 USGS-OFR-85-36

UNITED STATES DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

COMPARISON OF SURVEY AND PHOTOGRAMMETRY METHODS TO POSITION GRAVITY DATA, YUCCA MOUNTAIN, NEVADA

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1985

Open-File Report 85-36

Prepared in cooperation with the
Nevada Operations Office
U.S. Department of Energy
(Interagency Agreement DE-AI08-78ET44802)

Menlo Park, California

1985

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Abstract

Locations of gravity stations at Yucca Mountain, Nev., were determined by a survey using an electronic distance-measuring device and by a photogrammetric method. The data from both methods were compared to determine if horizontal and vertical coordinates developed from photogrammetry are sufficently accurate to position gravity data at the site. The results show that elevations from the photogrammetric data have a mean difference of 0.57 ± 0.70 m when compared with those of the surveyed data. Comparison of the horizontal control shows that the two methods agreed to within 0.01 minute. At a latitude of 45°, an error of 0.01 minute (18 m) corresponds to a gravity anomaly error of 0.015 mGal.

Bouguer gravity anomalies are most sensitive to errors in elevation, thus elevation is the determining factor for use of photogrammetric or survey methods to position gravity data. Because gravity station positions are difficult to locate on aerial photographs, photogrammetric positions are not always exactly at the gravity station; therefore, large disagreements may appear when comparing electronic and photogrammetric measurements. A mean photogrammetric elevation error of 0.57 m corresponds to a gravity anomaly error of 0.11 mGal. Errors of 0.11 mGal are too large for high-precision or detailed gravity measurements but are acceptable for regional work.

Introduction

A feasibility study was begun in August 1983 to determine if X, Y, and Z coordinates developed from stereo models of Yucca Mountain, Nev. (figs. 1 and 2) are sufficiently accurate to position detailed gravity stations. Accurate locations of gravity stations are needed to help geophysically characterize a potential high-level nuclear waste repository at Yucca Mountain. If the photogrammetric technique is successful it would enable rapid gravity measurements. Coordinates for 21 gravity stations were compared using survey and photogrammetric methods.

Acknowledgments

H.W. Oliver and D.J. Roddy of the U.S. Geological Survey (USGS) coordinated the photogrammetric study. And B.A. Chuchel, USGS, assisted in the electronic survey.

