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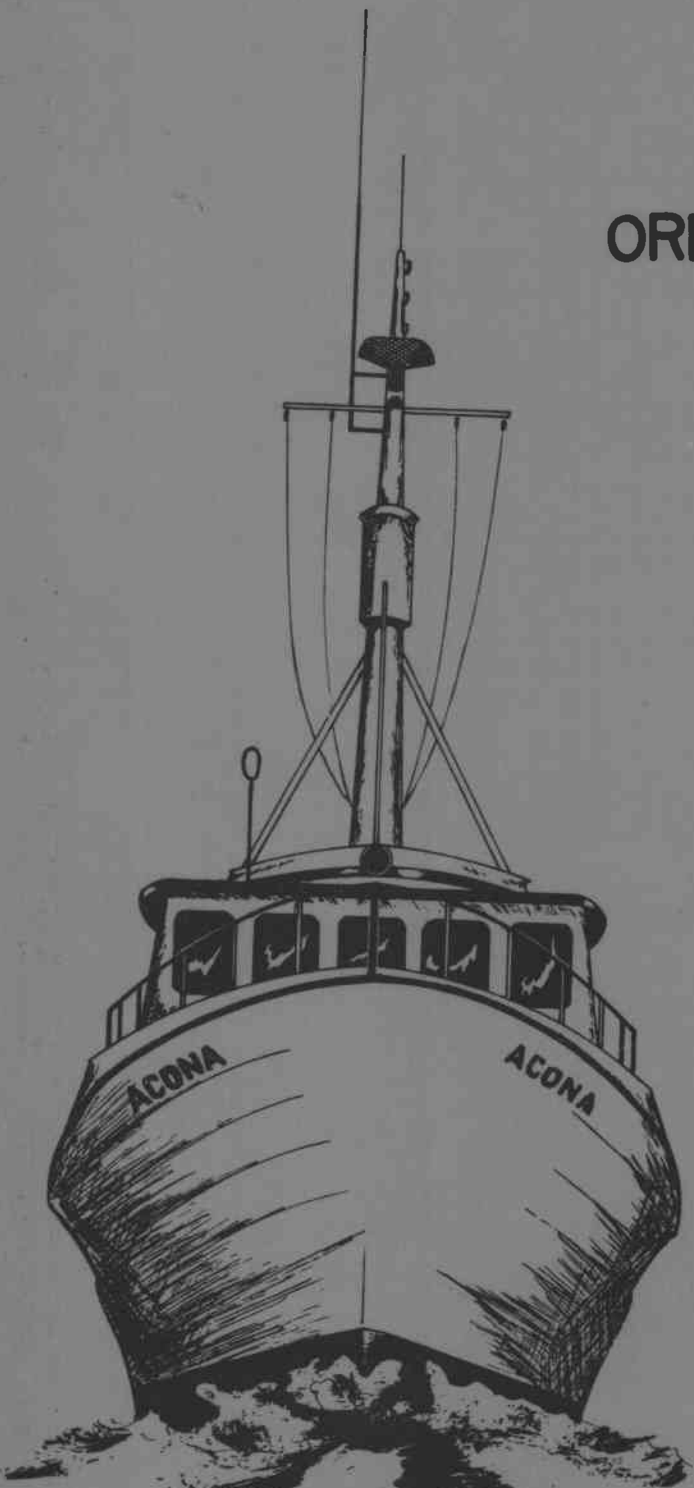

