

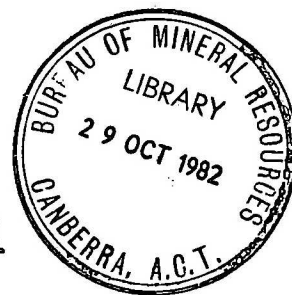
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RECORD

Record 1982/30

Analysis of repeat levelling measurements
to give ground deformation, southwest Australia

by

R.M. TRACEY

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ABSTRACT

There is a dense levelling network over the central part of the southwest seismic zone near Meckering, W.A., and some traverses have been levelled as many as four times. A comparison of pre- and post-earthquake data, using a least squares network adjustment, indicates movement with a wavelength of approximately 100 km and a peak-to-peak amplitude of approximately 300 mm. By identifying significant height changes between adjacent benchmarks this regional movement can be shown to be at least partly due to movement concentrated on narrow faults or weak zones. The analysis reported here indicates that releveing gives useful information on small vertical crustal movements, that movements occur up to 100 km from known surface faulting, and that movements of both short and long wavelength can be identified.

INTRODUCTION

In the Southwest Seismic Zone of Western Australia (Figure 1) a number of geophysical methods are being used to study the stress and strain changes resulting from earthquakes. The purpose of these studies is to assess long term earthquake risk for the various parts of the area, and to try to predict the time and location of earthquakes.

The methods being used include: seismological work on earthquake locations and focal mechanisms, geological work on surface displacements, in-situ stress measurements, and crustal strain measurements. The crustal strain measurements include horizontal measurements using distance measuring instruments, and vertical measurements using both gravity meters and optical levelling.

A large number of levelling data exist for the Meckering area. Original first and third order levelling was undertaken in the early 1960's. Immediately following the Meckering earthquake of the 14th October 1968 some lines were repeated at third order accuracy to determine the extent of movement due to the earthquake. More third order repeat levelling was done in 1977 to monitor post-earthquake movement. In 1980 a new program of second order levelling over the whole of the Southwest Seismic Zone was instigated. The Meckering area was completed during 1981.

This Record is an analysis of all levelling data in this resurveyed area near Meckering. Short wavelength changes are identified using a comparison of height differences between adjacent benchmarks, and long wavelength changes are identified by a least squares network adjustment.

Although the results presented are preliminary, they enable an assessment of the analysis methods used and also allow some reassessment of the earthquake risk in the Meckering area. It is intended that this type of preliminary analysis will be made on later releveilling data, so that results become available from each stage of the program.

COMPARISON OF ADJACENT BENCHMARKS

This analysis compares the height difference between adjacent

benchmarks obtained during one survey with the difference between the same benchmarks obtained during a later survey.

Appendix I contains the results of the calculations in tabular form. Each traverse is identified by one or more Australian Height Datum junction point, the locations of which are shown in Figure 2. The dates of the surveys being compared are shown at the beginning of each run. Unadjusted measured differences are used in the calculations.

There may be more than one first and second measurement between so-called adjacent benchmarks, either because benchmarks have been destroyed and a replacement mark made, or because intermediate benchmarks have been placed.

For any two adjacent benchmarks the difference between the first and second measurements represents the apparent change in height between these benchmarks during the period of time between the surveys. The height change (measured in millimetres) divided by the square root of the distance between the benchmarks (measured in kilometres) normalises the height change to that of benchmarks a constant distance apart. (The square root is because errors accumulate according to the number of staff set-ups, and errors are random, so accumulative errors can be described by random walk statistics).

The sign of the change of height and normalised difference gives the direction of fall between the benchmarks during the time from the first to the second measurement: a positive value indicates a fall from the first to the second benchmark.

The significance of the change in height depends on the accuracy of the surveys being compared.

It was assumed that differences obtained outside zones of suspected movement would be normally distributed and standard deviations for the errors in the surveying could be calculated. The area within approximately 50 km radius of Meckering was assumed to be the main zone of suspected movement. Only the third order with second order comparisons had enough data outside this zone to verify the assumption. Figure 3

shows the distribution of these data. The data are not significantly skewed and are not significantly kurtic. (This depends on the fourth moments). They therefore fit the normal curve to within experimental error. The standard deviation of this distribution is 8.8 mm km-1/2.

Using this value and the ratio between National Mapping's accuracy requirements (National Mapping Council of Australia, 1976) of 4.0, 8.4, and 12.0 mm km-1/2 for first, second, and third order levelling; the accuracies of 2.5, 4.5, and 7.6 mm km-1/2 were calculated respectively. (The 7.6 mm km-1/2 is consistent with 7.9 mm km-1/2 derived by Roelse & others (1971) for third order surveys). From these accuracies, standard deviations can be calculated of 4.4 mm km-1/2, for first order compared with second order; 10.7 mm km-1/2, for third order compared with third order; and 8.0 mm km-1/2, for third order compared with first order.

The significance of the individual observed normalised differences was determined using these derived standard deviations and dividing the differences into three classes with boundaries at two standard deviations (5% significance) and three standard deviations (1% significance).

The significant differences are underlined in the table in Appendix I with an asterisk marking those with 1% significance.

The results from this comparison of adjacent benchmarks are shown on the map in Figure 2. The direction of the fall between benchmarks is indicated by arrows, with the amount of fall shown beside the arrows. Those amounts underlined have 1% significance while all others have 5% significance.

The letters A,B,C,D, and E specify for each comparison the time span between the first and second surveys as follows:

A - 1st, early 1960's;	2nd, Nov. 1968
B - 1st, early 1960's;	2nd, 1977
C - 1st, early 1960's;	2nd, 1980-1981
D - 1st, Nov. 1968 ;	2nd, 1980-1981
E - 1st, 1977 ;	2nd, 1980-1981

A number of differences shown on the map are adjacent to an approximately equal difference of opposite sign. This is almost certainly due to a vertically unstable benchmark in between, and not due to crustal strain. These height differences are not considered further.

From these results it can be seen that this type of analysis is useful to identify unstable benchmarks, and areas of fast relative movement that are areas of high earthquake risk.

NATIONAL MAPPING NETWORK ADJUSTMENT

Three data sets were used for the network adjustment by National Mapping. These are shown by the heavy lines in Figures 4, 5, and 6 with the data points indicated by filled circles. The first set was measured in the early 1960's, the second set immediately following the Meckering earthquake in 1968, and the third set in 1977.

In this analysis each of the three independent data sets was adjusted as a network adopting Australian Height Datum junction point 172 as the fixed point. This is data point 7 and has a fixed height of 149.224 m. The heights obtained from the adjustment are listed in Appendix II.

Comparisons were made between the pre and the first post-earthquake data, and the first post and the second post-earthquake data. The differences between adjusted heights of common points in these comparisons were calculated and have been contoured in Figures 7 and 8. The common points of the comparisons are indicated by filled circles.

The pre and first post-earthquake comparison shows long wavelength movement with an area of uplift extending at least 50 km north and south of Meckering and having an amplitude of approximately 150 mm; and a depression 80 km east of Meckering extending about 100 km north south having an amplitude of approximately 150 mm and a wavelength of approximately 100 km. This movement is thought to be due to deformation associated with the Meckering earthquake.

The first post and second post-earthquake comparison shows further uplift of approximately 100 mm in the Meckering area since the earthquake.

The significance of these results is limited because of the small number of common points in the network. If larger networks with more common points can be compared a better picture of the overall movement will be obtained. The uncertainty of the level changes has not been calculated, but the consistency of the patterns of movement on adjacent lines suggests that the movement is real. Future analyses will include a calculation of relative errors.

DISCUSSION OF RESULTS

Similarities can be seen in the results from the network adjustment analysis and the adjacent benchmark comparisons. Figure 9 shows the axes of the long wavelength movements, calculated from the network adjustment, on the map of the results of the adjacent benchmark comparisons. It can be seen that at least part of the long wavelength movement can be explained by a series of steps on localized faults, and so the movement is not all by long wavelength warping.

The results obtained from the adjacent benchmark comparisons are supported by observations of surface faulting, the most obvious being the main fault scarp of the Meckering earthquake with its 1.8 m displacement. Most of the calculated differences in the immediate vicinity of Meckering can no doubt be correlated with surface faulting directly associated with the earthquake of 1968 (Gordon & Lewis, 1980). Other differences can also be correlated with surface observations such as cracks in the road to the west of Australian Height Datum junction point 1025, which were found in late 1970 (Gordon & Lewis, 1980), and which may explain the 54 mm change shown in that vicinity on the map in Figure 2.

The completion of the second order relevening, and a repeat of gravity measurements at benchmarks at 10 km spacing, should allow identification of long and short wavelength ground movement over the

whole of the deformation area. These results would allow the area of vertical deformation to be mapped, and its relation to the area of seismic activity to be determined. The identification of the zones of more rapid movement allows future monitoring to be concentrated in specific areas, (thus reducing costs), on the assumption that those areas are representative of crustal movement over a larger area. The knowledge of the pattern of movement should help in formulating models of stress and strain in the area, and help in refining estimates of earthquake risk.

ACKNOWLEDGEMENTS

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APPENDIX I

Bench mark number	Interval dist. (km)	First meas. (m)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 854-853 (159-172)					
AHD computed 5/4/74 /Feb 1981 (1st order/2nd order)					
F 385					
F 385A	1.63	15.3385	15.3376	0.90	0.70
F 384	1.61	9.7871	9.7828	4.30	3.39
F 384A	1.64	12.1844	12.1814	3.00	2.34
F 383	1.65	13.9440	13.9692	-25.20	-19.62*
F 383A	1.62	24.8488	24.8186	30.20	23.73*
		9.3775	1.7375		
		20.5015	24.3078		
F 381	4.88	-13.5188	-9.6874	2.30	1.04
F 381A	1.63	-20.1080	-20.0923	-15.70	-12.30
		-21.8712	-18.9832		
		-13.5871	-16.6827		
F 379	4.91	-8.3107	-8.0992	-3.90	-1.76
Run between AHD junction points 1030-853					
AHD computed 31/8/78 /April 1981 (3rd order/2nd order)					
UA 80		4.3340			
TOS 1	1.20	-3.4190	0.9142	0.80	0.73
UA 81A	1.77	16.0060	16.0095	-3.50	-2.63
		-10.4560	18.4253		
UA 82	3.31	70.9080	42.0268	-0.10	-0.05
			33.9130		
			63.1348		
		97.4960	26.0018		
UA 84	6.86	31.0590	5.5291	-23.70	-9.05
			-13.1152		
HZ 182	3.23	-37.0670	-23.9613	9.50	5.29
			-25.4435		
UA 86	3.18	-49.5080	-24.0910	26.50	14.86

Bench mark number	Interval dist. (km)	First meas. (m)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 849-845					
AHD computed 9/5/74 /Sept 1981 (3rd order/2nd order)					
UA 96			-14.9567		
UA 95	2.93	4.1773	19.1425	-8.50	-4.97
UA 94	2.54	-32.1869	-32.1468	-40.10	<u>-25.16</u>
			-5.1865		
UA 93	3.77	21.0769	26.2420	21.40	11.02
			15.2181		
UA 92	4.09	11.2883	-3.9165	-13.30	-6.58
			1.2680		
UA 91	3.39	10.6329	9.3950	-30.10	-16.35
			-9.2373		
UA 90	3.49	-15.3071	-6.0343	-35.50	<u>-19.00</u>
			7.3235		
UA 89	3.22	23.5748	16.2388	12.50	6.97
			0.4324		
UA 88	4.47	4.3510	3.8981	20.50	9.70
			-0.6206		
UA 87	3.53	-9.7414	-9.1212	0.40	0.21
Run between AHD junction points 1029-1030					
AHD computed 31/3/78 /April 1981 (3rd order/2nd order)					
UA 10			-0.0310		
UE 9	3.29	1.3640	1.3926	12.40	6.84
			12.8492		
UB 10	2.94	25.3533	12.5019	2.20	1.28
			-42.9928		
UB 11	2.32	-42.3687	0.6777	-53.60	<u>-35.19</u> *
			13.2493		
UB 12	3.86	17.7637	4.4731	41.30	<u>21.02</u>
			38.5958		
UB 13	3.21	67.3105	28.6653	49.40	<u>27.57</u> *
			-54.6803		
			3.6336		
UB 14	4.56	-52.9179	-1.8527	-18.50	-8.66
			10.0611		
UB 15	3.37	18.3657	8.2882	16.40	8.93
			57.5528		
UB 16	3.76	54.5882	-2.9682	3.60	1.86
			-7.7003		
			-42.8931		
UB 17	3.76	-25.7663	24.7910	36.10	<u>18.62</u>
			-85.7253		
UB 18	4.07	-101.1235	-15.4157	17.50	8.67

