Report on Tellurometer Tests

by

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Introduction:

The Division of National Mapping, Department of National Development, acquired one of the first batch of instruments manufactured, and the function of this report is to present the results of the tests which have been carried out, and to offer a considered opinion as to:

(a) the accuracy which may be obtained under normal conditions,

(b) the probable range of the instrument,

(c) the suitability of the equipment for use by normal field survey personnel.

Narrative:

The equipment Serial No. MA.11 (Master) and MR.11 (Remote), was received in Canberra from South Africa by air-freight, during the last week in April, 1957. It was unpacked, inspected, and a trial of the instrument was made on the line Mount Ainslie to Mount Stromlo, near Canberra.

It was then immediately despatched to Brisbane in order that it could be shown to the members of the National Mapping Council, whose annual meeting was held in that city from 7th to 9th May, 1957.

A demonstration of the manner in which the system operated was given in the grounds of the University of Brisbane on 9th May.

The Director of National Mapping then arranged for the testing of the system by the Topographic Survey Section of his organisation.

As weather conditions permitted, test measurements were carried out from 24th May to 5th July.

Standards of Comparison:

The brochures supplied by the manufacturers of the equipment gave reason to expect that the results from the system would be of geodetic quality, and that possibly they could be accurate to within 1 part in 200,000. Such being the case it was necessary that the distances used in checking the performance of the system should be as accurate as possible.

First Order triangulation networks are available in Victoria, and at first sight would appear to be the logical standards against which to test the system. However, a considerable amount of work has been carried out with the Geodimeter on this network and it has been discovered that errors greater than 10 parts in 10^6 could be expected in some of the distances.

The distances obtained with the Geodimeter are considered to have errors which are not greater than 2 parts in 10^6, and are far more reliable as standards than the lengths of the First Order Triangulation, but unfortunately in the southern portion of Victoria where the Geodimeter lines were available, atmospheric conditions have limited the length of lines measured with the Geodimeter to 15 miles, and only one reliable line longer than this distance is available. This limits the direct testing to distances of 22 miles and under.

For short lines, a very good miniature Base Line 6,900 feet long, was available at the Army School of Survey at Mount Martha. This line has been repeatedly measured during Army schools as part of the students' training and the values should be accurate to within 0.04 feet.

In addition, it was found possible to select a very well observed braced quadrilateral, one side of which had been measured by the Geodimeter, and by careful survey extended to 30 miles in length.

The standards of comparison listed above provide very sound material on which to assess the performance of the Tellurometer in that, as far as possible, they consist of directly measured distances of superior accuracy.

A further line 44 miles long was measured as a test of ultimate range.

Summarising the lines available for comparison were:—

(a) short distances to 5,900 feet — a baseline measured with invar tapes and considered accurate to 0.04 feet,

(b) medium distances to 22 miles consisting of Geodimeter measurements estimated to be correct within 2 parts in 10^6,

(c) long distances consisting of 30 miles — side of a well observed figure based on Geodimeter length, possibly accurate to 4 parts in 10^6,

(d) a length of about 44 miles computed between second and third order triangulation stations.

It should be noted that both the Geodimeter and Tellurometer are electronic distance measuring systems relying on the velocity of electromagnetic waves as a standard. Direct comparisons are therefore possible between the measurements, provided that the same velocity is used in both cases. In this case a velocity of 299,793.1 Km/s (in vacuo) has been used.

DETAILS OF TESTS

TEST FOR INDEX ERROR:

With this type of instrument, provided any line is measured in two parts and as a whole, it is possible to deduce the index error.

Accordingly a line was selected in a flat area near Laverton and the following results obtained:

Whole distance	4199.47 feet
Sum of parts	4199.70 feet
Index error	+0.23 feet

TEST OVER SHORT DISTANCES:

This test was carried out for the purpose of checking the deduced index correction of —.23 feet and ascertaining the accuracy of measurement over shorter distances.

Actually the trace is usually read to the nearest ¼ division, or nearest 3 inches of distance, and to determine precisely the Index Error it would be necessary to carry out a statistical study of a large number of measurements made over accurately known short distances.

However, minor study can be made of the measurements at Mount Martha, by different observers under different atmospheric conditions.