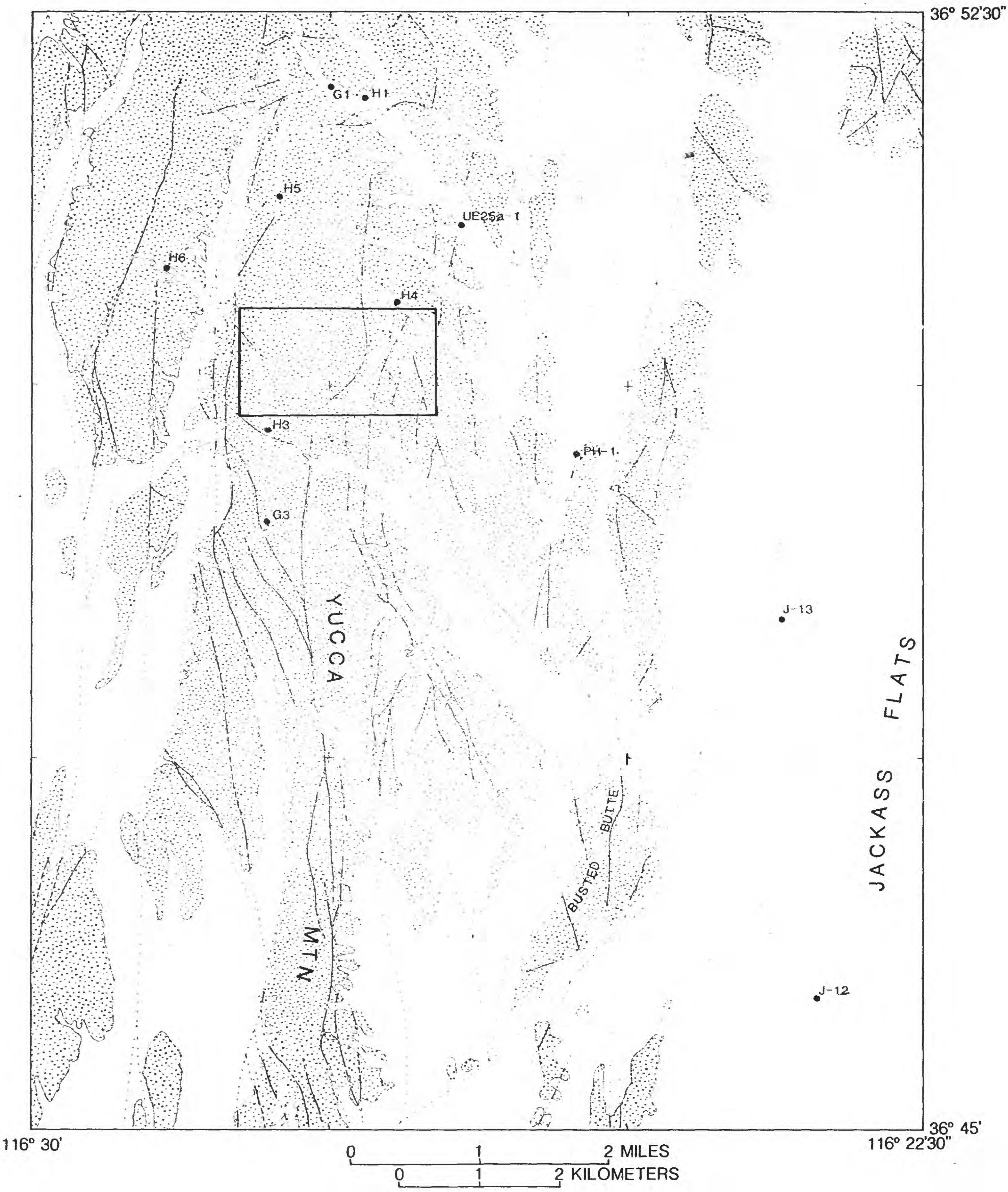

Figure 1. -- Index map of Yucca Mountain, Nev., showing outline of study area.