Bench mark number	Interval dist. (km)	First meas. (m)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 859-854					
AHD computed 4/9/79 /Feb 1981 (3rd order/2nd order)					
F 365					
			0.0024		
UB 29	2.13	23.7370	23.7358	-1.20	-0.82
			45.8089		
UB 30	3.18	91.8600	46.0630	-11.90	-6.67
			34.9274		
UB 31	3.14	26.7960	-8.1154	-16.00	-9.03
			-30.8131		
			-6.7300		
UB 32	3.33	-37.4550	0.1158	-27.70	-15.18
		5.9140	15.7245		
UB 33	3.23	43.5660	34.7200	35.50	19.75
			-18.1735		
UB 34	3.26	-30.5510	-12.3806	8.10	4.49
			-6.6010		
UB 35	3.28	-7.8700	-1.2700	1.00	0.55
			-0.3709		
HZ 247	1.32	28.3480	28.7082	10.70	9.31
			-6.3516		
UB 36	2.01	-9.9030	-3.5360	-5.40	-3.31
			-12.4675		
UB 37	3.18	-52.7860	-40.3120	-6.50	-3.65
			27.3190		
UB 38	3.31	-37.6330	10.3165	-2.50	-1.37
			-0.3194		
			29.0223		
			-6.0145		
		23.4930	-5.9608		
UB 40	6.53	-6.5160	0.2345	14.90	5.83
			-5.1260		
UB 41	3.27	-10.6050	-5.4754	-3.60	-1.99
			-0.3830		
			21.4024		
UB 42	3.27	34.4120	13.3920	0.50	0.33
			-59.6134		
UB 43	2.64	-59.3870	0.2416	-15.20	-9.35

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{k}$ m)
Run between AHD junction points 172-1029(146-172)					
Early 60's/March 1981 (3rd order/2nd order)					
UA 2			0.9991		
		6.2650	21.9011		
UA 3	3.31	67.4300	-0.4610	23.04	12.66
		63.9800	17.8192		
UA 4	3.21	-18.4150	-3.9196	-11.39	-6.36
		-42.0950	-12.1522		
UA 5	3.27	32.8600	9.3474	-10.03	-5.55
		-5.3300	-2.7510		
UA 6	3.30	63.0450	20.3540	-11.47	-6.31
			1.6292		
		25.8450	-13.8871		
		-96.9650	-9.4524		
		36.2600	10.8004		
UA 8	6.56	-42.3050	-12.6118	2.81	1.10
			9.4493		
		33.5650	23.1374		
UA 9	3.22	74.1350	0.2355	4.76	2.65
Run between AHD junction points 172-1029(146-172)					
Oct-Nov 1968/Marc 1981 (3rd order/2nd order)					
UA 2			0.9991		
			21.9011		
UA 3	3.31	73.5280	-0.4610	-27.87	-15.32
			17.8192		
UA 4	3.21	45.6100	-3.9196	2.33	1.30
			-12.1522		
UA 5	3.27	-9.1820	9.3474	6.13	3.39
		-4.5500	-2.7510		
UA 6	3.30	62.2820	20.3540	-6.29	-3.46
			1.6292		
			-13.8871		
			-9.4524		
		-71.1220	10.8004		
UA 8	6.56	-6.0380	-12.6118	4.33	1.69
			9.4493		
		9.1400	23.1374		
UA 9	3.22	98.5530	0.2355	2.63	1.46

Bench mark number	Interval dist. (km)	First meas. (m)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/√km)
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Run between AHD junction points 172-1029(146-172)
1977/March 1981 (3rd order/2nd order)
UA 2

			0.9991		
			21.9011		
UA 3	3.31	22.4320	-0.4610	-7.20	-3.96
			17.8192		
UA 4	3.21	13.8960	-3.9196	-3.60	-2.01
			-12.1522		
UA 5	3.27	-2.8070	9.3474	-2.20	-1.22
			-2.7510		
UA 6	3.30	17.5930	20.3540	-10.00	-5.50

Run between AHD junction points 1030-? (846-847-1030)
AHD computed 31/8/78 /Sept 1981 (3rd order/2nd order)
UA 79

			-3.4791		
			9.8299		
		4.1636	3.8104		
		9.3375	3.0560		
UA 76	3.09	15.1699	15.4974	-43.60	-15.33
			2.0940		
UB 19	3.15	23.3751	21.3006	-19.50	-10.99
			27.6507		
UB 20	3.20	67.2450	39.5886	5.70	3.19
			34.2563		
			51.1348		
		84.9874	5.9478		
UB 22	6.40	-32.9931	-39.2480	-96.60	-38.18 *
			-19.1943		
UB 23	3.17	-24.8686	-5.6710	-3.30	-1.85

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/√km)
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Run between AHD junction points 172-2685
Early 60's/Oct-Nov 1968 (3rd order/3rd order)
UA 1

		69.3950	70.3570		
UA 2	3.27	-78.4350	-79.3920	-1.52	-0.84
		6.2650			
UA 3	3.23	67.4300	73.5280	50.90	<u>28.30</u>
		63.9800			
UA 4	3.20	-18.4150	45.6100	-13.72	-7.66
		-42.0950			
UA 5	3.32	32.8600	-9.1820	-16.15	-8.87
		-5.3300	-4.5500		
UA 6	3.56	63.0450	62.2820	-5.13	-2.75

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
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Run between AHD junction points 172-2685

Early 60's/1977 (3rd order/3rd order)

UA 2		6.2650			
UA 3	3.22	67.4300	22.4320	30.24	16.85
		63.9800			
UA 4	3.22	-18.4150	13.8960	-7.79	-4.34
		-42.0950			
UA 5	3.22	32.8600	-2.8070	-7.83	-4.36
		-5.3300			
UA 6	3.22	63.0450	17.5930	-1.47	-0.82

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
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Run between AHD junction points 2685-849

Early 60's/Oct-Nov 1968 (3rd order/3rd order)

UA 6		25.8450			
UA 7	3.22	-96.9650	-71.1220	0.61	0.34
		36.2600			
UA 8	3.22	-42.3050	-6.0380	-2.13	-1.19
		33.5650	9.1400		
UA 9	3.22	74.1350	98.5530	2.13	1.19
		-54.7550			
UA 10	3.22	-2.3350	-56.9980	-28.04	-15.63
		82.0400			
UA 11	3.22	40.7200	122.8250	-19.81	-11.04
		-32.2150	-32.2580		
UA 12	3.22	-31.7650	-31.6450	-23.47	-13.08
		11.9250			
UA 13	3.22	73.3050	85.2470	-5.18	-2.89
		112.3200	112.3350		
UA 14	3.22	-10.7850	-10.8950	28.96	16.14
		-64.8300			
UA 15	3.22	-46.3000	-111.0850	-13.72	-7.65

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 1029-849(146-172)					
Early 60's/July 1981 (3rd order/2nd order)					
UA 9			-0.2355		
		-54.7550	-13.2412		
UA 10	3.07	-2.3350	1.1039	-33.23	-18.97
		82.0400	24.0160		
UA 11	3.23	40.7200	13.4133	-17.05	-9.49
		-32.2150	-9.1185		
UA 12	3.20	-31.7650	-10.3539	-22.70	-16.05
			-1.4891		
		11.9250	8.8717		
UA 13	3.23	73.3050	18.5951	0.40	0.22
		112.3200	32.3360		
UA 14	3.05	-10.7850	-1.4026	14.47	8.28
Run between AHD junction points 1029-849(146-172)					
Oct-Nov 1958/July 1981 (3rd order/2nd order)					
UA 9			-0.2355		
			-13.2412		
UA 10	3.07	-56.9980	1.1039	-5.19	-2.96
			24.0160		
UA 11	3.23	122.8250	13.4133	2.76	1.54
		-32.2580	-9.1185		
UA 12	3.20	-31.6450	-10.3539	-5.23	-2.93
			-1.4891		
			8.8717		
UA 13	3.23	95.2470	18.5951	5.59	3.11
		112.3350	32.3360		
UA 14	3.05	-10.8950	-1.4026	-14.49	-8.30

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AND junction points 849-1025					
Early 60's/July 1981 (3rd order/2nd order)					
UA 97		99.1750	25.2317		
UA 98	3.24	13.2100	8.9826	40.55	<u>22.53</u>
		-56.0350	-7.2909		
		80.4900	14.1541		
UA 100	6.55	-111.4850	-33.9124	11.42	4.46
		-33.7900	-9.7964		
		-21.4900	-2.9810		
UE 1	3.26	10.6200	-0.2972	-34.98	<u>-19.37</u>
		-18.4700	-3.6735		
		27.1450	5.8151		
		51.2950	12.3393		
UE 3	6.47	-27.7950	-4.7057	31.74	12.49
		71.1950	21.5907		
UE 4	3.29	82.0250	25.0245	86.26	<u>47.55 *</u>
		58.2700	23.7506		
		-20.6350	-12.6571		
		-92.3550	-34.8900		
UE 6	6.50	-29.3100	-1.7329	-82.94	<u>-32.53 *</u>
		68.3600	23.9791		
UE 7	3.27	72.9900	19.0501	54.28	<u>30.02 *</u>
Run between AND junction points 849-1025					
Oct-Nov 1968/July 1981 (3rd order/2nd order)					
UA 97			25.2317		
UA 98	3.24	112.2420	8.9826	-2.94	-1.63
			-7.2909		
		-56.5600	14.1541		
		80.9190	-33.9194		
UA 100	6.55	-145.1620	-9.7964	1.06	0.41
			-2.9810		
UE 1	3.26	-10.8150	-0.2972	-13.21	-10.09
			-3.6735		
			5.8151		
		8.5580	12.3393		
UE 3	6.47	23.4820	-4.7057	-9.41	-3.70
		71.0250	21.5907		
UE 4	3.29	81.9120	25.0245	-0.00	-0.00
			23.7506		
			-12.6571		
		37.6820	-34.8900		
UE 6	6.50	-121.4500	-1.7329	-3.09	-1.21
		68.2300	23.9791		
UE 7	3.27	72.8900	19.0501	-0.58	-0.32