Line	Individual Tellurometer Measurements	Mean Telluro-meter	Taped Measure-ment	Taped Minus Mean Telluro-meter
E. Base/W. Base ..	5899.41 5899.49	.45	.41	—.04
Peg 20/E. Base ..	3279.16 3279.53 3279.16 3279.53 3279.28 3279.13	.30	.33	+.03
Peg 20/W. Base ..	2620.07	.07	.08	+.01
Peg 19/E. Base ..	3115.36 3115.54	.45	.41	—.04
Peg 19/W. Base ..	2784.01 2784.08	.04	.00	—.04

(All measurements in feet).

The differences of the individual Tellurometer and taped measurements varied between ± .20 feet, and the average difference was .004 feet.

Analysis of the sums of parts for pegs 20 and 19 indicated possible modifications to the accepted index error of —.08 feet and +.05 feet respectively.

It would therefore be difficult to choose a more suitable index correction than —.23 feet.

In all but one of the sixteen measurements made the ground swing was less than .75 feet and in the case of the exception it was 1.20 feet.

It is reasonable to expect that under normal conditions and where no strong reflecting object is close to the line, distances of up to one mile can be measured with an error which should not exceed 0.20 feet in any one set of measurements. It also could be expected that the mean of 4 or 5 sets would be very much nearer the true value than 0.20 feet, and in this test the means for all lines measured were correct to within 0.04 feet.

It is not suggested that this exceedingly close agreement could be regarded as a criterion, but it is evident that the accuracy of the result can be considerably improved if a number of sets are taken.

TESTS OVER MEDIUM DISTANCES:

These tests comprised measurements of the following lines, all of which had been previously measured with the Geodimeter:

(a) Mount Stromlo to Mount Ainslie (9 miles).
(b) Kangaroo Ground to Quarry Hill (10 miles).
(c) Kangaroo Ground to Mount Dandenong (11.6 miles).
(d) Mount Dandenong to Quarry Hill (21.5 miles).
(e) Mount Atkinson to Mount Aitkin (14.6 miles).

The manufacturers advise that where a ground swing greater than 4 feet is encountered the measurement should be rejected. Swings greater than 4 feet were encountered only on the Mount Atkinson-Mount Aitkin line. This measurement will therefore be dealt with separately.

Mount Stromlo to Mount Ainslie: (See Figure 1).—This was the first measurement carried out after receiving the instruments from the makers. The first set occupied 1 hour 40 minutes, whilst the operator was learning the technique with the aid of the manual. Under these conditions, the result was very satisfactory. The second set occupied only 30 minutes, with an improved result.

Geodimeter Distance (47202.51 feet) minus Tellurometer Distance

Observation	Difference in ft.	Difference in parts/10^6
1	+0.40	8.5
2.	+0.03	.6
Mean	+0.22	4.6

The observations disclosed a fairly symmetrical ground swing with a range of 2 to 3 feet.

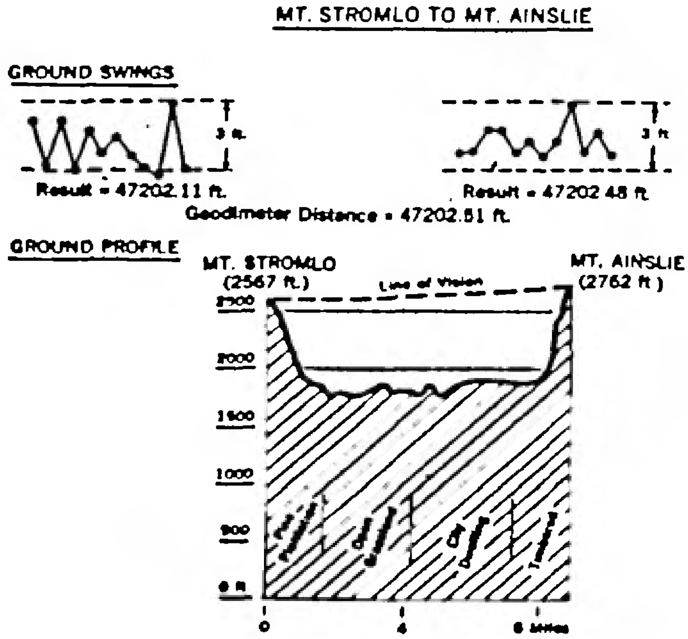
MT. STROMLO TO MT. AINSLIE
GROUND SWINGS
3 ft.
Result = 47202.11 ft.
Result = 47202.48 ft.
Geodimeter Distance = 47202.81 ft.
GROUND PROFILE
MT. STROMLO
(2567 ft.)
Line of Vision
MT. AINSLIE
(2762 ft.)
1000
0 ft.
0
4
8 Miles