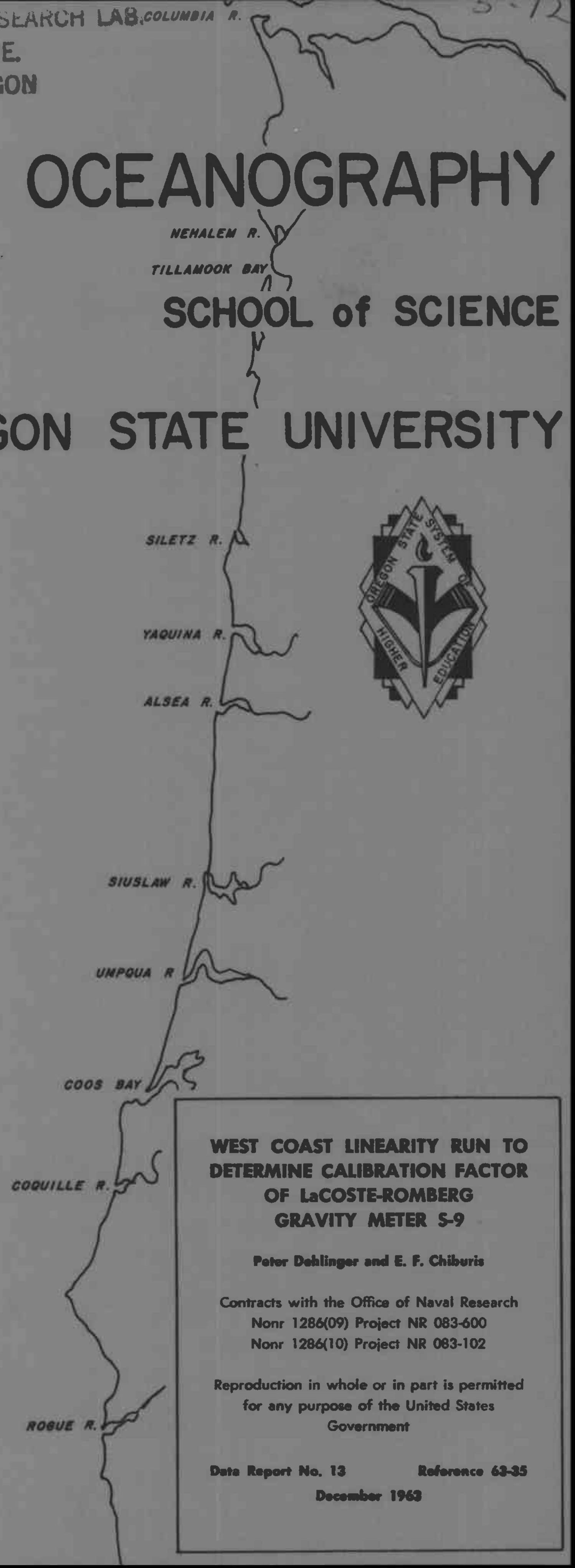

WEST COAST LINEARITY RUN TO DETERMINE CALIBRATION FACTOR OF LaCOSTE-ROMBERG GRAVITY METER S-9

Peter Dehlinger and E. F. Chiburis

Contracts with the Office of Naval Research
Nonr 1286(09) Project NR 083-600
Nonr 1286(10) Project NR 083-102

Data Report No. 13 **Reference 63-35**
December 1963

DEPARTMENT OF OCEANOGRAPHY

Geophysics Research Group

OREGON STATE UNIVERSITY

Corvallis, Oregon

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Abstract

The calibration factor of LaCoste-Romberg surface-ship gravity meter S-9 was checked against a 1200 mgal range of land base stations along the West Coast of the United States. Previous checks at other base stations provided conflicting results as to the accuracy of this meter's calibration factor supplied by the manufacturers. Results of the West Coast base station checks provided a calibration factor which is within 0.1% of that provided by the manufacturers. A revised calibration table was calculated and is presented in this report for use with meter S-9.

Introduction

The LaCoste-Romberg surface-ship gravity meters are geodetic meters capable of measuring gravity differences between any two points on the surface of the earth without resettings in measuring scale. Measurements at sea are sometimes made in areas where gravity values are considerably larger or smaller than at the nearest base station. To obtain correct values of gravity under such conditions requires an accurate meter calibration factor. This factor varies slightly over the range of counter scale, however, such that the calibration factor must be known accurately for each value of meter counter reading. The variation in spring constant with counter reading, as provided by the manufacturers from laboratory measurements, is taken as correct. The absolute calibration factor at any counter reading is determined from checks against known gravity differences at two or more base stations.

Historical Note

In November of 1960, when LaCoste-Romberg surface-ship gravity meter S-9 was still new, its calibration factor and linearity were checked against a range of land base stations between upper New York state and Virginia. This range consisted of 21 stations over which there was an 800 mgal change in gravity. A least-square analysis of the results indicated that the manufacturers' calibration factor was correct over the corresponding counter readings by 1 part in 10^4. The standard error of estimate in each reading was 0.6 mgal and the probable error 0.4 mgal.