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 850-?(850-1003)					
Aug 1967/Aug 1981 (3rd order/2nd order)					
UH 19		-5.2900			
		4.5060			
		60.0580	16.5078		
UH 20	4.37	-146.6850	-43.4587	3.23	1.54
			-10.1744		
UH 21	3.91	-45.7650	-3.7595	-15.27	-7.72
			22.2308		
			15.2958		
UH 22	3.89	124.8030	0.4904	22.95	11.64
			-27.4583		
UH 23	4.11	-151.7410	-18.7668	-25.56	-12.61
			27.7961		
UH 24	3.64	136.9000	13.9262	4.82	2.53
Run between AHD junction points 850-?(850-1003)					
Oct-Nov 1968/Aug 1981 (3rd order/2nd order)					
UH 19			16.5078		
UH 20	4.37	-88.4020	-43.4587	5.97	2.86
		18.2220	-10.1744		
UH 21	3.91	-63.9590	-3.7595	-6.43	-3.25
			22.2308		
			15.2958		
UH 22	3.89	124.7920	0.4904	10.60	9.94
			-27.4583		
UH 23	4.11	-151.6950	-18.7668	-11.54	-5.69
			27.7961		
UH 24	3.64	136.9300	13.9262	13.96	7.32
Run between AHD junction points ?-1003(850-1003)					
Aug 1957/Aug 1981 (3rd order/2nd order)					
UH 25			-4.6010		
UH 26	2.92	-15.7660	-0.1997	-4.78	-2.80
			2.1547		
UH 27	3.55	1.3360	-1.7453	-2.19	-1.16
			-0.0012		
			2.4194		
		8.2820	13.7348		
UH 29	6.99	38.4320	-1.8148	-9.77	-3.70
			-10.7145		
UH 30	3.16	-28.9370	1.8742	20.30	11.42
			12.0440		
UH 31	3.29	106.5920	20.4387	6.54	3.61

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 2-1003(850-1003) Oct-Nov 1968/Aug 1981 (3rd order/2nd order)					
UH 25			-4.6010		
UH 26	2.92	-15.7820	-0.1997	-9.65	-5.65
			2.1547		
UH 27	3.55	1.3400	-1.7453	-0.97	-0.51
			-0.0912		
			2.4194		
		8.3650	13.7348		
UH 29	6.99	38.3980	-1.8148	5.16	1.95
		-25.2450	-10.7145		
UH 30	3.16	-3.6680	1.8742	27.62	15.54
			12.0440		
UH 3	3.29	106.5850	20.4387	4.41	2.43
Run between AHD junction points 1025-1003(1003-1025) Late 50's/Feb, June, July 1981 (3rd order/2nd order)					
CK 34					
CK 35	1.61	-54.9500	-16.7268	-21.96	-17.31
CK 36	1.61	-34.8400	-10.5988	-20.43	-16.10
CK 37	1.59	-29.5500	-9.0290	22.16	17.57
CK 38	1.61	-11.2600	-3.4079	-24.15	-19.03
CK 39	1.61	36.5800	11.1437	5.88	4.64
CK 40	1.61	30.8200	9.3913	2.64	2.09
Run between AHD junction points 1025-1003(1003-1025) Oct-Nov 1968/Feb, June, July 1981 (3rd order/2nd order)					
CK 34					
CK 35	1.61	-54.8870	-16.7268	-2.76	-2.17
CK 36	1.61	-34.7870	-10.5988	-4.23	-3.37
CK 37	1.59	-29.6020	-9.0290	6.31	5.00
CK 38	1.61	-11.2250	-3.4079	-13.48	-10.62
CK 39	1.61	36.5750	11.1437	4.36	3.44
CK 40	1.61	30.7670	9.3913	-13.52	-10.65

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 1000-850 1967/Oct-Nov 1968 (3rd order/3rd order) MK 13					
		-17.3950	-37.2750		
UH 53	3.22	-14.6740	5.1200	26.21	14.61
UH 52	3.22	50.4330	50.5180	-25.91	-14.44
UH 51	3.22	99.6340	99.6600	-7.92	-4.42
UH 50	3.22	137.4340	137.4200	4.27	2.38
UH 49	3.22	-116.1960	-116.2200	7.32	4.08
			-79.5430		
UH 48	3.22	-114.3800	-34.8020	-10.67	-5.95
UH 47	3.22	-43.4130	-43.4250	3.66	2.04
UH 46	3.22	21.6650	21.6550	3.05	1.70
UH 45	3.22	-1.3500	-1.3280	-6.71	-3.74
UH 44	3.22	29.9520	29.9500	0.61	0.34
UH 43	3.22	10.1060	10.1200	-4.27	-2.38
			-1.4200		
UH 42	3.22	12.3120	13.6650	20.42	11.38
UH 41	3.22	76.0640	76.0480	4.88	2.72
UH 40	3.22	6.9670	6.9380	8.84	4.93
UH 39	3.22	68.9200	68.9280	-2.44	-1.36
		-24.8460	-85.2080		
UH 37	6.44	-68.7700	-8.4550	14.33	5.65
UH 36	3.22	25.9550	25.9450	3.05	1.70
UH 35	3.22	83.6540	83.6520	0.61	0.34
UH 18	3.22	-34.5420	-34.5470	1.52	0.85

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 181-1000 Pre 1968/Oct-Nov 1968 (1st order/3rd order)					
MK 1		77.8506			
MK 2	3.22	46.4694 -16.1677	124.2880	9.75	5.44
MK 2	3.25	44.0714 -5.9786	27.9120	-2.53	-1.40
MK 4	3.20	-63.4615 -51.4316	-69.4780	11.55	6.46
MK 5	3.28	2.1422 -57.2140	-49.2680 -57.2330	-6.52	-3.60
MK 6	3.27	-21.1797 -27.4656	-21.1700	2.83	1.57
MK 7	3.27	-13.8488 -13.9842	-41.2550	-18.11	-10.02
MK 8	3.22	21.6598 75.9346	7.6170	17.86	9.96
		68.1124	75.8850		
MK 10	6.44	30.7524 -61.7607 -46.3482	66.3550 -29.2150	4.18	1.65
MK 11	3.25	-29.1654 32.7186	-75.4680	-13.90	-7.71
MK 12	3.23	0.9796 -61.4334	33.7070	-2.68	-1.49
MK 13	3.22	-41.5280	-102.9980	11.16	6.22
Bench mark number	Interval dist. (km)	First meas. (m)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 1025-850 AHD computed 7/9/78 /July 1981 (3rd order/2nd order)					
HU 49			0.5054		
HU 50	3.37	11.3740 -2.8650 -2.0680	10.8692	-0.60	-0.33
		1.9110	0.5780		
HU 52	5.79	-19.5570 -1.4570	-17.1008 2.9430	0.40	0.17
HU 53	3.17	-0.0430	-4.4458	2.90	1.57
BM 5	2.34	0.5930 1.3540	0.5821 4.4158	0.90	0.59
		3.3510	-2.6736		
UH33	5.11	-18.4210	-15.4621 -8.2660	3.90	1.73
UH 34	3.35	10.2200	18.4978	-11.80	-6.45

Bench mark number	Interval dist. (km)	First meas. (m)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 172-852(172-181) Dec 1977/May 1981 (3rd order/2nd order)					
NM 2		4.6610	4.8024		
NM 4	3.27	28.7160	28.5742	0.40	0.22
NM 5	1.62	32.5500	32.5549	-4.90	-3.85
NM 6	1.73	-28.9360	-28.9402	4.20	3.19
NM 7	1.56	-10.3090	-10.3110	2.00	1.60
NM 8	1.62	7.6130	7.6132	-0.20	-0.16
			4.3255		
NM 9	1.62	5.2520	0.9303	-3.80	-2.99
NM 10	1.62	31.0630	31.0666	-3.60	-2.83
NM 11	1.67	-2.4060	-2.4062	0.20	0.15
NM 12	1.56	16.2340	16.2358	-1.80	-1.44
NM 13	1.67	12.2250	12.2286	-3.60	-2.79
NM 14	1.56	9.9630	9.9614	1.60	1.28
			-3.7907		
NM 15	1.68	-18.6950	-14.9146	0.30	0.23
NM 16	1.69	-12.1070	-12.1062	-0.80	-0.62
NM 17A	2.60	-14.1100	-14.1127	2.70	1.67
NM 19	2.23	-8.3340	-8.3244	-9.60	-6.43
		-1.5780			
		1.1040	-1.7628		
		-2.2440	-0.9536		
NM 22	4.84	3.8580	3.8566	-0.20	-0.09
NM 22A	1.36	-6.2060	-6.2032	-2.80	-2.40
NM 24	1.83	6.4340	6.4382	-4.20	-3.10
NM 25	1.65	1.9300	1.9332	-3.20	-2.49
		-2.0580	-2.2540		
NM 26A	3.04	-2.8950	-2.6992	0.20	0.11
NM 27	0.14	0.0840	0.0814	2.60	6.95
BO 64	0.77	1.5300	1.5324	-2.40	-2.74
		3.2200			
BO 65	1.61	0.2110	3.4299	1.10	0.87
NM 29	0.94	5.5760	5.5774	-1.40	-1.44
BO 66	0.67	1.5830	1.5804	2.60	3.18
NM 30	0.89	-1.8290	-1.8260	-3.00	-3.18
NM 31	1.62	-2.8290	-2.8262	-2.80	-2.20
BO 68	0.72	1.3640	1.3656	-1.60	-1.89
		-0.9000	-1.0866		
BO 69	1.61	-0.5780	-0.3970	5.60	4.41
NM 33	0.89	2.3640	2.3687	-4.70	-4.99
NM 34	1.61	8.2280	8.2288	-0.80	-0.63
NM 35	1.61	2.5700	2.5733	-3.30	-2.60
NM 36	1.61	-9.3020	-9.3040	2.00	1.53
NM 37	1.61	9.5850	9.5895	-4.50	-3.55

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 172-852(172-181) Nov 1968/May 1981 (3rd order/2nd order)					
NM 2		2.4450			
		12.8300	4.8024		
NM 4	3.27	94.2700	23.5742	12.72	7.03
NM 5	1.62	106.8075	32.5549	0.03	0.02
NM 6	1.73	-94.9900	-23.9402	-12.75	-9.70
NM 7	1.56	-33.8100	-10.3110	5.71	4.57
NM 8	1.62	25.0000	7.6132	6.80	5.34
			4.3255		
NM 9	1.62	17.1925	0.9303	-15.53	-12.20
NM 10	1.62	101.9325	31.0666	2.43	1.91
NM 11	1.67	-7.9125	-2.4062	-5.53	-4.28
NM 12	1.56	53.2250	16.2358	-12.82	-10.26
NM 13	1.67	40.1300	12.2286	3.02	2.34
NM 14	1.56	32.7075	9.9614	7.85	6.28
			-3.7807		
NM 15	1.68	-61.3850	-14.9146	-14.35	-11.46
NM 16	1.69	-39.7500	-12.1062	-9.60	-7.38
		-22.7575			
NM 17A	2.60	-23.5550	-14.1127	-3.35	-2.08
		0.7300			
NM 19	2.23	-28.0900	-8.3244	-14.93	-10.00
		-1.6800	-1.7623		
		-29.1075	-0.9536		
NM 22	4.84	34.3175	3.8566	-64.26	-29.21*
NM 22A	1.36	-20.3450	-6.2032	2.04	1.75
		-3.6400			
NM 24	1.83	24.8525	6.4332	27.37	20.23
NM 25	1.65	6.3875	1.9332	13.71	10.67
		-6.6500	-2.2540		
NM 26A	3.04	-9.4075	-2.6992	31.44	19.03
NM 27	0.14	0.2375	0.0814	6.23	16.65
			1.5324		
		15.6800	3.4299		
NM 29	3.32	18.9675	5.5774	20.86	11.45
			1.5804		
NM 30	1.56	-0.8025	-1.8260	1.00	0.30
NM 31	1.62	-9.2725	-2.3262	-0.06	-0.05
			1.3656		
			-1.0866		
		1.5375	-0.3970		
NM 33	3.22	5.8875	2.3687	12.44	6.93
NM 34	1.61	27.0300	8.2283	9.94	7.84
NM 35	1.61	8.3700	2.5733	-22.12	-17.44
NM 36	1.61	-30.5375	-9.3040	-3.83	-3.02
NM 37	1.61	31.4675	9.5895	1.79	1.41