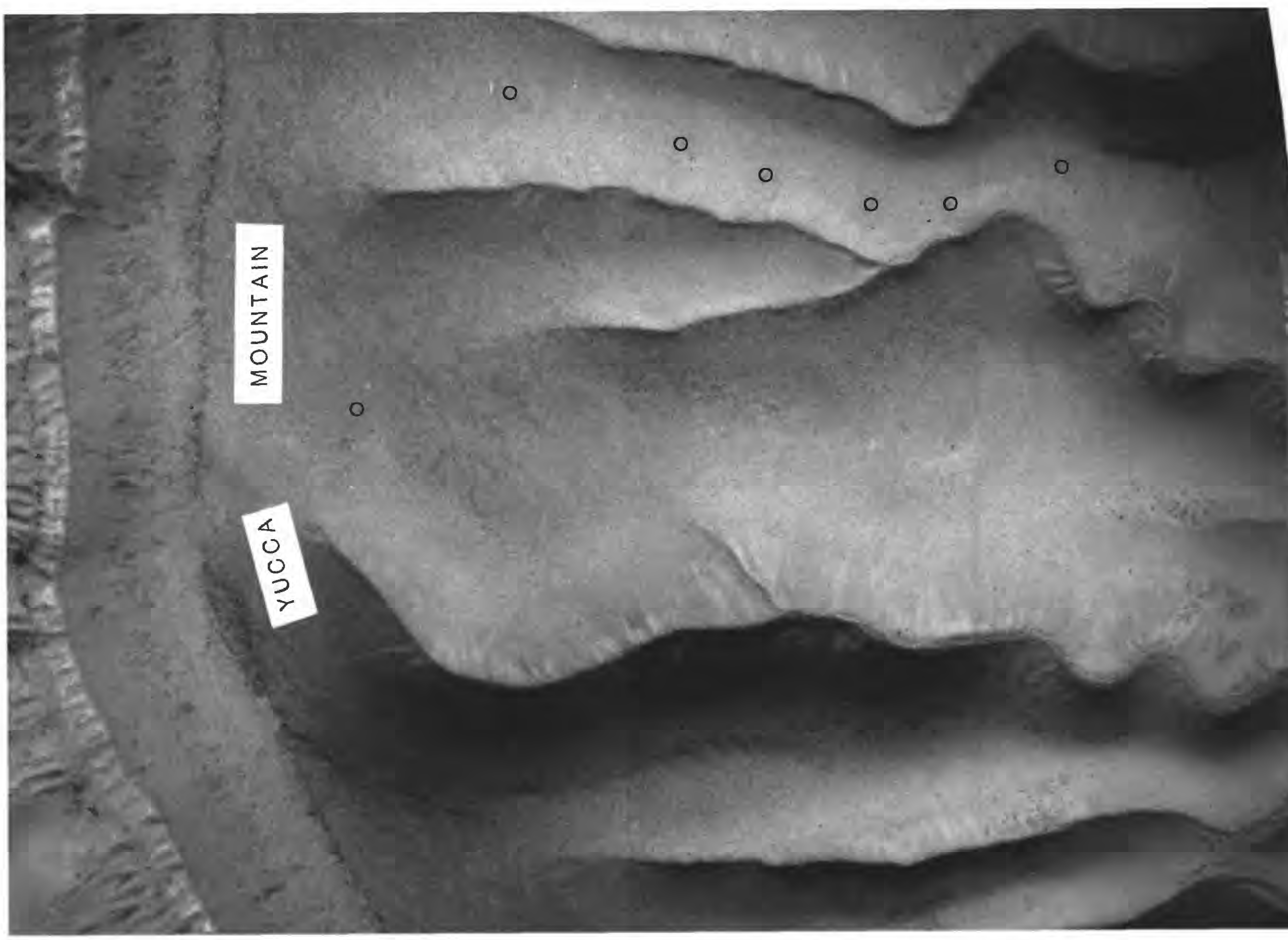

Figure 2. -- Aerial photograph of part of the study area showing gravity station locations of stations 1 to 7. Photo scale 1:7,500.

Survey Method

An electronic distance measuring device (EDM), a Hewlett-Packard 3820A Electronic Total Station, was used to survey the gravity stations. The surveyed data provided the elevation control.

The surveying instrument transmits an amplitude modulated light beam to a retroreflector target that sends the beam back to the instrument. The phase shift between the transmitted and received signals is proportional to the slope distance being measured. Manufacturer-reported accuracy of the slope distance is 0.005 m + 0.005 m/km (0.016 ft + 0.005 ft/1000 ft) at temperatures from -10 to 40° C (15 to 105° F), vertical and horizontal angle measurement are accurate to 4 and 2 sec, respectively.

Gravity-field operations employing survey methods require a field party of at least two persons, an instrument and a rod person. The rod person often makes the gravity measurements, also. Two significant advantages of using EDM methods are apparent: (a) fewer instrument set-ups are needed than for conventional transit-survey methods, and (b) measurements are immediately displayed for analysis. Although the survey elevation data are reported to within 0.1 m (0.3 ft), the accuracy of the elevation survey was about 0.02 m (0.05 ft). Elevations were referenced to a recent USGS survey that included a reoccupation of vertical angle bench mark (VABM) Mile. VABM Mile and bench mark 45TJS, used as absolute elevation references, have values of 4,951.646 ft (1,509.2617 m) and 4,727.672 ft (1,440.9944 m), respectively. The elevation difference at 45TJS was -0.014 m (-0.047 ft) and that at bench mark 46TJS was -0.0027 m (-0.009 ft) for a traverse length of about 4.3 km (2.7 mi).

Photogrammetric Method

Photogrammetric methods were used to derive X, Y (horizontal position), and Z (elevation) coordinates of gravity stations from a stereomodel. Stereomodels on analytical plotters were established by using aerial photographs that were taken with a T-12 aerial camera with a 6-in focal length, at an altitude of 3,750 ft (1,140 m) above ground level, and at a photoscale of 1:7,500. At a photoscale of 1:7,500, elevation measurements are accurate to within 0.3 m (1 ft). However, due to the difficulty in precisely locating gravity stations on aerial photographs, the photogrammetric elevation measurements disagree by about 1.5 m (4.9 ft) in comparison with the electronic measurements obtained in the field. Photogrammetry measurements are particularly sensitive to elevation uncertainties on steep terrain, where most of the gravity stations in this study were located.