Fig. 1

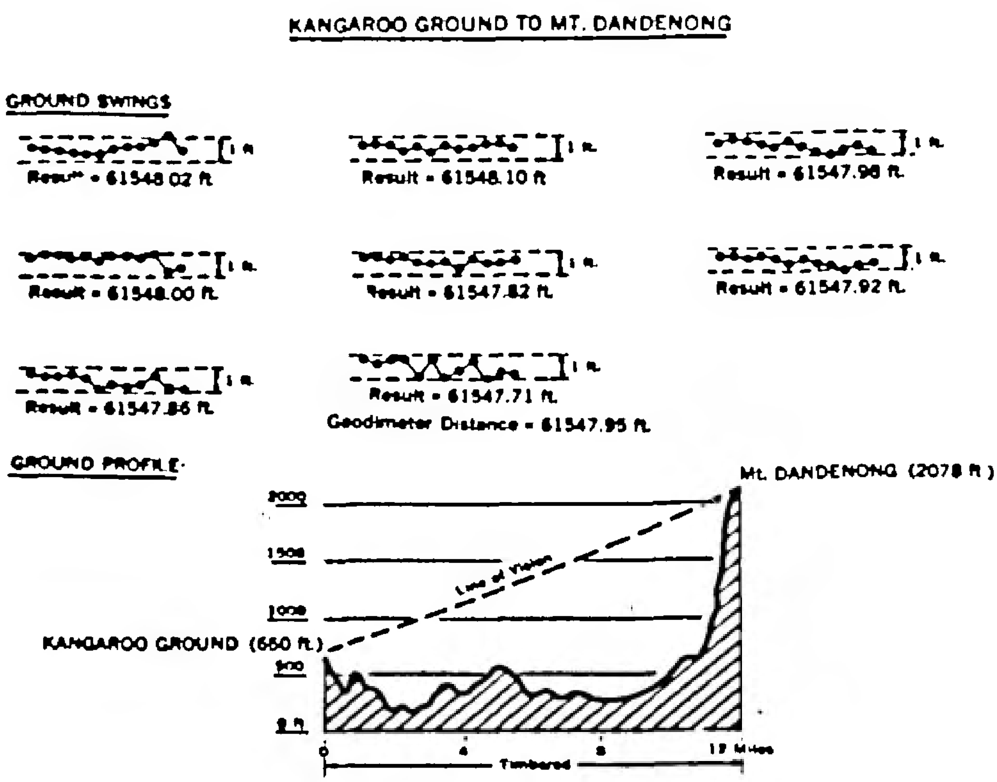
KANGAROO GROUND TO MT. DANDENONG
GROUND SWINGS
Result = 61548.02 ft.
Result = 61548.10 ft.
Result = 61547.98 ft.
Result = 61548.00 ft.
Result = 61547.82 ft.
Result = 61547.92 ft.
Result = 61547.86 ft.
Result = 61547.71 ft.
Geodimeter Distance = 61547.95 ft.
GROUND PROFILE
Mt. DANDENONG (2078 ft.)
2000
1500
1000
KANGAROO GROUND (650 ft.)
Line of Vision
0 ft.
0
4
8
12 Miles
Timbered

Fig. 2

Kangaroo Ground to Mt. Dandenong: (See Figure 2).—Eight measurements, taken on four different days, were carried out on this line. Five different operators were used, and four of these operators were carrying out their first measurement with the instrument. The discrepancies were:—

Geodimeter Distance (61547.95 feet) minus Tellurometer Distance

Observation	Difference in ft.	Difference in parts/10^6
1	—0.07	1.1
2	—0.15	2.4
3	—0.03	0.5
4	—0.05	0.8
5	+0.13	2.1
6	+0.03	0.5
7	+0.09	1.5
8	+0.24	3.9
Mean	+0.02	0.4

There was practically no ground swing and this was no doubt due to the almost complete tree cover that exists between the two ends of the line. The discrepancies are very similar in magnitude to those obtained in the short distance tests, and show that in the presence of such small ground swings, one set of measurements over 11 or 12 miles can give a result which should not be in error by more than 4 parts in 10^6 for one set.

This test again showed that the mean of a number of sets considerably improved the result.