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 172-852(172-181)					
Early 60's/May 1981 (1st order/2nd order)					
NM 2		2.4448	4.8024		
NM 4	3.27	107.0487	28.5742	-2.98	-1.65
NM 5	1.62	106.7954	32.5549	-3.66	-2.88
NM 6	1.73	-94.9722	-28.9402	-7.33	-5.57
NM 7	1.56	-33.8234	-10.3110	0.10	0.08
NM 8	1.62	24.9944	7.6132	5.09	4.00
			4.3255		
NM 9	1.62	17.1899	0.9303	-16.32	-12.82
NM 10	1.62	101.9168	31.0666	-2.36	-1.85
NM 11	1.67	-7.9148	-2.4062	-6.23	-4.82
NM 12	1.56	53.2519	16.2358	-4.62	-3.70
NM 13	1.67	40.1052	12.2286	-4.54	-3.51
NM 14	1.56	32.6922	9.9614	3.18	2.55
			-3.7807		
NM 15	1.68	-61.3358	-14.9146	-0.16	-0.12
NM 16	1.69	-39.7312	-12.1062	-3.87	-2.98
		-23.4936			
NM 17A	2.60	-22.7286	-14.1127	24.17	<u>14.99</u> *
		0.7568			
NM 19	2.23	-28.0375	-8.3244	9.24	6.19
		-6.9675			
		-29.2983	-1.7628		
FDM 3	4.48	22.7913	-0.9536	-1390.78	-657.08*
NM 22	0.36	12.9834	3.8566	100.74	<u>167.90</u> *
		-23.3808	-6.2032		
NM 24	3.19	25.7950	6.4382	500.85	<u>280.42</u> *
NM 25	1.65	6.7526	1.9332	124.99	<u>97.31</u> *
			-2.2540		
		-5.5946	-2.6992		
NM 27	3.18	-8.3046	0.0814	635.32	<u>356.27</u> *
			1.5324		
		15.8758	3.4299		
NM 29	3.32	18.9254	5.5774	67.71	<u>37.16</u> *
			1.5804		
NM 30	1.56	-0.8902	-1.8260	-25.73	-20.60*
NM 31	1.62	-9.3618	-2.8262	-27.28	-21.43*
			1.3656		
			-1.0866		
		1.4636	-0.3970		
NM 33	3.22	5.8674	2.3687	-16.21	-9.03
NM 34	1.61	26.9512	8.2238	-14.07	-11.09
NM 35	1.61	8.4371	2.5733	-1.67	-1.32
NM 36	1.61	-30.5034	-9.3040	6.56	5.17
NM 37	1.61	31.4253	9.5895	-11.07	-8.72

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 852-181					
Early 60's/Nov 1968 (1st order/3rd order)					
NM 38					
NM 39	1.56	-2.7817	-2.8150	10.15	8.12
NM 40	1.61	-13.0385	-13.0200	-5.64	-4.44
NM 41	1.54	-2.9061	-2.9350	8.81	7.09
		-3.3256	-3.3450		
NM 43	3.22	27.5738	27.5600	9.81	5.42
		-12.4602	-16.4450		
		-8.1735	-4.0250		
NM 46	4.83	2.7454	2.6750	-28.44	-12.94
NM 47	1.61	3.8256	3.8075	5.52	4.35
NM 48	1.54	33.9308	33.9725	-12.71	-10.23
		-4.6188	-3.8825		
NM 50	3.40	47.9232	47.1975	-3.23	-1.75
NM 51	1.61	-12.4465	-12.4450	-0.46	-0.36
		-1.8114	-3.5725		
NM 53	3.22	21.6418	23.4300	-8.26	-4.60
		22.7126	21.7450		
NM 55	3.22	29.2318	30.2825	-25.33	-14.12
NM 56	1.61	55.2356	55.2375	-0.58	-0.46
NM 57	1.61	-31.9798	-31.9475	-9.85	-7.76
NM 58	1.61	7.2752	7.2600	4.63	3.65
NM 59	1.66	31.7352	31.7425	-2.23	-1.73
NM 60	1.54	26.3376	26.3425	-1.49	-1.20
NM 61	1.64	33.9032	33.9225	-5.88	-4.59
NM 62	1.63	89.9442	90.0200	-23.10	-18.12
NM 63	1.61	-44.3482	-44.3750	8.17	6.44
		-80.0225			
		-79.9588	-18.0350		
NM 65	3.35	-79.6577	-61.6750	35.36	19.33
NM 66	1.63	-40.7168	-40.7400	7.07	5.55
NM 66A	0.76	-13.3722	-13.4100	11.52	13.25
		-0.0522			
NM 67	0.93	0.5958	0.6450	-30.91	-31.99
NM 68	1.64	-4.2411	-4.2400	-0.34	-0.26
NM 69	1.61	-12.8973	-12.8925	-1.46	-1.15
		3.6789	13.4800		
NM 71	3.22	13.6158	3.8075	2.19	1.22
NM 72	1.64	1.8061	1.8075	-0.43	-0.33
NM 73	1.59	41.3941	41.3700	7.35	5.82
NM 74	1.66	57.6719	57.7325	-18.47	-14.35
NM 75	1.59	-35.4399	-35.3950	-13.69	-10.84
NM 76	1.54	-38.8316	-38.7700	-18.78	-15.11

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 852-181(Cont.)					
Early 60's/Nov 1968					
NM 76			-5.8650		
		-4.8061	0.3525		
		-9.3856	-7.8400		
NM 79	4.92	2.5612	1.7000	6.71	3.02
NM 80	1.61	6.9474	6.9500	-3.84	-3.03
NM 81	1.64	-9.6018	-9.5775	-7.41	-5.78
NM 82	1.64	-15.0220	-15.0000	-6.71	-5.23
NM 83	1.34	-2.2405	-2.2425	0.61	0.53
NM 84	1.90	9.4912	9.4800	3.41	2.48
NM 85	1.63	60.1896	60.1625	7.96	6.24
NM 86	1.59	77.8479	77.9675	-36.45	-28.88
			-28.9525		
FBM 6	2.38	-41.2087	-12.2400	-4.94	-3.20
		12.2256			
NM 88	2.09	-40.6032	-28.3700	-2.32	-1.60
NM 89	1.63	-61.8389	-61.8300	-2.71	-2.13
NM 90	1.63	11.0759	11.1175	-12.68	-9.95
NM 91	1.63	58.2258	58.2550	-8.90	-6.98
		7.0192	6.5975		
NM 93	3.25	3.2586	3.7150	-10.58	-5.87
NM 94	1.63	-21.5228	-21.4375	-26.00	-20.39
NM 95	1.64	9.9358	9.9225	4.05	3.16
NM 96	1.59	19.6840	19.7175	-10.21	-8.09
NM 97	1.63	41.7082	41.7300	-6.64	-5.21
NM 98	1.64	3.2930	3.2225	21.49	16.77
		15.9542	16.3350		
NM 100	3.22	18.6212	18.3325	-28.07	-15.65
NM 101	1.63	22.0007	21.9900	3.26	2.56
BRM 11	2.32	26.5088	26.5625	-16.37	-10.75

Bench mark number	Interval dist. (km)	First meas. (ft)	Second -meas. (m)	Change in height (mm)	Normalised -difference (mm/√km)
Run between AHD junction points 852-851(172-181)					
Nov 1968/May 1981 (3rd order/2nd order)					
NM 43			-0.2629		
		-16.4450	-5.1534		
		-4.0525	-0.8622		
NM 46	4.83	2.6750	0.8322	14.00	6.37
			0.6804		
NM 47	1.61	3.8075	0.4849	-4.77	-3.76
NM 48	1.50	33.9725	10.3381	16.72	13.65
		-3.8825			
		47.1975	11.4328		
NM 51	5.01	-12.4450	-2.0345	10.88	4.86
Run between AHD junction points 851-?(172-181)					
Nov 1968/May 1981 (3rd order/2nd order)					
NM 55		55.2375	17.1932		
NM 57	3.22	-31.9475	-10.1190	24.59	13.70
NM 58	1.60	7.2600	2.2366	-23.75	-18.78
NM 59	1.66	31.7425	9.6579	17.21	13.36
			0.1540		
NM 60	1.54	26.3425	7.8807	-5.51	-4.44
NM 61	1.62	33.9225	10.3351	4.48	3.52
NM 62	1.62	90.0200	27.4142	23.90	18.77
NM 63	1.60	-44.3750	-13.5169	-8.60	-6.80
		-80.0225			
		-18.0350	-24.3714		
		-61.6750	-24.1591		
NM 66	4.85	-40.7400	-12.5483	-25.22	-11.45

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 2-131(172-131)					
Early 60's/May 1981 (1st order/2nd order)					
NM 68		-12.8973	-3.4903		
		13.6158	2.9920		
NM 71	4.33	3.6789	1.8354	3.23	1.47
			-0.0530		
NM 72	1.63	1.8061	0.6003	3.20	2.51
NM 73	1.60	41.3941	12.6198	-2.38	-2.23
NM 74	1.65	57.6719	17.5822	-3.80	-2.96
NM 75	1.59	-35.4399	-10.7987	-3.38	-2.68
NM 76	1.55	-38.8316	-11.8307	-5.17	-4.15
NM 77	1.66	-4.8061	-1.4692	4.30	3.34
			-3.0854		
		-9.3356	0.4312		
		2.5612	0.6603		
		6.9474	1.7992		
NM 81	6.55	-9.6018	-2.7373	-7.74	-3.02
NM 82	1.61	-15.0220	-4.5779	-0.81	-0.63
NM 83	1.32	-2.2405	-0.6817	-1.20	-1.05
		9.4912	2.6260		
		60.1886	17.8124		
NM 86	5.14	77.8479	24.5321	-4.06	-1.79
			-9.9825		
FBM 6	2.10	-41.2037	-2.5682	-9.71	-6.70
		12.2256			
		-40.6032	-8.6753		
NM 89	2.80	-61.8389	-18.8154	-6.79	-4.06
NM 90	1.63	11.0750	3.3801	-4.17	-3.26
		58.2258	19.4741		
		7.0192	0.5174		
NM 93	4.89	3.2586	0.8360	2.40	1.03
NM 94	1.61	-21.5228	-5.5511	-9.05	-7.13
NM 95	1.63	9.9358	3.0293	-0.87	-0.68
		19.6840	5.5240		
NM 97	3.25	41.7032	13.0063	-7.96	-4.41
		3.2930	1.2279		
		15.9542	1.6021		
NM 100	4.83	18.6212	8.7138	-1.51	-0.69
NM 101	1.61	22.0007	6.7147	-3.89	-7.00

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 7-181(172-181)					
Nov 1958/May 1981 (3rd order/2nd order)					
NM 68		-12.8925	-3.4903		
		13.4800	2.9920		
NM 71	4.83	3.8075	1.8354	2.50	1.14
			-0.0530		
NM 72	1.53	1.8075	0.6003	3.63	2.34
NM 73	1.60	41.3700	12.6198	-10.22	-8.08
NM 74	1.65	57.7325	17.5822	14.67	11.42
NM 75	1.59	-35.3950	-10.7987	10.30	8.17
NM 76	1.55	-38.7700	-11.3307	13.60	10.93
		-5.8650	-1.4692		
		0.3525	-3.0854		
NM 78A	3.29	-7.8400	0.4818	2.96	1.63
		1.7000	0.6603		
		6.9600	1.7992		
NM 81	4.92	-9.5775	-2.7373	-1.85	-0.84
NM 82	1.61	-15.0000	-4.5779	5.90	4.65
NM 83	1.32	-2.2425	-0.6817	-1.81	-1.58
		9.4300	2.6260		
		60.1625	17.8124		
NM 86	5.14	77.9675	24.5321	21.03	9.28
		-29.9525	-9.9825		
FEN 6	2.10	-12.2400	-2.5682	-4.77	-3.29
		-23.3700	-8.6758		
NM 89	2.80	-61.8300	-18.8154	-1.76	-1.05
NM 90	1.63	11.1175	3.3801	8.51	6.67
		58.2550	19.4741		
		6.5975	0.5174		
NM 93	4.89	3.7150	0.8860	21.37	9.89
NM 94	1.61	-21.4375	-6.5511	16.95	13.36
NM 95	1.63	9.9225	3.0293	-4.92	-3.86
		19.7175	5.6240		
NM 97	3.25	41.7300	13.0963	8.90	4.94
		3.2225	1.2279		
		16.3350	1.6021		
NM 100	4.83	18.3325	8.7138	5.07	2.31
NM 101	1.61	21.9900	6.7147	-12.15	-9.57