Accuracy Requirements for Gravity Data

In general, regional Bouguer gravity data require an elevation accuracy of about 3 m (10 ft) whereas for detailed or high-precision measurements an elevation error of less than 0.3 m (1 ft) is desirable. Elevation errors of 3 m and 0.3 m correspond to gravity anomaly errors of about 0.6 and 0.06 mGal, respectively. The accuracy for horizontal control of gravity data is affected by the latitude correction. At a latitude of 45°, the correction is 0.812 mGal/km (1.307 mGal/mi). Thus, a horizontal error of 120 m (400 ft) in a north-south direction at latitude 45° results in a gravity anomaly error of 0.1 mGal. To reduce the gravity anomaly error to 0.01 mGal, an accuracy within 12 m (40 ft) is required in a north-south direction.

Results

Elevation

The results of a comparison of the elevation data derived from surveyed and photogrammetric methods are shown in table 1. The data indicate that all but two photogrammetric elevations are within about 1.5 m of the surveyed elevations. Stations 2 and 8 are clearly anomalous, with elevation differences of 3.6 and -12.4 m, respectively. A determination of the source of these differences is desirable.

The dramatic elevation error of -12.4 m for station 8 is the easier of the two errors to resolve. Survey field notes and the 110-m difference in the Y coordinates shown in table 2 clearly indicate that an operator error occured while locating the gravity station on the aerial photograph. Thus, an incorrect photogrammetric location causes this measurement to be quite different from the electronic measurement at the surveyed location.

An error of 3.6 m at station 2 is somewhat more difficult to resolve. One possibility is that an operator error occurred while recording the elevation during the survey, but this is unlikely because each station is 'shot' and recorded three times. Another explanation is that a large shrub may have caused an error in the photogrammetric determination of the ground surface. A more resonable explanation is that station 2 was mislocated on the aerial photograph, as indicated by the X-Y coordinates shown in table 2 that have a difference of -22 m between the surveyed and photogrammetrically derived Y coordinates. Thus, errors at stations 2 and 8 probably resulted from errors in locating the gravity station on the aerial photographs. Excluding stations 2 and 8 the mean elevation error is 0.57 ± 0.70 m.

Horizontal Location

Results of a comparison of Nevada State X and Y coordinates derived from surveyed and photogrammetric data are shown in table 2. Comparison of the X and Y coordinates shows that the mean difference for X is 4 ± 3 m and, excluding the two anomalous stations 2 and 8 the mean difference for Y is 5 ± 3 m. As discussed above, a latitude error of 18 m results in a gravity anomaly error of about 0.015 mGal. Thus, all stations (except anomalous stations 2 and 8) are within the allowable latitude error for gravity work.

Results of a comparison of surveyed and photogrammetrically derived latitudes and longitudes are shown in table 3. Latitude and longitude of the surveyed data were derived from a standard topographic map at a scale of 1:24,000, whereas latitude and longitude of the photogrammetric data were derived from a photogrammetrically compiled contour map at a scale of 1:5,000. The comparison of surveyed and photogrammetrically derived latitude and longitude (table 3) shows that all data except that for station 8 are accurate to 0.01 minute. An error of 0.01 minute of latitude is about 18 m and results in a gravity anomaly error of 0.015 mGal.