Kangaroo Ground to Quarry Hill: (See Figure 3).—Only two measurements were made over this line, on the same day. The nrst measurement was made by an operator having his first experience with the instrument. The path of the measurement was over rolling ground with little or no herbage. Light ground swing was present, the range of the twelve measurements in a set being nearly 3 feet. The discrepancies were:

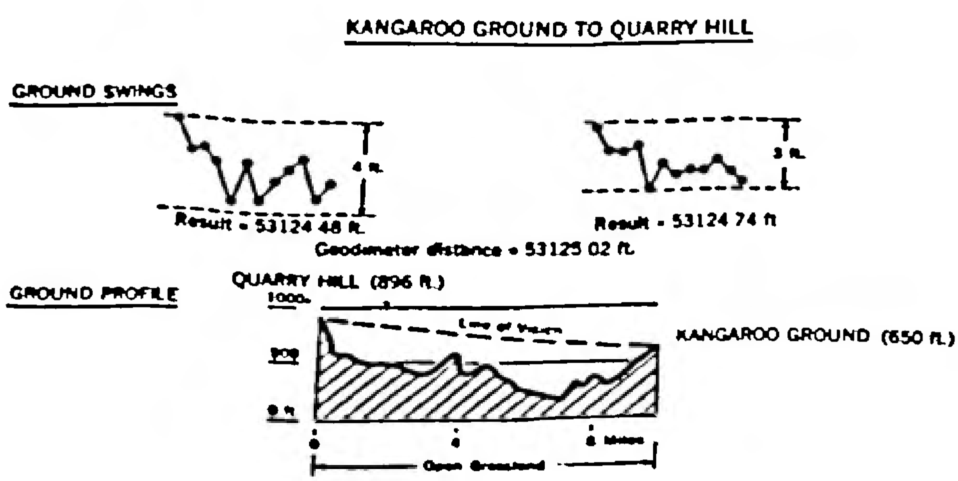

Fig. 3

Geodimeter Distance (53125.02 feet) minus Tellurometer Distance

Observation	Difference in ft.	Difference in parts/10^6
1	+0.54	10.2
2	+0.28	5.3
Mean	+0.41	7.7

Mount Dandenong to Quarry Hill: (See Figure 4).—The length for comparison was obtained from the two previous lines; Kangaroo Ground being close to the line Mount Dandenong/Quarry Hill. This line was measured twice on the one day using two different operators. The first half of the distance is tree-covered, the balance being rolling ground with practically no herbage. The discrepancies were:

Geodimeter Distance (113588.09 feet) minus Tellurometer Distance

Observation	Difference in ft.	Difference in parts/10^6
1	+0.23	2.0
2	+0.56	4.9
Mean	+0.40	3.5

Light ground swings were present on this line, the range of the 12 measurements of a set being 1.50 ft.

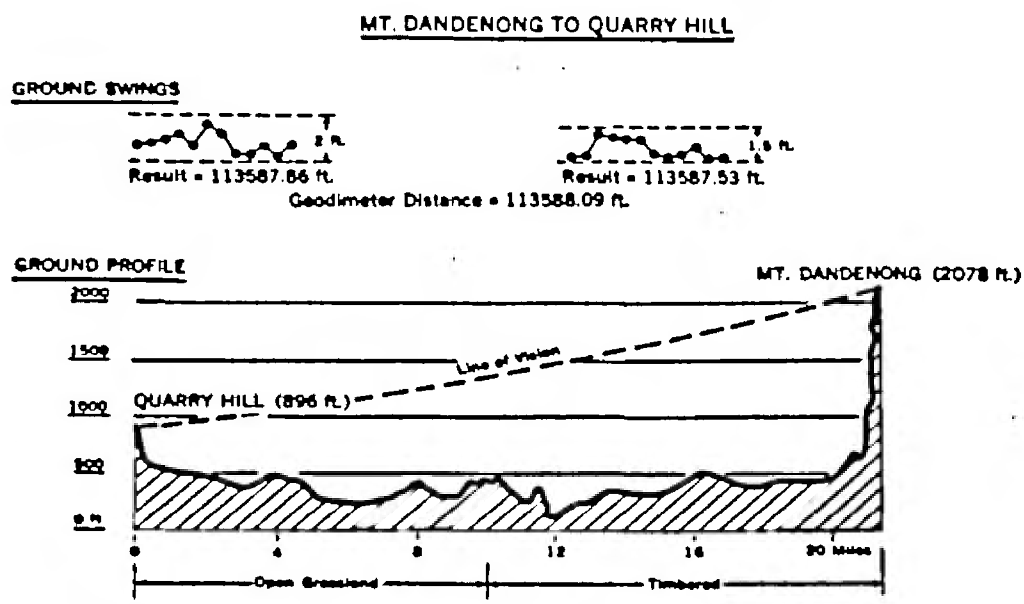

Fig. 4

TESTS OVER LONG DISTANCES

Camel's Hump to Mt. Disappointment: (See Figure 5).—No precise value is available for this line, it being beyond the normal range of the Geodimeter. However, it is one line of a very well observed quadrilateral, one side of which has been measured by the Geodimeter. The value so obtained has been used as a basis of comparison.