Bench mark number	Interval dist. (km)	First meas. (m)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/√km)
Run between AHD junction points ?-172(172-198) 1977/March1981 (3rd order/2nd order)					
SB 1			-0.3750		
SB 2	1.68	3.5380	3.9216	-3.60	-6.64
SB 3	1.85	-5.6560	-5.6530	-3.00	-2.21
			-2.1288		
SB 5	3.10	-0.1240	1.9994	5.40	3.07
Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/√km)
Run between AHD junction points ?-172(172-198) Oct-Nov1968/March1981 (3rd order/2nd order)					
SB 1			-0.3750		
SB 2	1.68	11.6550	3.9216	5.84	4.51
SB 3	1.85	-18.5480	-5.6530	-0.43	-0.32
		-6.0920	-2.1288		
SB 5	3.10	5.7300	1.9994	19.06	10.83
Run between AHD junction points ?-859(172-198) Oct-Nov1968/Feb1981 (3rd order/2nd order)					
SB 1			-0.3750		
F 373	2.32	0.6180	0.5572	6.17	4.05
F 373A	1.70	19.0700	5.8035	9.04	6.93
		4.9400			
		-4.4200	6.9129		
F 371	4.88	18.6070	-1.0864	3.41	1.54
		-21.0850	-6.5837		
F 370	3.29	13.3720	4.2260	6.78	3.74
F 370A	1.57	-0.3050	-0.0912	-1.76	-1.41
F 369	1.58	-1.9820	-0.5002	-3.91	-3.02
F 369A	1.62	16.0400	4.8756	13.39	10.52
F 368	1.62	11.2380	3.4223	3.04	2.39
		8.0020	2.2143		
F 367	3.34	-1.2620	-0.1574	-2.55	-1.39
F 367A	1.61	3.6250	1.0845	20.40	16.08
F 366	1.64	-9.3020	-2.8221	-13.15	-10.27
			-1.5847		
		-0.2650	3.8760		
F 365	3.32	7.5450	-0.0024	-69.96	-33.39*

Bench mark number	Interval dist. (km)	First meas. (m)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/√km)
Run between AHD junction points 2-859(172-193) 1977/Feb1981 (3rd order/2nd order)					
SB 1			-0.3750		
F 373	2.32	0.1770	0.5572	-5.20	-3.41
F 373A	1.70	5.8060	5.8035	2.50	1.92
			6.9129		
F 371	4.88	5.8280	-1.0864	1.50	0.68
		-6.4310	-6.5837		
F 370	3.29	4.0760	4.2260	2.70	1.49
F 370A	1.57	-0.0910	-0.0912	-0.20	-0.16
F 369	1.68	-0.5960	-0.6002	4.20	3.24
F 369A	1.62	4.8700	4.8756	-5.60	-4.40
F 368	1.62	3.4200	3.4223	-2.30	-1.81
		2.4280	2.2143		
F 367	3.34	-0.3720	-0.1574	-0.90	-0.49
F 367A	1.61	1.0850	1.0845	0.50	0.39
F 366	1.64	-2.8220	-2.8221	0.10	0.08
			-1.5847		
			3.8760		
F 365	3.32	2.2760	-0.0024	-12.90	-7.08

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/√km)
Run between AHD junction points 859-2131 Early 60's/1977 (3rd order/3rd order)					
F 365		40.2900			
		-31.3000			
		13.3200			
YQ 2	5.23	63.8600	26.3140	-49.38	<u>-21.59</u>
		63.0200			
		115.8600			
		-92.1400			
YQ 3	4.43	-6.9600	24.3050	11.94	5.68
		-26.8000			
		-35.1300	-8.0220		
YQ 4	4.83	-25.4600	-18.6220	7.53	3.43
		-0.2400			
		60.6300			
YQ 5	3.62	-61.7600	-0.3960	-21.58	-11.34
		24.4800			
		11.3800			
YQ 6	4.02	11.5800	14.4520	7.71	3.84

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/√km)
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Run between AHD junction points 859-2131
Early 60's/Oct-Nov 1968 (3rd order/3rd order)
F 365

		40.2900			
		-31.3000			
		13.3200	-5.3630		
YQ 2	5.23	63.8600	91.9120	-115.52	<u>-50.51</u> *
		63.0200			
		115.8600			
		-92.1400			
YQ 3	4.43	-6.9600	79.7380	12.80	6.09
		-26.8000			
		-35.1300			
YQ 4	4.83	-25.4600	-87.4280	11.58	5.27
		-0.2400			
		60.6300			
YQ 5	3.62	-61.7600	-1.3050	-19.81	-10.41
		24.4800			
		11.3800			
YQ 6	4.02	11.5800	47.4680	-8.53	-4.25

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/√km)
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Run between AHD junction points 857-2697
Early 60's/May-June 1980 (3rd order/3rd order)
YQ 16

		122.7900			
QC 1	3.54	-20.5000	31.1240	53.99	<u>28.69</u>
		-70.3600			
QC 2	1.93	15.5400	-16.6570	-52.14	<u>-37.52</u> *
		-11.0900			
		-6.2600	-4.4720		
QC 3	4.99	48.6000	13.9750	22.00	9.85
		23.5000			
		98.3000	21.5130		
QC 4	5.63	-61.2800	-3.0410	-25.50	-10.75
			-1.3100		
			-0.5540		
		-18.3100	-10.9190		
QC 5	3.86	-8.7000	4.5790	-28.65	-14.58
		130.2000	36.9290		
		59.8300	11.5030		
QC 6	4.51	-18.1200	3.9990	-32.83	-15.47
			-27.1110		
		-118.5100	-13.3270		
		-16.9800	8.1350		
QC 7	4.83	3.6400	-7.9100	25.12	11.43

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 857-856					
Early 60's/Oct-Nov 1968 (3rd order/3rd order)					
YQ 16					
		-11.8400			
QBR 1	2.41	-24.6700	-36.7580	75.59	48.65 *
		-6.0800			
QBR 2	4.35	-33.9400	-40.0450	7.62	3.66
QBR 3	2.57	-4.8800	-4.9400	18.29	11.40
		22.3600			
		33.4400			
QBR 4	4.02	-11.8000	43.9650	10.67	5.32
		27.2900			
		28.7000			
QBR 5	4.83	85.8000	141.9000	-33.53	-15.26
		-6.7200			
QBR 6	2.74	14.1400	7.3920	8.53	5.16
		92.8800			
		69.8000			
QBR 7	5.31	-24.3000	138.3020	23.77	10.32
		16.5400			
		-79.1000			
QBR 8	4.18	67.6600	5.1380	-11.58	-5.66
		32.2400			
		-24.1500			
		-89.6800			
QBR 9	5.47	14.0100	-67.5380	-12.80	-5.47
		-56.4800			
		-75.8100			
		-36.4200			
QBR 10	6.03	-12.4600	-181.2000	9.14	3.72
		-2.0400			
QBR 11	2.82	-4.6800	-6.7300	3.05	1.82
		15.1800			
		-48.0200			
QBR 12	5.63	15.8500	-17.0220	9.75	4.11
		4.3000			
		29.0000			
QBR 13	4.35	116.2600	149.5750	-4.57	-2.19
		-47.9800			
		9.1200			
QBR 14	4.43	-29.7400	-68.4820	-35.97	-17.10

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
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Run between AHD junction points 857-856 (Cont.)

Early 60's/Oct-Nov 1968

QBR 14

		-47.3400			
		52.8700			
		6.2200			
		-33.9800			
		-1.6200			
		10.4000	8.2830		
QBR 16	8.05	0.8600	-20.9300	17.37	6.12
		52.7100			
		-43.0600			
QBR 17	5.39	29.1400	38.7150	22.86	9.85
		61.3000			
		-52.6100			
QBR 18	10.70	8.9400	17.6250	1.52	0.47

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
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Run between AHD junction points 2697-852

Early 60's/1977 (3rd order/3rd order)

QC 7

		92.5400	38.8480		
		-50.6100	-48.4570		
QC 8	5.31	-91.7800	-5.5660	-19.28	-8.37
			-6.2140		
		-25.5400	-10.2750		
		-26.9200	-9.6310		
QC 9	4.35	-35.3500	-0.6180	-26.49	-12.71
		-6.5000	4.3140		
		-40.3100	-17.0160		
QC 10	4.51	-12.1500	-5.2700	0.99	0.47

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 856-181					
Early 60's/Oct-Nov 1968 (3rd order/3rd order)					
QBR 18					
		24.5000			
		13.9000			
BRM 1	5.23	50.2600	88.4980	49.38	21.59
		61.6200			
		-31.9400			
BRM 2	4.83	-36.0400	-6.3580	-0.61	-0.28
		36.0100			
		-68.1800			
BRM 3	4.43	-34.3800	-66.5180	-9.75	-4.64
		-14.0600			
		11.7000			
		15.7400			
BRM 4	6.44	-29.4700	-15.9700	-36.58	-14.42
		0.8400			
		47.1200			
BRM 5	4.02	28.6600	76.5480	21.95	10.94
		1.4500			
		25.7200			
BRM 6	4.43	-3.2600	23.3280	28.04	13.33
		-91.4000			
		7.6400			
BRM 7	4.83	43.3200	-40.2480	-58.52	-26.63
		83.9800			
		-0.2600			
BRM 8	4.83	15.7600	99.3280	46.33	21.09
		25.9400			
		-16.4800			
		-6.0200			
BRM 9	6.44	30.3000	33.6150	38.10	15.02
		46.7400			
BRM 10	2.41	-28.3600	18.3120	20.73	13.34

Bench mark number	Interval dist. (km)	First meas. (m)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 2688-2685 1977/June 1981 (3rd order/2nd order)					
HU 54			0.3482		
		1.1700	0.4192		
HU 56	5.84	10.1460	10.5452	3.40	1.41
HU 57	2.64	32.0320	32.0905	-9.50	-5.23
HU 58	2.83	-2.4660	-2.4618	-4.20	-2.50
			-15.7118		
		-32.6590	-17.2473		
HU 16A	5.82	-11.0520	-10.7450	-6.40	-2.65
			-2.6046		
HU 17	3.75	7.4480	10.0546	-2.00	-1.03
			-6.6706		
			-2.9516		
		-9.3820	-0.5497		
		-18.7370	-17.4692		
HZ 203	11.10	12.1210	11.6596	-16.50	-4.95
			4.3334		
		-11.3390	-15.6906		
HZ 201	6.05	4.5360	4.6160	-61.80	-25.13
HZ 200	2.41	-0.0960	-0.0966	0.60	0.39
HZ 199	2.72	-2.7390	-2.7360	-3.00	-1.82
			-3.4907		
			6.3126		
		3.2700	-2.9140		
HZ 197	6.21	-29.7720	-26.4116	1.70	0.68
Run between AHD junction points 850-?(850-851) AHD computed 4/10/78 /June 1981 (3rd order/2nd order)					
UH 17			-41.3049		
UH 16	3.87	-42.5843	-1.2992	19.30	9.81
			18.7753		
			-20.1636		
		-1.2229	37.2421		
UH 14	7.99	41.8829	4.8152	-9.50	-3.36
			-25.5324		
UH 13	3.16	-50.6465	-25.1136	-0.50	-0.28
			-13.6388		
UH 12	3.02	-12.6663	0.9726	-0.10	-0.06