Checks with meter S-9 made subsequently at several harbor base stations between New York and Florida and between northern Italy and Sicily indicated that the manufacturers' calibration factor, which checked out with remarkable precision before, was too large by about 3 parts in 10^3. It could not be determined whether any of the sets of base stations used might have contained errors or whether the manufacturers' calibration was in error.

To obtain more confidence in the calibration factor, it was decided to check the meter against another set of land base stations in August 1963. The stations used are located on the West Coast of the United States, involving a range of more than 1200 mgals.

Discussion

Meter S-9 was read at base stations between Vancouver, B. C., and Paso Robles, California. Of 26 stations occupied,

- 8 were at USC and GS bench marks for which gravity values were published by the Coast Survey.
- 2 were at Woollard base stations.
- 13 were at stations offset less than 30 feet from USC and GS bench marks; gravity differences between the station occupied by meter S-9 and the Survey bench marks were measured with a Worden gravity meter.
- 2 were at stations offset about 100 feet from Woollard stations (at Vancouver and San Francisco); gravity differences were measured with the Worden meter.
- 1 station (Corvallis) was tied to the Woollard station in Portland with the Worden gravity meter.

Most of the base values are considered to be correct within $\pm$ 1.0 mgal.

The S-9 and Worden meters were taken to the stations by truck, such that each station was read at two different times. A least-square analysis provided a meter calibration factor that applied over the 1200 mgal range of base stations. The calibration factor was known to be linear over the corresponding counter readings from the previous laboratory tests made by the manufacturers, such that a linear fit between counter readings and gravity value is entirely satisfactory.

Results

The least-square analysis indicated a calibration factor of 1.02708 mgal/scale division between counter readings of 7700 and 8900. This factor is applicable in the middle of the counter range, i.e. at 8300 scale divisions. The manufacturers' factor at 8300 is 1.02800. Hence, the scale factor should be 0.999105, or slightly less than 0.1 percent smaller than that provided by the manufacturers. Although this amounts to a difference of only 1 mgal in 1000, a new table of calibration factors was constructed to provide for a small increase in accuracy of gravity calculations.

Table 1 lists the revised calibration factors, which were obtained by multiplying by 0.999105 the manufacturers' values corresponding to each 100 counter interval.

Figure 1 shows the residuals in gravity at each base station as a function of observed gravity. The standard error of estimate of the residuals is 0.9 mgal, the probable error 0.6 mgal. A part of the errors is probably due to inaccuracies in the base station values. The average difference in S-9 measurements for the two readings made at each station, without regard to sign was 0.9 mgal. While the repeatability of separate readings at one station was about 1 mgal, experience at sea has shown that variations in gravity along a line over which the meter is operating continuously are accurate to about 0.5 mgal.

Gravity residual calculations were also made for these West Coast stations using an assumed S-9 meter calibration factor differing by 0.997 of that provided by the manufacturers in an attempt to determine whether such a factor, which would provide for better agreements at the several harbor base stations between New York and Florida and between northern Italy and Sicily, would also provide a satisfactory agreement over the range of West Coast stations. It was found that for these factors the standard deviation was 2.4 mgals and the probable error 1.6 mgals; the average line in Figure 1 for this factor was not horizontal. It is concluded that the correct calibration factor is that shown in Table 1 and that the errors observed between New York and Florida and in Italy probably involve some errors in the harbor base values.

Acknowledgments

The Department of Geology at the University of Oregon is gratefully acknowledged for lending its Worden gravity meter for making ties between base stations and sites at which the S-9 meter readings were made. Mr. B. R. Jones of Texas A and M University helped in obtaining the field measurements. Mr. W. A. Rinehart provided the base station value at Corvallis by having tied it previously to the Woollard base station in Portland. Meter S-9 is owned by the Office of Naval Research; the work was wholly supported by ONR under Contracts Nonr 1286(09) and Nonr 1286(10).