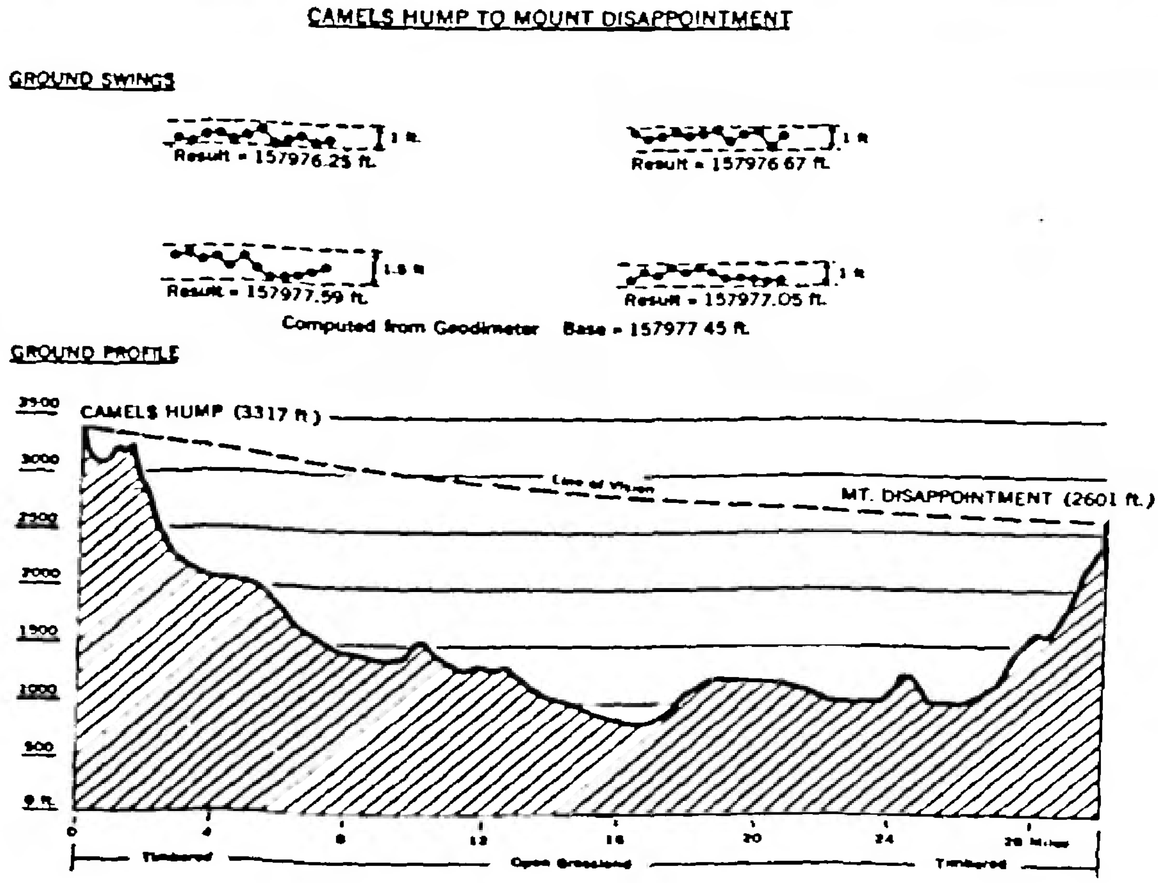

Fig. 5

Four measurements were made, two on each of two days. Wide differences of temperature were encountered, 56°F. on the first day and 39°F. on the second day. Discrepancies were:

Accepted Distance (157977.45 feet) minus Tellurometer Distance

Observation	Difference in ft.	Difference in parts/10⁶
1	+1.20	7.6
2	+0.78	4.9
1st Day		
3	—0.14	.9
4	+0.40	2.5
2nd Day (instruments reversed)		
Mean	+0.56	3.5

There was very little evidence of ground swing on this line.