Bench mark number	Interval dist. (km)	First meas. (m)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 852-?(852-1025)					
1977/Jan, Feb, June, July 1981 (3rd order/2nd order)					
CK 2					
CK 3	1.61	-0.0620	-0.0620	0.00	0.00
CK 4	1.61	4.0350	4.0824	2.60	2.05
CK 5	1.62	13.3580	13.3564	1.60	1.26
		0.6480	0.4156		
CK 7	3.24	21.7140	21.9532	-6.80	-3.78
CK 8	1.02	-3.4680	-3.4289	-39.10	-38.71*
CK 9	2.22	7.5770	7.5388	38.20	25.64
CK 10	1.61	6.9840	6.9844	-0.40	-0.32
CK 11	1.62	21.8570	21.8614	-4.40	-3.46
		21.6830	21.4414		
CK 13	3.23	-15.0420	-14.7924	-8.00	-4.45
CK 14	1.64	-15.7220	-15.7192	-2.80	-2.19
CK 15	1.61	8.5760	8.5766	-0.60	-0.47
Run between AHD junction points 851-?(851-1026)					
AHD computed 18/10/79 /May 1981 (3rd order/2nd order)					
UH 92			21.7155		
UH 91	3.32	12.2200	-9.4853	-10.20	-5.60
			-31.4937		
			20.9624		
		-10.3130	3.9858		
UH 89	7.23	16.3910	12.6492	-25.70	-9.56
UH 88	2.57	-37.0690	-37.0597	-9.30	-5.80
Run between AHD junction points 851-?(850-851)					
AHD computed 4/10/78 /June 1981 (3rd order/2nd order)					
UH 4			24.4356		
UH 5	3.86	0.1094	-24.2950	-31.20	-15.88
			-5.4050		
			22.3142		
UH 6	4.21	14.2436	-1.6617	-3.90	-1.90
			-19.4844		
UH 7	3.38	-16.9542	2.5367	-6.50	-3.54
			-2.6048		
UH 8	3.34	0.6553	3.2417	18.40	10.07
			3.8493		
			2.0062		
		6.1542	12.0222		
UH 10	6.61	48.8088	37.0874	-2.10	-0.82
			-22.2683		
UH 11	3.15	-30.7074	-9.4171	-22.00	-12.40

Pench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (m)	Change in height (mm)	Normalised difference (mm/√km)
Run between AHD junction points ?-1025(852-1025)					
Late 50's/Jan, Feb, June, July 1981 (3rd order/2nd order)					
CK 19					
CK 20	1.61	-68.0700 -2.9300	-20.7357 -0.7974	-12.04	-9.49
CK 22	3.22	-68.2700	-20.8963	-8.06	-4.49
CK 23	1.61	-30.1900 2.0400	-9.1892 0.4263	-12.71	-10.02
CK 25	3.22	14.2300	4.4994	33.40	<u>18.61</u>
CK 26	1.61	14.4800	4.4042	9.30	<u>7.33</u>
CK 27	1.61	19.6000	5.9714	2.69	2.11
CK 28	1.61	23.2100	7.0738	0.61	0.48
CK 29	1.61	69.5600 50.1400	21.1900 15.0348	11.89	9.37
CK 31	3.24	80.6000	24.7017	113.05	<u>62.81</u> *
CK 32	1.61	2.1000	0.7228	-82.72	<u>-65.19</u> *
CK 33	1.61	-31.7600	-9.6749	-5.55	-4.37
Run between AHD junction points 852-?(852-1025)					
Late 50's/Jan, Feb, June, July 1981 (3rd order/2nd order)					
CK 2					
CK 3	1.61	-0.2000	-0.0620	1.04	0.82
CK 4	1.61	13.4600	4.0824	20.21	15.93
CK 5	1.62	43.8500 2.0900	13.3564 0.4156	9.08	7.13
CK 7	3.24	71.3000	21.9532	0.47	0.26
CK 8	1.02	-11.3600	-3.4289	-33.63	<u>-33.30</u> *
CK 9	2.22	24.8700	7.5388	41.58	<u>27.90</u> *
CK 10	1.61	22.9200	6.9844	1.62	1.27
CK 11	1.62	71.7700 71.1900	21.8614 21.4414	14.10	11.07
CK 13	3.23	-49.3200	-14.7924	16.98	9.45
CK 14	1.64	-51.6200	-15.7192	-14.58	-11.38
CK 15	1.61	28.2600 2.6250	8.5766 -2.6112	37.05	<u>29.20</u> *
CK 17	3.22	1.0400 36.2900	-2.6112 11.3352	29.18	16.26

Bench mark number	Interval dist. (km)	First meas. (ft)	Second meas. (ft)	Change in height (mm)	Normalised difference (mm/ $\sqrt{\text{km}}$)
Run between AHD junction points 2131-857					
Early 60's/Oct-Nov 1968 (3rd order/3rd order)					
YQ 6		58.9000 4.0700			
YQ 7	4.83	-31.3700 43.1600 30.2600 -11.3500	31.6350	-10.67	-4.86
YQ 8	4.43	45.9400 78.6600 35.0000 -55.2200	108.1780	-51.21	<u>-24.34</u>
YQ 9	5.63	-57.8000 -13.1400 1.7300 87.9600	0.5970	13.11	5.52
YQ 10	5.63	-72.1000 40.7600	4.2880	49.38	20.81
YQ 11	3.62	41.0800 49.0000 30.4000	81.8300	3.05	1.60
YQ 12	4.83	-7.5400 18.8400 -68.7000 -44.9000	71.8150	13.72	6.24
YQ 13	4.83	-11.5200 25.7900 44.0600	-106.5520	82.91	<u>37.73</u> *
YQ 14	4.43	-22.8800 -53.9800 -56.2000 20.4800	46.9370	10.06	4.78
YQ 15	6.03	5.0400 -3.3400 -17.0600	-84.9400	85.34	<u>34.74</u> *
YQ 16	5.23	-27.6200	-47.8900	-39.62	-17.33

APPENDIX II

NETWORK ADJUSTMENT RESULTS

DATA POINT	ADJUSTED HEIGHT ABOVE SEA LEVEL
Pre-earthquake data	
7	149.224
27	205.434
23	341.718
21	342.286
20	321.107
1	315.814
17	262.400
16	222.005
13	246.848
10	214.482
8	170.489
2	246.126
3	245.486
4	222.243
5	202.418
6	188.767
15	293.312
32	283.729
22	322.464
1st post-earthquake data	
7	149.224
27	205.433
23	341.681
21	342.211
20	321.107
1	316.891
17	262.411
16	221.974
13	246.889
10	214.610
8	170.535
2	246.113
3	245.421
4	222.233
5	203.623
6	188.761
22	322.431
2nd post-earthquake data	
7	149.224
27	205.414
28	273.823
30	239.969
32	283.701
4	222.264
14	234.541
10	214.581
8	170.533
5	203.741
6	188.766
15	293.339

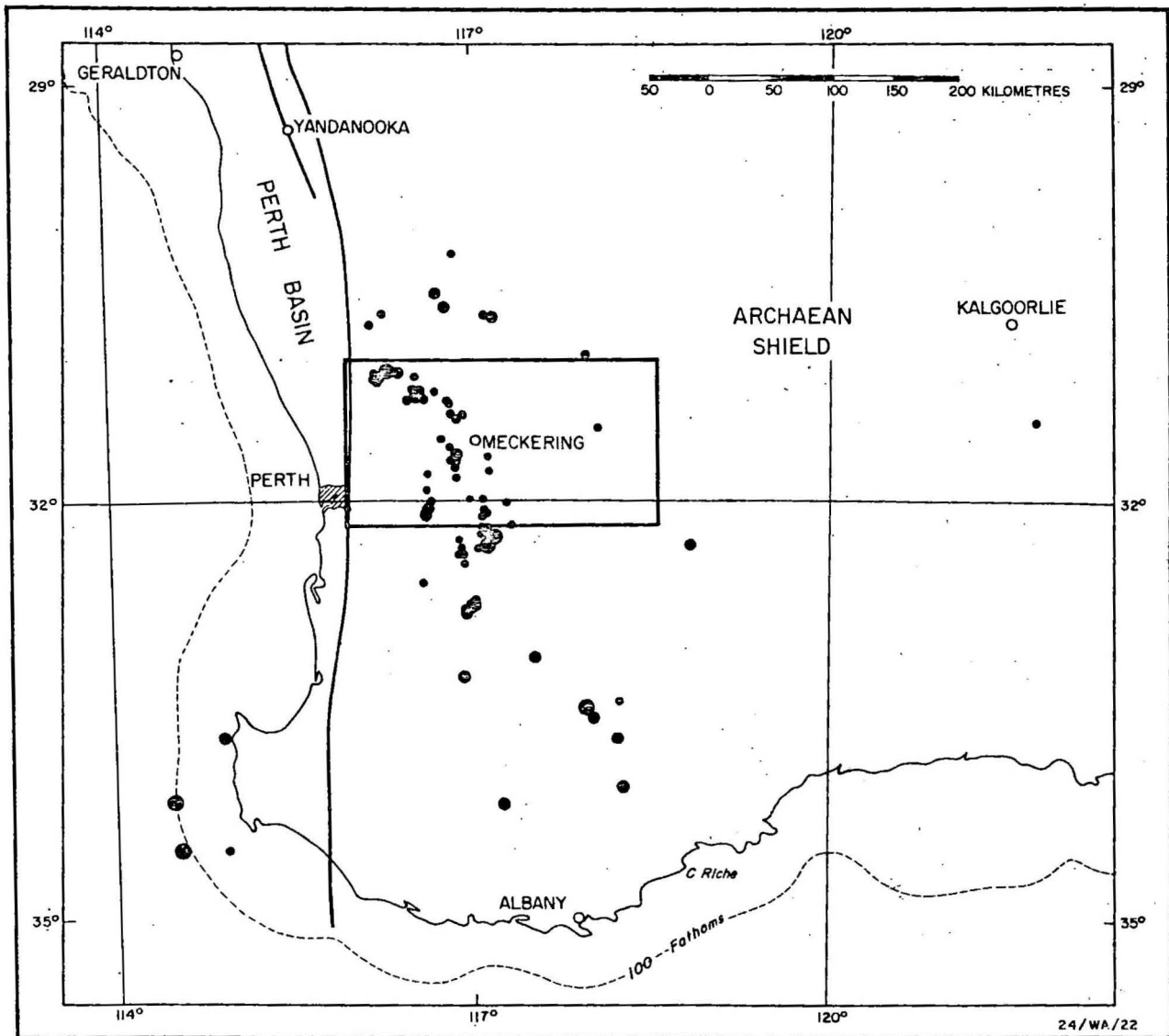


Figure 1. Locality Map.
 Dots show earthquake epicentres and relative magnitudes.
 Rectangle is location of figures 2, and 4 to 9.

