Micro-g LaCoste
Borehole Gravimeter Test Report
November 23, 2004
University of Texas, Austin Campus
Borehole Gravimeter #12

Micro- g LaCoste refurbished and upgraded borehole gravimeter (BHGM) #12. The project included service on the sensor, upgrading the electronics to an Aliod feedback, new power supply, new telemetry electronics, and new software. The BHGM was tested in the JJ Pickle Well on the University of Austin at Texas campus. The BHGM was placed inside of a high pressure Dewar sonde with outside diameter of 4 ¼" and a temperature rating of 185C. Figure 1 shows a photograph of the BHGM in its sonde. Figure 2 shows a photograph of the BHGM prior to being lowered into a borehole.

Figure 1 BHGM #12 in High Pressure Dewar Sonde

These photos (figure 1 and 2) show the logging procedure on a nice sunny day. However, the test described in this report was actually performed on a rainy day in a very wet week in Austin where about 12cm of rain fell in 5 days (local river flooding). The ground was assumed to be saturated with water, with water movement in the well

The borehole test consisted of nine measurements each lasting about 6 minutes (4 minutes logged) at three different depths: nominally 960, 1020, and 1100 feet. The raw data was transmitted via RS232 to an up-hole field computer where it was logged.

Figure 2 Deploying the BHGM in the test well

The raw data were averaged for the last 2 minutes of each occupation and are shown in Table 1. The first column is the nominal depth, the second is the time, and the raw gravity value is in column 3. The actual depth is in column 4 and the temperature of the BHGM is in column 5. The sixth column is gravity is corrected for depth differences (around the average depth at each station) using the formula $g_c = g_r - \left(f - 4\pi G\rho\right)\left(D - \langle D \rangle\right)$; where g_c is the corrected gravity, g_r is the raw gravity value, f is the free air gradient, ρ is the density (assumed 2.5gm/cm^3), and $\langle D \rangle$ is the average depth of each station. The corrected value of gravity takes into account that the repeat observations were not done at exactly the same depth.

Station	Time	graw	Depth (ft)	Temp C	G (corrected)
1100	20:57:34	146.382	1,100.40	130.170	146.38038
1020	21:08:46	144.023	1,020.08	130.160	144.02077
960	21:20:20	142.250	960.31	130.170	142.24982
1100	21:34:09	146.365	1,100.31	130.150	146.36579
1020	21:44:36	144.003	1,019.94	130.110	144.00472
960	21:53:40	142.240	960.30	130.120	142.23963
1100	22:05:50	146.371	1,100.33	130.130	146.37195
1020	22:15:13	144.022	1,019.97	130.180	144.02297
960	22:23:56	142.248	960.26	130.170	142.24886

Table 1 BHGM Raw Data Averages (last two minutes of each observation)

The data were analyzed with three different models of increasing complexity in order to estimate the sensitivity of the least squares fit to the model. The first model (Model I) used only a least squares fit for a single station value for each of the three depths, Model II included a temperature coefficient, and Model III also included a drift. The results of these three models are shown in Table 2. The residual is the standard deviation of the difference between the observations and the model and therefore is a measure of the repeatability of the BHGM.

960	142.2461
1020	144.0162
1100	146.3727
Residual	σ= 0.0068
dg/dz	**new ρ**
0.02947476	2.5269

Temp	0.236915
960	142.2456
1020	144.0164
1100	146.3730
Residual	σ= 0.0033
dg/dz	**new ρ**
0.0294801	2.5267

Drift	-0.022221
Temp	0.234307
960	142.2464
1020	144.0171
1100	146.3735
Residual	σ= 0.0032
dg/dz	**new ρ**
0.0294778	2.5268

Table 2: Least square analysis for three models

Note that the residual standard deviation is 6.8μGal if no temperature coefficient or drift is included. The inclusion of a temperature coefficient of 237μGal/ºC is quite important and reduces the residual error on the repeat stations to a standard deviation of 3.3 μGal. If we include a drift term, the standard deviation is not reduced significantly (only to 3.2 μGal). This means that there was no measurable (significant) drift of the BHGM during the survey. The last row for each model provides an estimate of the average vertical gravity gradient (a linear trend) that is left in the data after the first correction that was made using a density of 2.5gm/cm^3. This residual gradient was then used to provide a better estimate of the density. Notice that all three models provide a very similar density of 2.527(5). This density is consistent with previous BHGM logs and Gamma-gamma logs in this borehole. The residual difference between the measured gravity values and the predicted gravity values for Model II (no drift) is shown in Figure 3.