TABLE 1

CALIBRATION FACTORS FOR LaCOSTE-ROMBERG GRAVITY METER S-9

BASED ON WEST COAST BASE STATION CHECK OF AUGUST 1963

Counter	Milligal Value	Interval Factor	Counter	Milligal Value	Interval Factor	Counter	Milligal Value	Interval Factor
000	0.00	1.02638	4100	4210.40	1.02723	8100	8320.41	1.02713
100	102.64	1.02643	4200	4313.13	1.02723	8200	8423.12	1.02713
200	205.28	1.02648	4300	4415.85	1.02728	8300	8525.83	1.02708
300	307.93	1.02653	4400	4518.58	1.02728	8400	8628.54	1.02703
400	410.58	1.02653	4500	4621.31	1.02733	8500	8731.25	1.02698
500	513.24	1.02658	4600	4724.04	1.02733	8600	8833.94	1.02693
600	615.89	1.02663	4700	4826.77	1.02733	8700	8936.64	1.02688
700	718.56	1.02668	4800	4929.51	1.02738	8800	9039.32	1.02688
800	821.22	1.02673	4900	5032.25	1.02743	8900	9142.01	1.02678
900	923.90	1.02673	5000	5134.99	1.02743	9000	9244.69	1.02678
1000	1026.57	1.02678	5100	5237.73	1.02748	9100	9347.37	1.02663
1100	1129.25	1.02683	5200	5340.48	1.02748	9200	9450.04	1.02663
1200	1231.93	1.02683	5300	5443.23	1.02748	9300	9552.70	1.02658
1300	1334.61	1.02688	5400	5545.98	1.02748	9400	9655.36	1.02648
1400	1437.30	1.02688	5500	5648.73	1.02748	9500	9758.01	1.02643
1500	1539.99	1.02693	5600	5751.47	1.02748	9600	9860.65	1.02633
1600	1642.68	1.02693	5700	5854.22	1.02748	9700	9963.28	1.02628
1700	1745.38	1.02698	5800	5956.97	1.02748	9800	10065.91	1.02618
1800	1848.07	1.02698	5900	6059.72	1.02748	9900	10168.53	1.02608
1900	1950.77	1.02698	6000	6162.47	1.02753	10000	10271.14	1.02593
2000	2053.47	1.02703	6100	6265.22	1.02753	10100	10373.73	1.02578
2100	2156.17	1.02703	6200	6367.97	1.02758	10200	10476.31	1.02563
2200	2258.88	1.02703	6300	6470.73	1.02763	10300	10578.87	1.02548
2300	2361.58	1.02703	6400	6573.49	1.02768	10400	10681.42	1.02533
2400	2464.28	1.02708	6500	6676.26	1.02768	10500	10783.95	1.02513
2500	2566.99	1.02708	6600	6779.03	1.02773	10600	10886.46	1.02493
2600	2669.70	1.02708	6700	6881.80	1.02773	10700	10988.96	1.02473
2700	2772.41	1.02713	6800	6983.57	1.02778	10800	11091.43	1.02453
2800	2875.12	1.02713	6900	7087.35	1.02778	10900	11193.88	1.02428
2900	2977.83	1.02713	7000	7190.13	1.02778	11000	11296.31	1.02408
3000	3080.55	1.02713	7100	7292.91	1.02778	11100	11398.72	1.02388
3100	3183.26	1.02713	7200	7395.69	1.02768	11200	11501.11	1.02368
3200	3285.97	1.02713	7300	7498.45	1.02768	11300	11603.47	1.02343
3300	3388.68	1.02713	7400	7601.22	1.02763	11400	11705.82	1.02323
3400	3491.40	1.02713	7500	7703.99	1.02758	11500	11808.14	1.02298
3500	3594.11	1.02713	7600	7806.74	1.02748	11600	11910.44	1.02278
3600	3696.82	1.02713	7700	7909.49	1.02738	11700	12012.72	1.02253
3700	3799.54	1.02713	6800	8012.23	1.02733	11800	12114.97	1.02228
3800	3902.25	1.02718	7900	8114.96	1.02728	11900	12217.20	1.02203
3900	4004.97	1.02718	8000	8217.69	1.02718	12000	12319.40	
4000	4107.69	1.02718						

