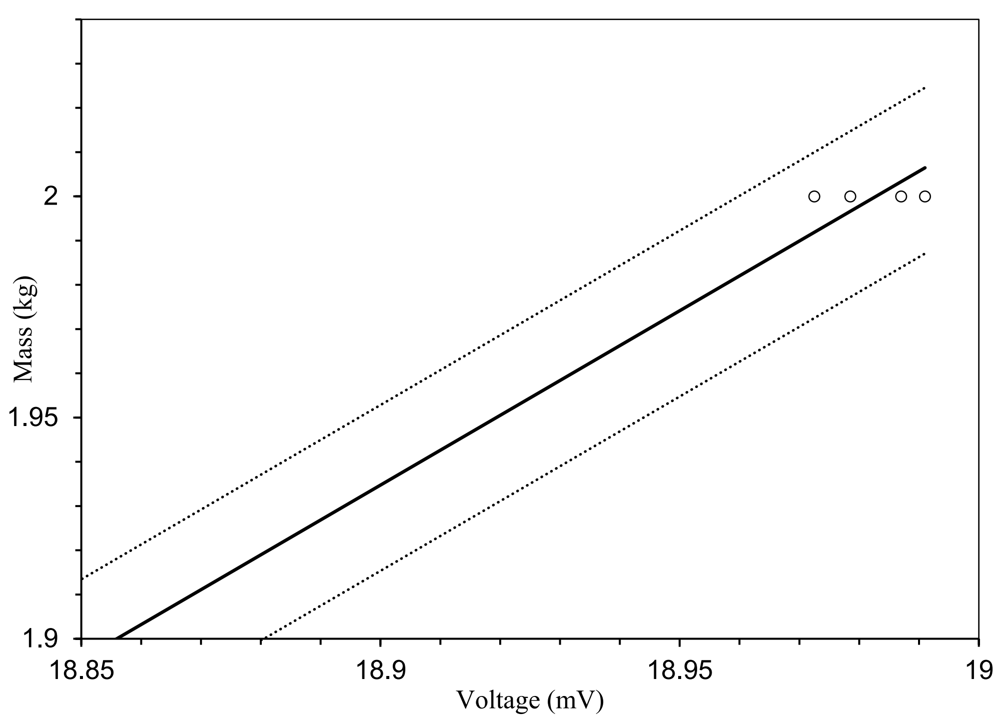

Figure 2. Detail of Calibration Uncertainty Around 2 kg

Attachment 4: Assessment of Linear Model

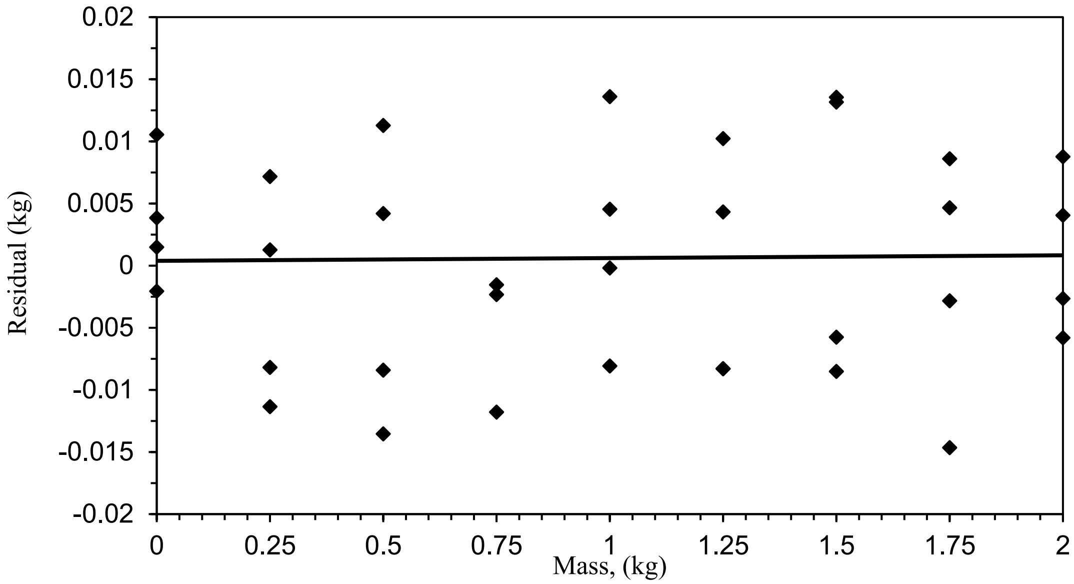

Figure 1. Residual plot

To assess whether the linear regression model used was adequate, we plot the residuals on the y-axis and the mass on the x axis. Since no trend can be seen on this plot, we know that the residuals are distributed fairly evenly about the regression line at all masses. This shows that the linear model is sufficient to fully describe the trends in the data.

Attachment 5: Original Data Sheet

Table 1. Original Data Sheet

mass (g)	Low (mV)	High (mV)
0	16.405	16.477
250	16.725	16.798
500	17.045	17.105
750	17.375	17.424
1000	17.705	17.745
1250	18.02	18.065
1500	18.33	18.39
1750	18.655	18.715
2000	18.94	19.005
2000	18.95	19.007
1750	18.645	18.695
1500	18.3	18.365
1250	17.995	18.043
1000	17.665	17.73
750	17.335	17.407
500	17.037	17.095
250	16.725	16.783
0	16.405	16.46
0	16.42	16.468
250	16.742	16.805
500	17.078	17.117
750	17.385	17.416
1000	17.682	17.736
1250	18.003	18.05
1500	18.308	18.356
1750	18.637	18.674
2000	18.967	19.007
2000	18.967	19.015
1750	18.627	18.694
1500	18.333	18.38
1250	18.01	18.075
1000	17.685	17.745
750	17.395	17.43
500	17.063	17.119
250	16.75	16.805
0	16.42	16.477