Table 1.--Comparison of surveyed and photogrammetric elevations

Gravity Station		Elevation (in m)		
Number	Name	Surveyed (S)	Photogrammetric (P)	Difference (S-P)
1	FS002	1495.6	1495.1	0.5
2	FS004	1463.0	1459.4	3.6[1]
3	FS006	1430.1	1429.6	0.5
4	FS007	1414.8	1413.8	1.0
5	FS008	1400.2	1399.6	0.6
6	FS009	1386.2	1384.8	1.4
7	FS010	1390.2	1389.1	1.1
8	FS011	1406.9	1419.3	-12.4[1]
9	FS012	1376.8	1375.5	1.3
10	FS013	1315.3	1313.7	1.6
11	FS016	1282.0	1282.8	-0.8
12	FS017	1264.4	1264.9	-0.5
13	FS018	1253.9	1252.9	1.0
14	FS019	1236.5	1235.4	1.1
15	FS020	1221.9	1221.8	0.1
16	FS021	1230.9	1230.9	0.0
17	FS023	1246.2	1245.6	0.6
18	FS-OE	1281.7	1281.1	0.6
19	FS024	1256.4	1257.1	-0.7
20	FS025	1294.4	1294.1	0.3
21	FS026	1335.0	1333.8	1.2
		Mean		1.47
		Standard deviation		2.61
		Excluding stations 2 and 8:		
		Mean		0.57
		Standard deviation		0.70

[1] Error probably caused by mislocation of station on aerial photograph.

Table 2.--Comparison of surveyed and photogrammetric data for Nevada State X and Y coordinates

Gravity station		Coordinates (in m)				Difference	
		Survey Data (S)[1]		Photogrammetry data (P)		(S - P, in m)	
Number	Name	X	Y	X	Y	X	Y
1	FS002	231,511	170,206	231,507	170,197	4	9
2	FS004	231,770	170,353	231,769	170,375	1	-22 [2]
3	FS006	231,724	170,536	231,716	170,527	8	9
4	FS007	231,685	170,609	231,680	170,605	5	4
5	FS008	231,648	170,711	231,643	170,702	5	9
6	FS009	231,645	170,779	231,636	170,782	9	-3
7	FS010	231,648	170,898	231,648	170,891	0	7
8	FS011	231,816	170,718	231,823	170,608	-7	110 [2]
9	FS012	231,854	170,880	231,850	170,882	4	-2
10	FS013	231,785	171,188	231,792	171,179	-7	11
11	FS016	231,907	171,435	231,902	171,428	5	7
12	FS017	231,925	171,673	231,923	171,674	2	-1
13	FS018	231,816	171,770	231,812	171,763	4	7
14	FS019	231,746	171,962	231,754	171,966	-8	-4
15	FS020	231,709	172,127	231,712	172,130	-3	-3
16	FS021	231,645	171,999	231,644	171,998	1	1
17	FS023	231,422	171,944	231,421	171,941	1	3
18	FS-OE	231,328	171,810	231,333	171,804	-5	6
19	FS024	231,288	171,880	231,287	171,875	1	5
20	FS025	231,176	171,685	231,171	171,683	5	2
21	FS026	231,246	171,447	231,248	171,447	-2	0
				Mean		4	11
				Standard deviation		3	23
			Excluding stations 2 and 8:				
				Mean		4	5
				Standard deviation		3	3

[1] X and Y coordinates derived from surveyed data are probably accurate to about 3 m (10 ft).

[2] Error probably caused by mislocation of station on aerial photograph.

Table 3.--Comparison of survey and photogrammetry data for latitude and longitude

Gravity station		Coordinates (in degrees and minutes to nearest 0.01 minute)				Difference (S-P, in 0.01 minute)	
Number	Name	Survey data (S) lat.	Survey data (S) lon.	Photogrammetry Data (P) lat.	Photogrammetry Data (P) lon.	lat.	lon.
1	FS002	36 50.20	116 28.03	36 50.20	116 28.04	0	-1
2	FS004	36 50.33	116 27.93	36 50.34	116 27.92	-1	1
3	FS006	36 50.31	116 27.81	36 50.31	116 27.82	0	-1
4	FS007	36 50.29	116 27.76	36 50.29	116 27.76	0	0
5	FS008	36 50.27	116 27.69	36 50.27	116 27.70	0	-1
6	FS009	36 5..27	116 27.65	36 50.26	116 27.64	1	1
7	FS010	36 50.27	116 27.57	36 50.27	116 27.57	0	0
8	FS011	36 50.36	116 27.69	36 50.37	116 27.71	-1	-2
9	FS012	36 50.38	116 27.58	36 50.38	116 27.57	0	1
10	FS013	36 50.34	116 27.37	36 50.35	116 27.38	-1	-1
11	FS016	36 50.41	116 27.21	36 50.41	116 27.21	0	0
12	FS017	36 50.42	116 27.04	36 50.42	116 27.04	0	0
13	FS018	36 50.36	116 26.98	36 50.36	116 26.99	0	-1
14	FS019	36 50.32	116 26.85	36 50.33	116 26.85	-1	0
15	FS020	36 50.30	116 26.73	36 50.31	116 26.74	-1	-1
16	FS021	36 50.27	116 26.82	36 50.27	116 26.83	0	-1
17	FS023	36 50.14	116 26.86	36 50.15	116 26.87	-1	-1
18	FS-OE	36 50.09	116 26.95	36 50.10	116 26.96	-1	-1
19	FS024	36 50.07	116 26.90	36 50.07	116 26.91	0	-1
20	FS025	36 50.01	116 27.04	36 50.01	116 27.04	0	0
21	FS026	36 50.05	116 27.20	36 50.05	116 27.20	0	0