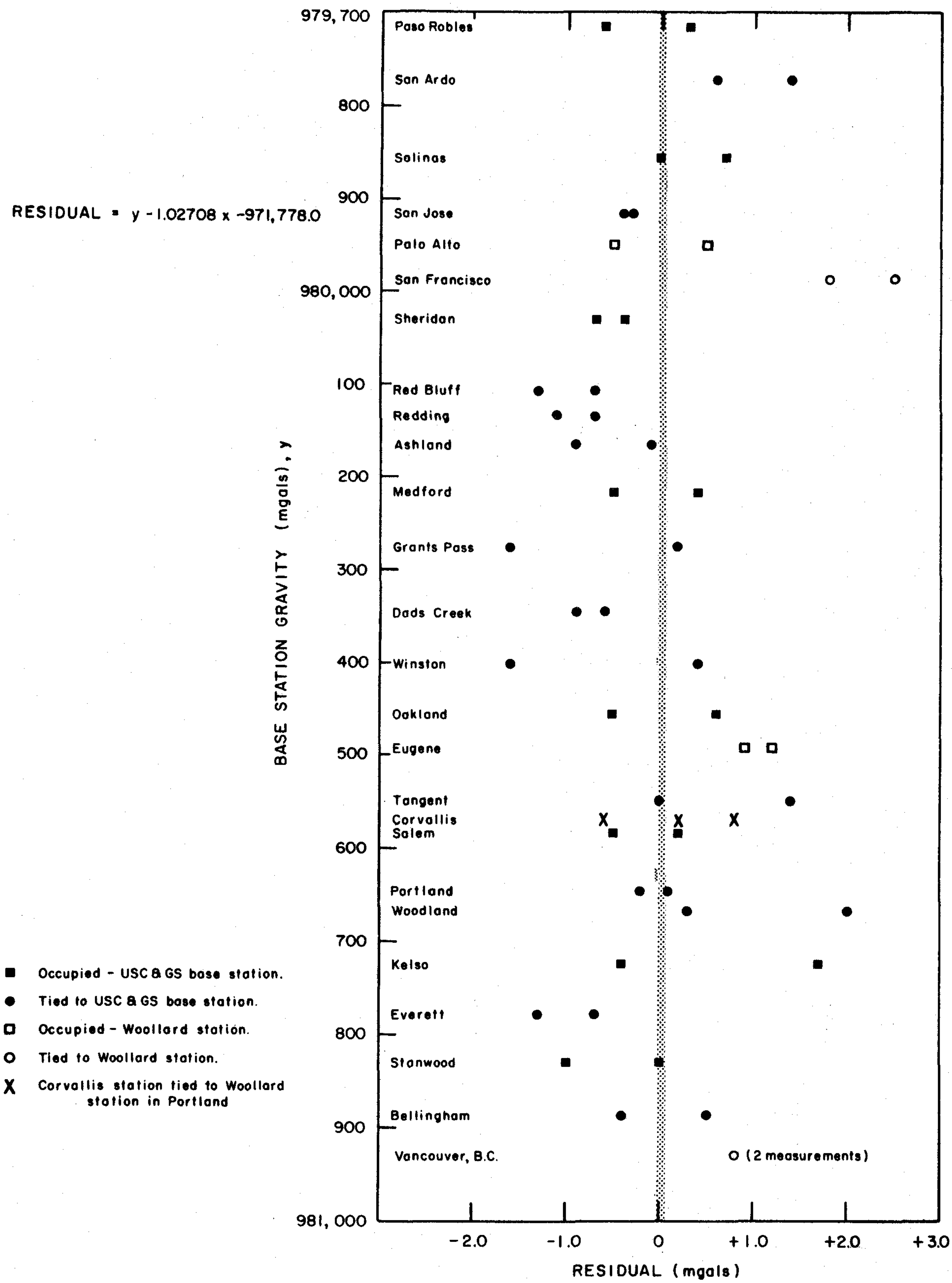

Figure 1. Residuals of gravity at the base stations occupied.

Appendix

Table 1A summarizes the data used for determining the calibration factor between counter readings of 7700 and 8900. The first and second columns give the value of gravity and counter readings at each base station. The third column gives the computed value of gravity, assuming a linear relationship

$$y = mx + b = 1.02708x + 971,778.0 \text{ mgals}$$

where

- y is the base gravity value
- m is the calibration factor
- x is the observed counter reading
- b is the gravity value corresponding to zero counter reading

The fourth column gives the gravity residual ($\Delta r = y - mx - b$) for each station observation, and the fifth column the square of the residual.