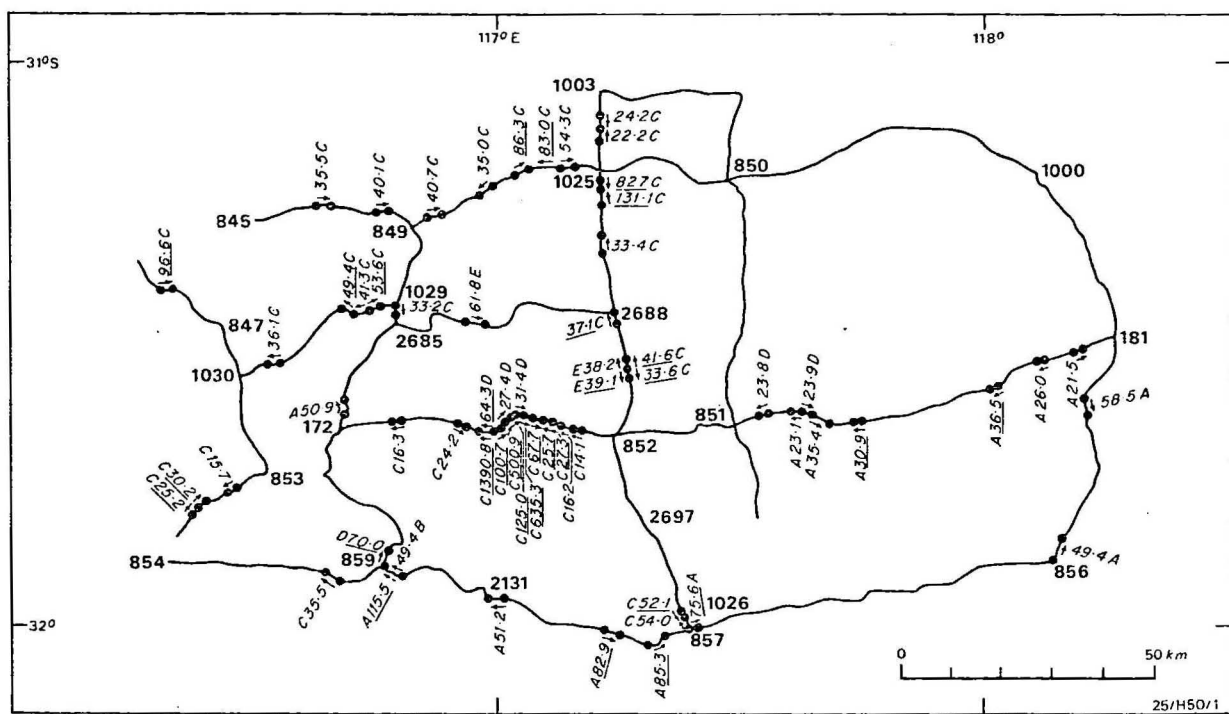


Figure 2. Results from the comparison of adjacent benchmarks.
The large numbers indicate the Australian Height Datum junction points.

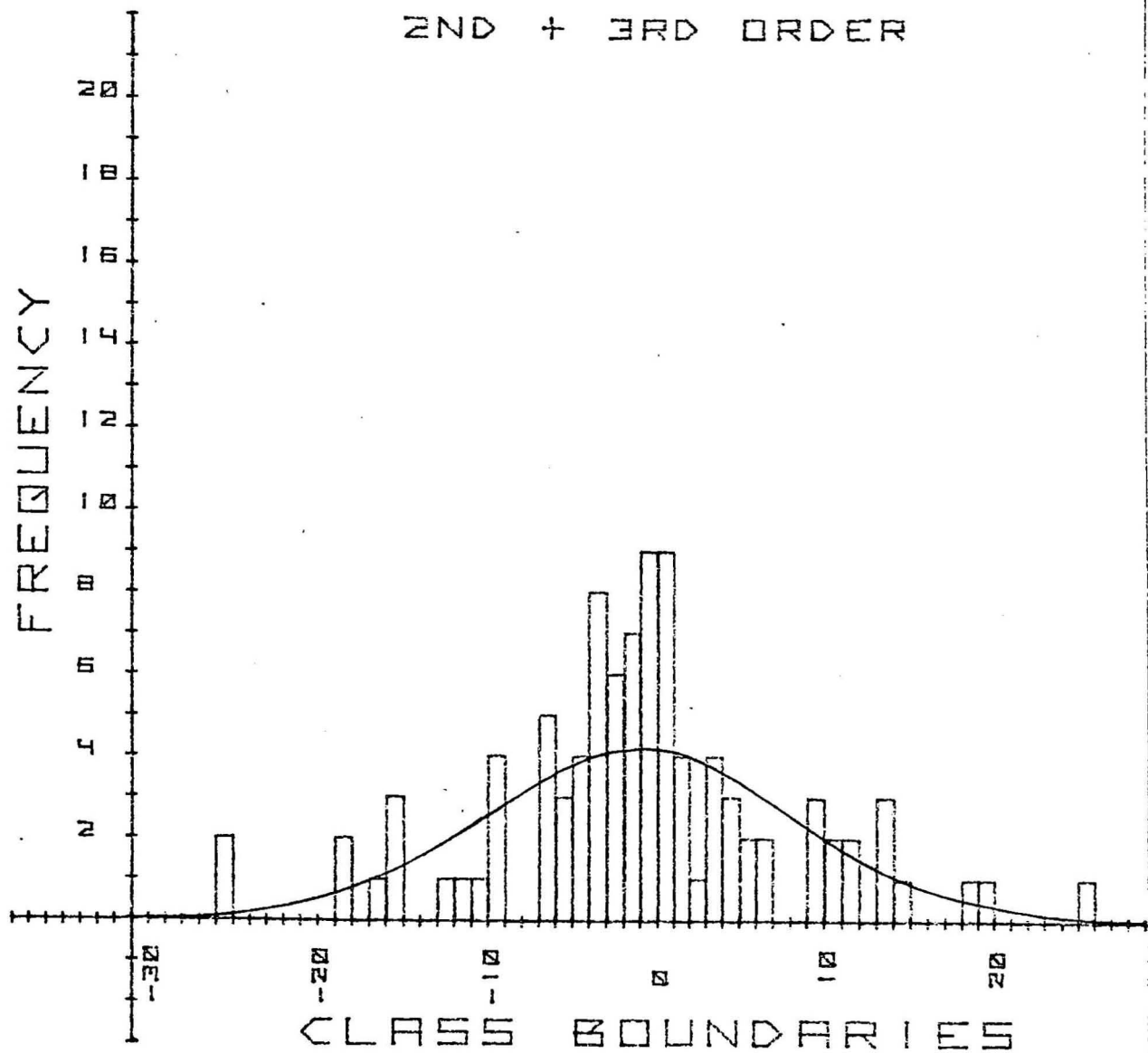


Figure 3. Histogram of differences between second and third order levelling.

The normal curve, calculated from the standard deviation of the differences, is also shown.

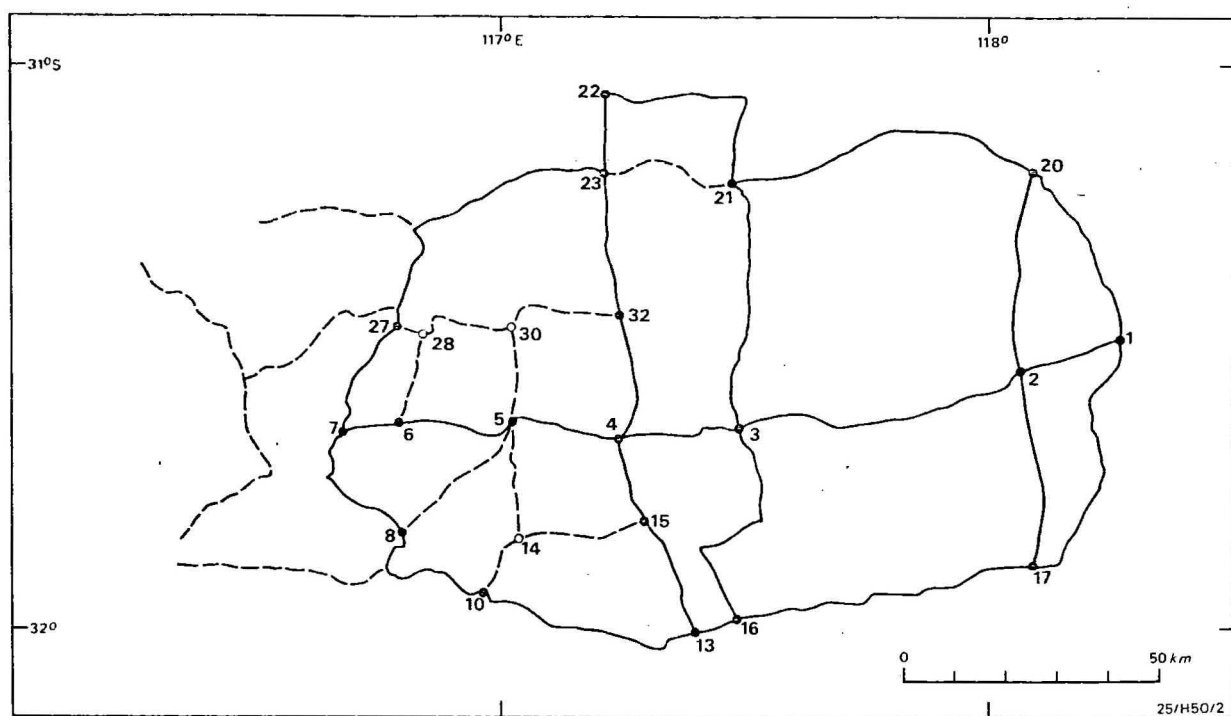


Figure 4. Pre-earthquake data network.

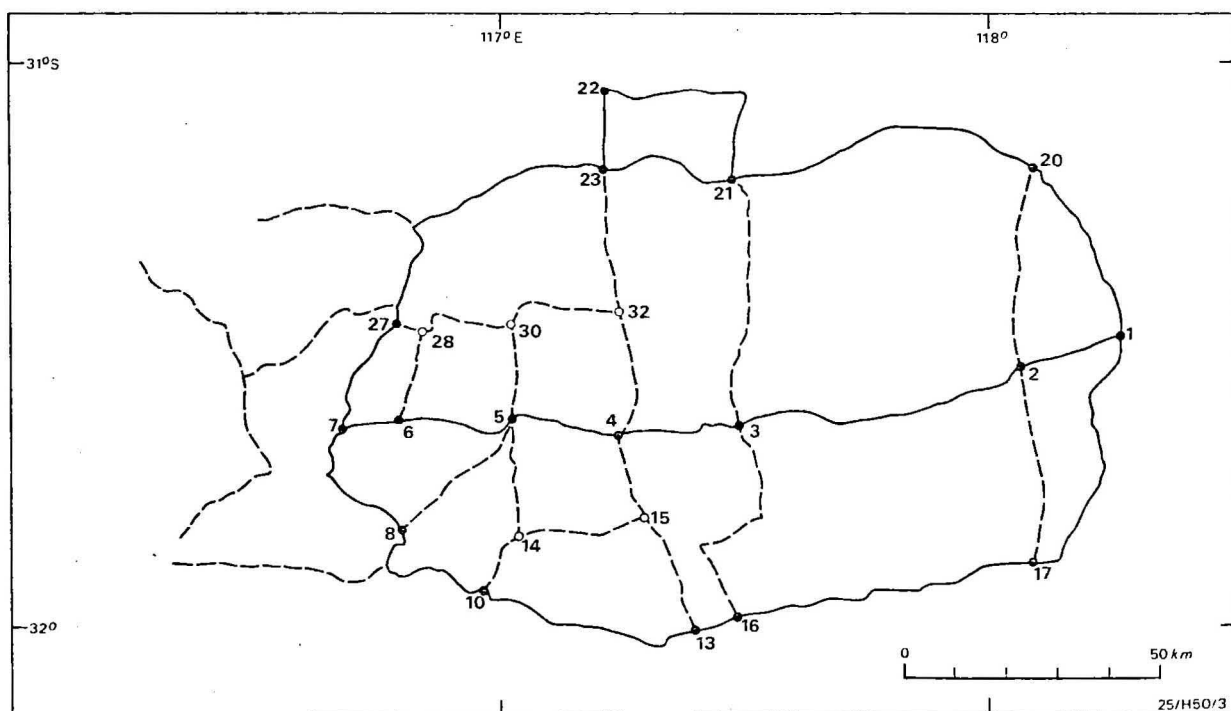


Figure 5. First post-earthquake data network.