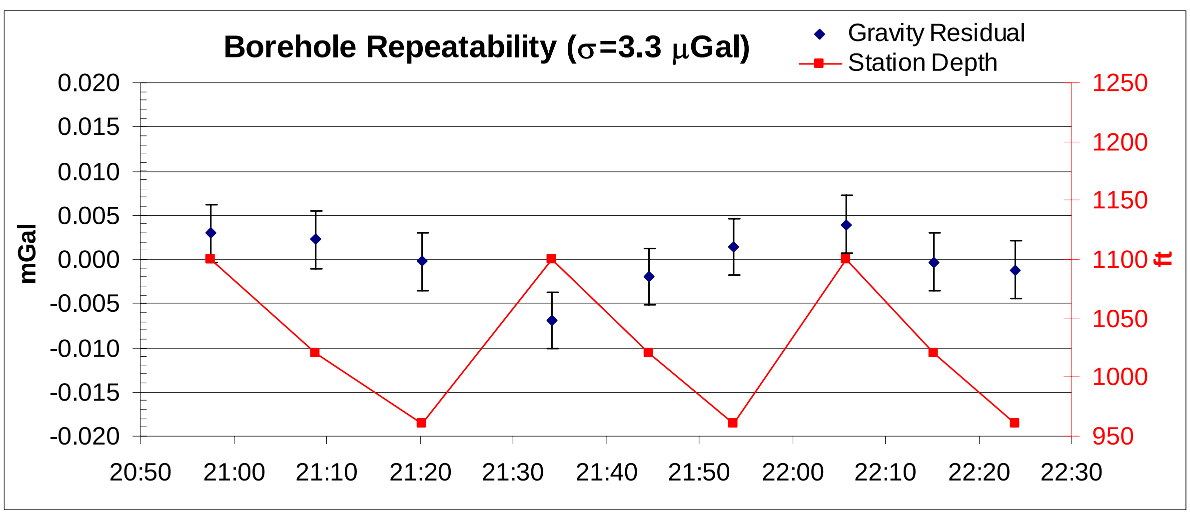

Figure 3: BHGM repeatability (Model II)

The repeats are shown as the dark blue diamonds and they reference the left axis in mGal. The violet curve shows the station depth for each repeat and it references the right hand y-axis. The standard deviation of these repeat measurements from Model II with no drift is 3.3 μGal. The residuals do not look random and probably indicate a problem with depth determination but in any case the repeatability of 3μGal is quite good.

These data and all of the analyses clearly demonstrate that the BHGM can be used to acquire gravity at better than 7 μGal with no drift or other correction. If one applies a temperature correction, we could demonstrate a repeatability of 3.3μGal with no drift. While this estimate may be a bit optimistic due to other errors in positioning of the cable, it clearly demonstrates that one can make excellent borehole measurements using the L&R BHGM with the new electronic improvements that have been made. Finally all of the analyses indicate that there was no measurable drift of the instrument during the survey.

The error on the density estimate due to the measured repeatability of the gravity can be estimated (ignoring depth errors) using the formula $\delta\rho = \delta(dg)/dz/(4\pi G)$. We can estimate the error on the gravity difference, δ(dg), between the top and bottom stations (dz=1100-960 ft = 140ft) as an uncorrelated repeatability error given by $\delta(dg) = \sqrt{2}\sigma = \sqrt{2}\cdot 3.3\mu\text{Gal} = 4.6\mu\text{Gal}$. This yields a measured average density of 2.5267± 0.0013 gm/cm^3 over a depth of 42m.