The standard error of estimate for each measurement with the meter was obtained from

$$S = \sqrt{\frac{\Sigma(\Delta r)^2}{n - 2}}$$

where n, the number of station observations, was 53. Then

$$S = \sqrt{\frac{43.72}{51}} = 0.93 \text{ mgal}$$

The probable error of each observation is 0.6745 that of the standard error of estimate or 0.62 mgal.

TABLE 1A

BASE GRAVITY VALUE, METER S-9 COUNTER READING

COMPUTED GRAVITY, GRAVITY RESIDUAL, AND SQUARE OF RESIDUALS

AT EACH OF 26 BASE STATIONS OCCUPIED

Station	y mgals	x scale divisions	mx + b mgals	Δr mgal	$(\Delta r)^2$ mgal
Vancouver	980,929.9	8909.8	980,929.1	+0.8	0.64
		8909.8	980,929.1	+0.8	.64
Bellingham	980,885.7	8867.4	980,885.5	+0.2	.04
		8868.0	980,886.1	-0.4	.16
Stanwood	980,829.0	8812.4	980,829.0	0.0	.00
		8813.4	980,830.1	-1.1	1.21
Everett	980,779.0	8664.4	980,779.7	-0.7	.49
		8764.9	980,780.3	-1.3	1.69
Kelso	980,722.3	8708.9	980,722.7	-0.4	.16
		8706.8	980,720.6	+1.7	2.89
Woodland	980,668.1	8655.4	980,667.8	+0.3	.09
		8653.8	980,666.1	+2.0	4.00
Portland	980,646.8	8635.2	980,647.0	-0.2	.04
		8634.9	980,646.7	+0.1	.01
Salem	980,584.9	8574.5	980,584.7	+0.2	.04
		8575.2	980,585.4	-0.5	.25
Corvallis	980,569.1	8559.1	980,568.9	+0.2	.04
		8558.5	980,568.3	+0.8	.64
		8559.9	980,569.7	-0.6	.36
Tangent	980,549.2	8538.6	980,547.8	+1.4	1.96
		8539.9	980,549.2	0.0	.00
Eugene	980,491.0	8482.4	980,490.1	+0.9	.81
		8482.1	980,489.8	+1.2	1.44
Oakland	980,453.6	8447.3	980,454.1	-0.5	.25
		8446.3	980,453.0	+0.6	.36
Winston	980,400.6	8396.8	980,402.2	-1.6	2.56
		8394.9	980,400.2	+0.4	.16
Dads Creek	980,343.8	8340.8	980,344.7	-0.9	.81
		8340.5	980,344.4	-0.6	.36
Grants Pass	980,276.8	8276.3	980,278.4	-1.6	2.56
		8274.5	980,276.6	+0.2	.04
Medford	980,218.2	8218.2	980,218.7	-0.5	.25
		8217.3	980,217.8	+0.4	.16
Ashland	980,162.6	8164.4	980,163.5	-0.9	.81
		8163.6	980,162.7	-0.1	.01
Redding	980,132.4	8134.8	980,133.1	-0.7	.49
	980,132.6	8135.2	980,133.5	-0.9	.81
Red Bluff	980,108.2	8111.8	980,109.5	-1.3	1.69
		8111.1	980,108.7	-0.5	.25
Sheridan	980,029.8	8034.6	980,030.2	-0.4	.16
		8034.9	980,030.5	-0.7	.49

Station	y mgals	x scale divisions	mx + b mgals	Δr mgal	(Δr)^2 mgal
San Francisco	979,988.7	7992.5	979,986.9	+1.8	3.24
		7991.8	979,986.2	+2.5	6.25
Palo Alto	979,948.9	7956.0	979,949.4	-0.5	.25
		7955.0	979,948.4	+0.5	.25
San Jose	979,916.1	7923.9	979,916.5	-0.4	.16
		7923.8	979,916.4	-0.3	.09
Salinas	979,857.2	7865.5	979,856.5	+0.7	.49
		7866.2	979,857.2	0.0	.00
San Ardo	979,774.4	7784.2	979,773.0	+1.4	1.96
		7785.0	979,773.8	+0.6	.36
Paso Robles	979,716.2	7729.5	979,716.8	-0.6	.36
		7728.6	979,715.9	+0.3	.09
			Σ	+1.6	43.72

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