[1]Degrees and minutes to the nearest 0.01 minute

Terrain Corrections

A comparison of the C and D inner-zone terrain corrections for some of the gravity stations are shown in table 4. Terrain corrections based on a photogrammetrically compiled contour map (scale 1:5,000) were compared with those based on the available standard topographic map (scale 1:24,000).

The corrections were manually computed by using a circular template based on Hayfords' system of zones (Swick, 1942, p. 66). Only the zones nearest the stations were compared. Although station 10, with a 0.10 mGal difference is somewhat anomalous, the data indicate that both maps produce terrain corrections of acceptable accuracy for gravity anomaly data. Thus, terrain corrections from the photogrammetrically compiled contour map, at a larger scale and with greater elevation accuracy, are probably more accurate, especially where the terrain is steep.

Table 4.--Comparison of inner-zone terrain corrections derived from topographic and photogrammetric maps

Terrain corrections (in 0.01 mGal)

Gravity station		Topographic map (S) Scale 1:24,000			Photogrammetric map (P) Scale 1:5,000			Difference (S-P)		
Number	Name	C-Zone	D-Zone	Total	C-Zone	D-Zone	Total	C-Zone	D-Zone	Total
1	FS002	19	89	108	20	85	105	-1	4	3
2	FS004	20	29	49	19	27	46	1	2	3
3	FS006	13	24	37	15	23	38	-2	1	-1
4	FS007	14	25	39	12	25	37	2	0	2
5	FS008	12	22	34	10	23	33	2	-1	1
6	FS009	13	21	34	12	21	33	1	0	1
7	FS010	18	18	36	18	18	36	0	0	0
9	FS012	22	19	41	16	21	37	6	-2	4
10	FS013	56	29	85	46	33	79	10	-4	6
11	FS016	56	37	93	51	39	90	5	-2	3
21	FS026	26	23	49	26	20	46	0	3	3
					Mean			2.2	0.9	2.3
					Standard Deviation			3.5	2.3	2.0

Conclusions

The combined results show that elevations from the photogrammetric data for the Yucca Mountain, Nev. survey are within 1.5 m of those from the surveyed data, with a mean difference of 0.57 ± 0.70 m. A comparison of the horizontal location data derived from surveyed and photogrammetric data show that they are both sufficiently accurate for gravity work. Conversion of horizontal location to latitude and longitude is accurate to 0.01 minute. Inner-zone C and D terrain corrections may be more accurate when derived from the larger scale lower altitude photogrammetrically compiled contour maps, especially in areas of steep terrain.

Gravity data are most sensitive to errors in elevation, thus elevation becomes the determining factor for use of photogrammetric or surveyed data to determine the location of a gravity station. The mean photogrammetric error in elevation is 0.57 m which corresponds to a gravity error of about 0.11 mGal, and is caused by the photographic scale, altitude of the survey, and the difficulty in precisely locating a gravity station on an aerial photograph. Elevation data derived from the photogrammetric survey at Yucca Mountain are not accurate enough for high-precision gravity measurements but are well within the accuracy needed for regional gravity work.

References

Swick, C. A., 1942, Pendulum gravity measurements and isostatic reductions: U.S. Coast and Geodetic Survey Special Publication 232, 82 p.