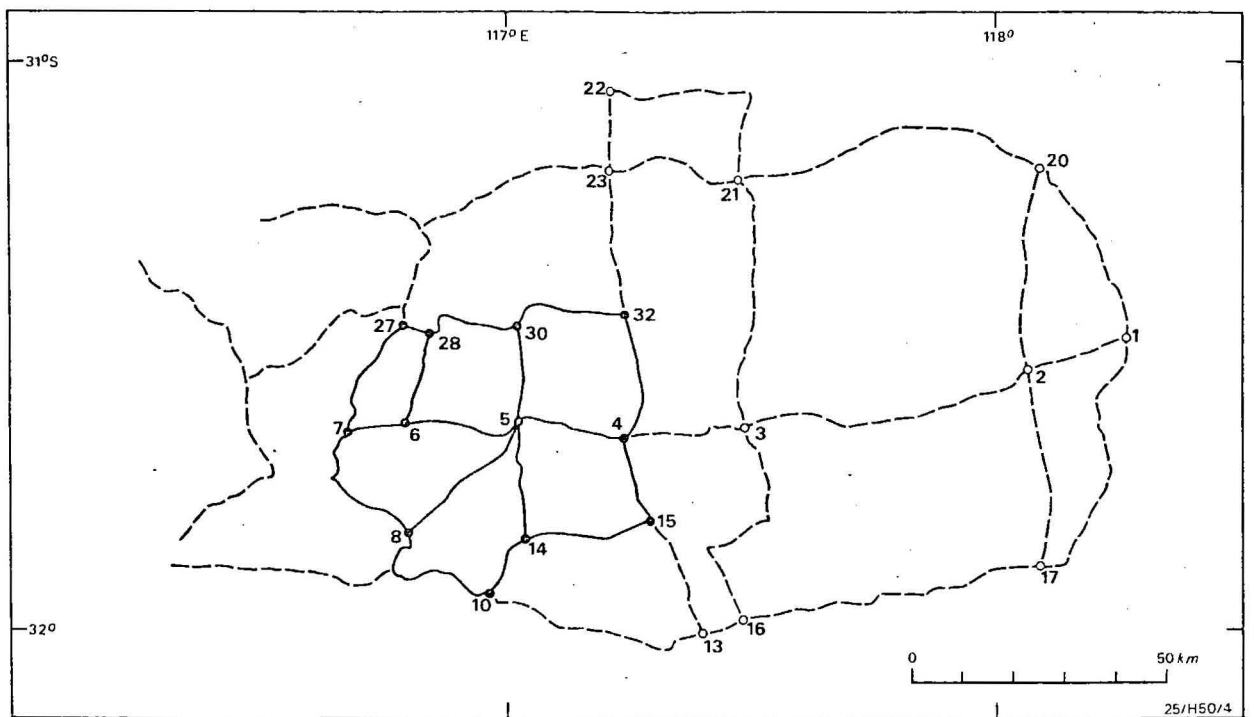


Figure 6. Second post-earthquake data network.

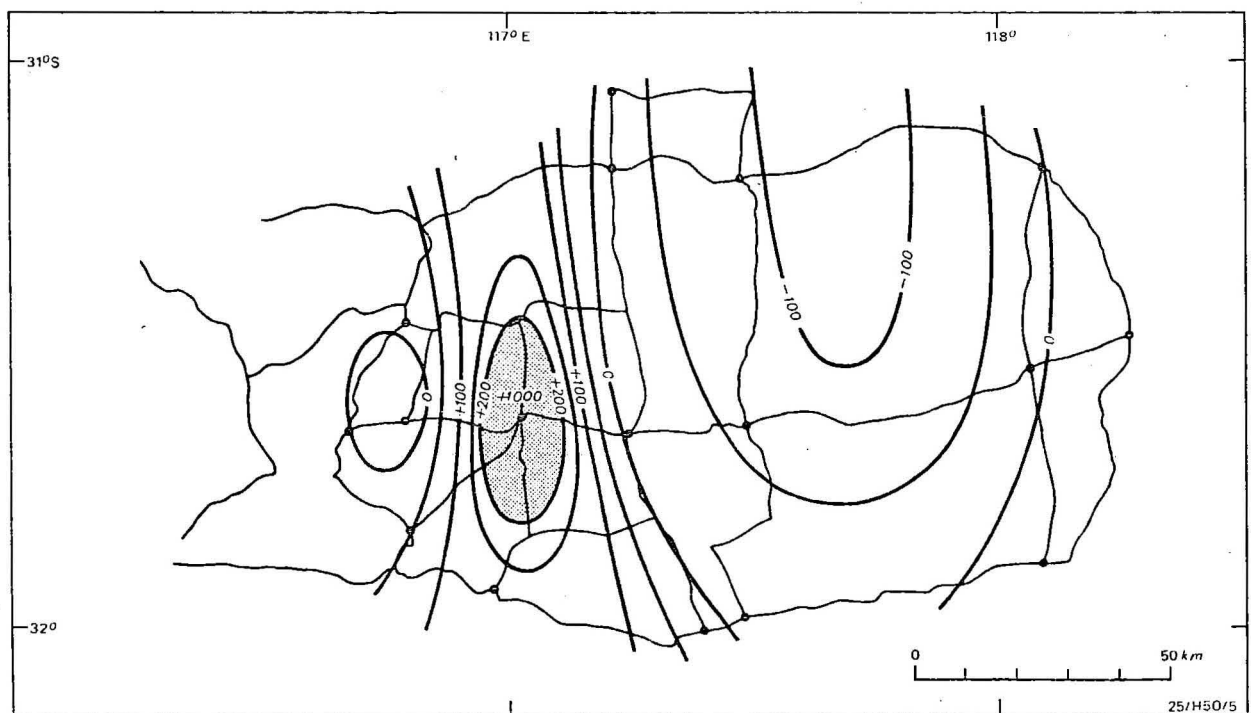


Figure 7. Pre and first post-earthquake network comparison.
The contour interval is 50 mm except in the shaded area.

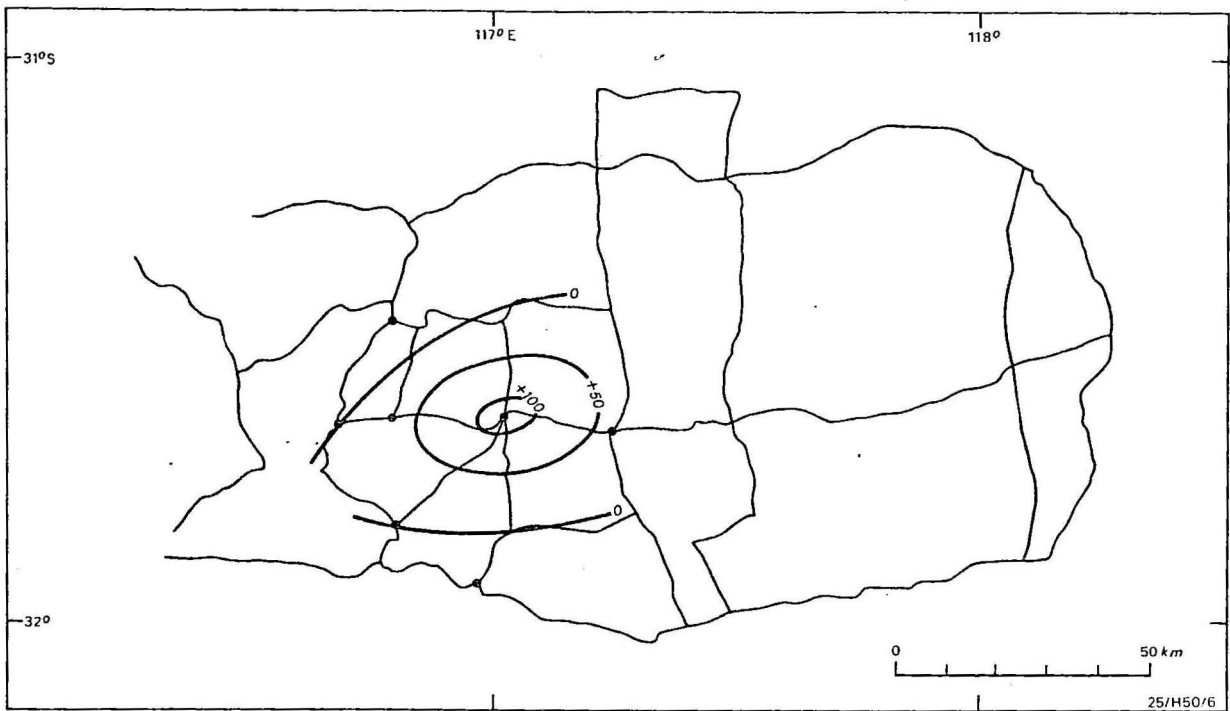


Figure 8. First and second post-earthquake network comparison.
The contour interval is 50 mm.

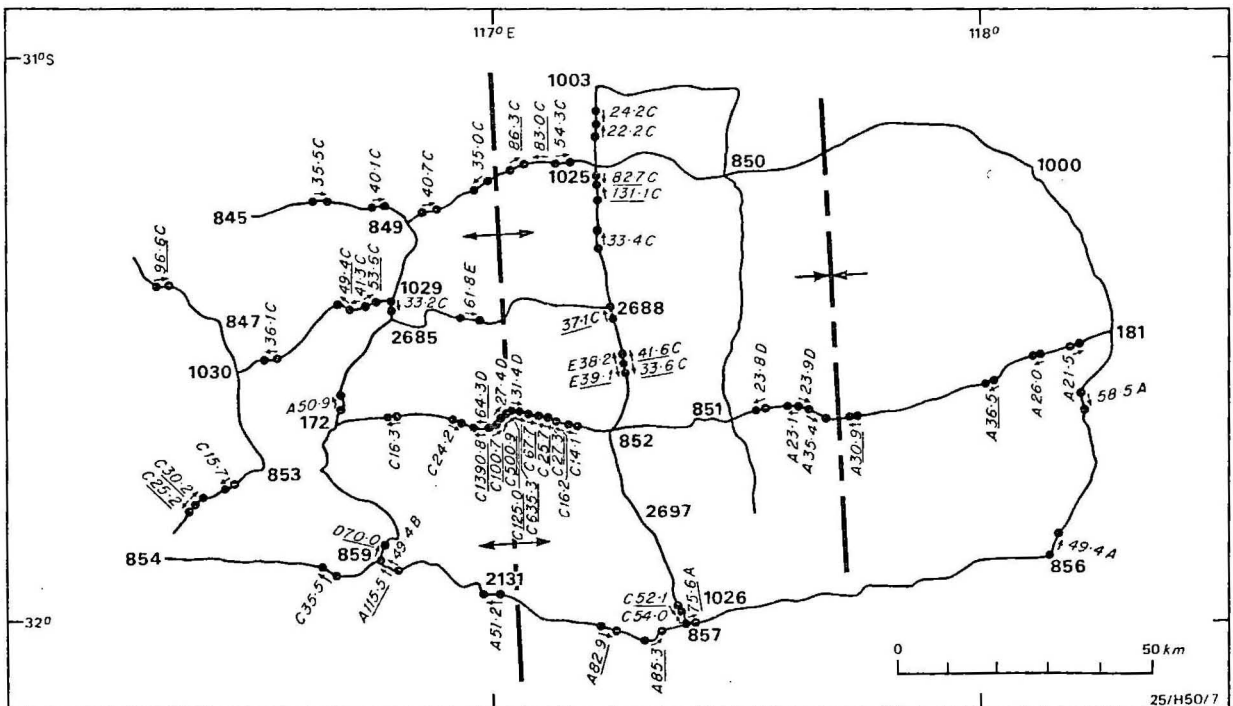


Figure 9. Comparison of results from the adjacent benchmark analysis
and the network adjustment analysis.