Arthurs Seat to Mt. Atkinson: (See Figure 6).—No good value is available for the length of this line. The length used for comparison was computed from an inverse solution between stations on different loops of indirectly connected triangulation. The test was carried out for range and consistency only.

Two measurements were made on the same day using different operators. The discrepancies were:

Computed Distance (230406.22 feet) minus Tellurometer Distance

Observation	Difference in ft.	Difference in parts/10^6
1	—1.70	7.3
2	—1.40	6.1
Mean	—1.55	6.7

No trace of ground swing was encountered, the range of the 12 measurements of each set being under 1 foot, and the consistency of the two measurements would lead to the belief that the Tellurometer distance is nearer to the true value than the computed distance.

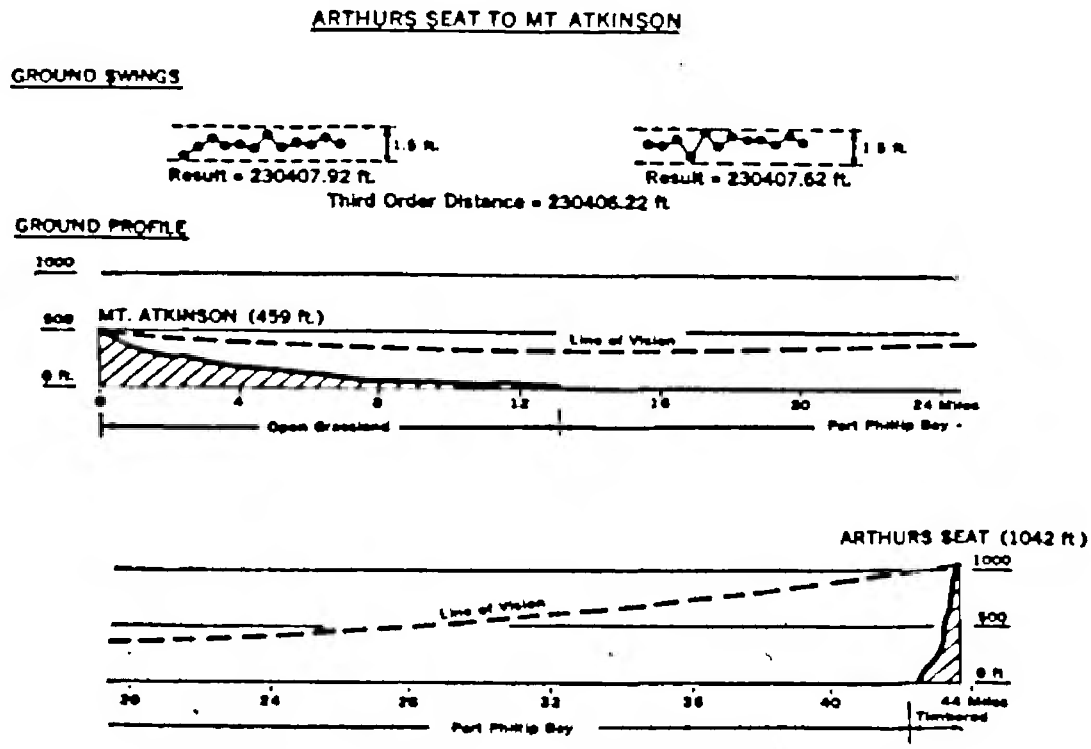

Fig. 6

The consistency of the two measurements is of the order of 1.3 parts in 10^6.

Abnormal Ground Swings (Mt. Atkinson/Mt. Aitkin: (See Figures 7 and 8).—In the manual supplied by the manufacturers of the equipment, the question of ground swings is discussed at length, and the conditions which cause it are listed. During the course of the tests which have been described most of the lines were selected with a view to developing as much ground swing as possible.

However, light swings only were encountered except on the line from Mt. Atkinson to Mt. Aitkin (14.8 miles), which is located entirely over almost bare ground, with an abrupt rise of 400 feet at the Mt. Aitkin end of the line.

This line developed such heavy swings that it may be considered as a breakdown of the normal measuring technique for *geodetic* purposes, and is of such interest that the experimental work performed warrants description.

The line was first measured on 31st May, 1957, the Master being located on the trig. mark at Mt. Atkinson and the Remote on the trig. mark at Mt. Aitkin. The Geodimeter measurement between these points had previously given a length of 77432.32 feet.

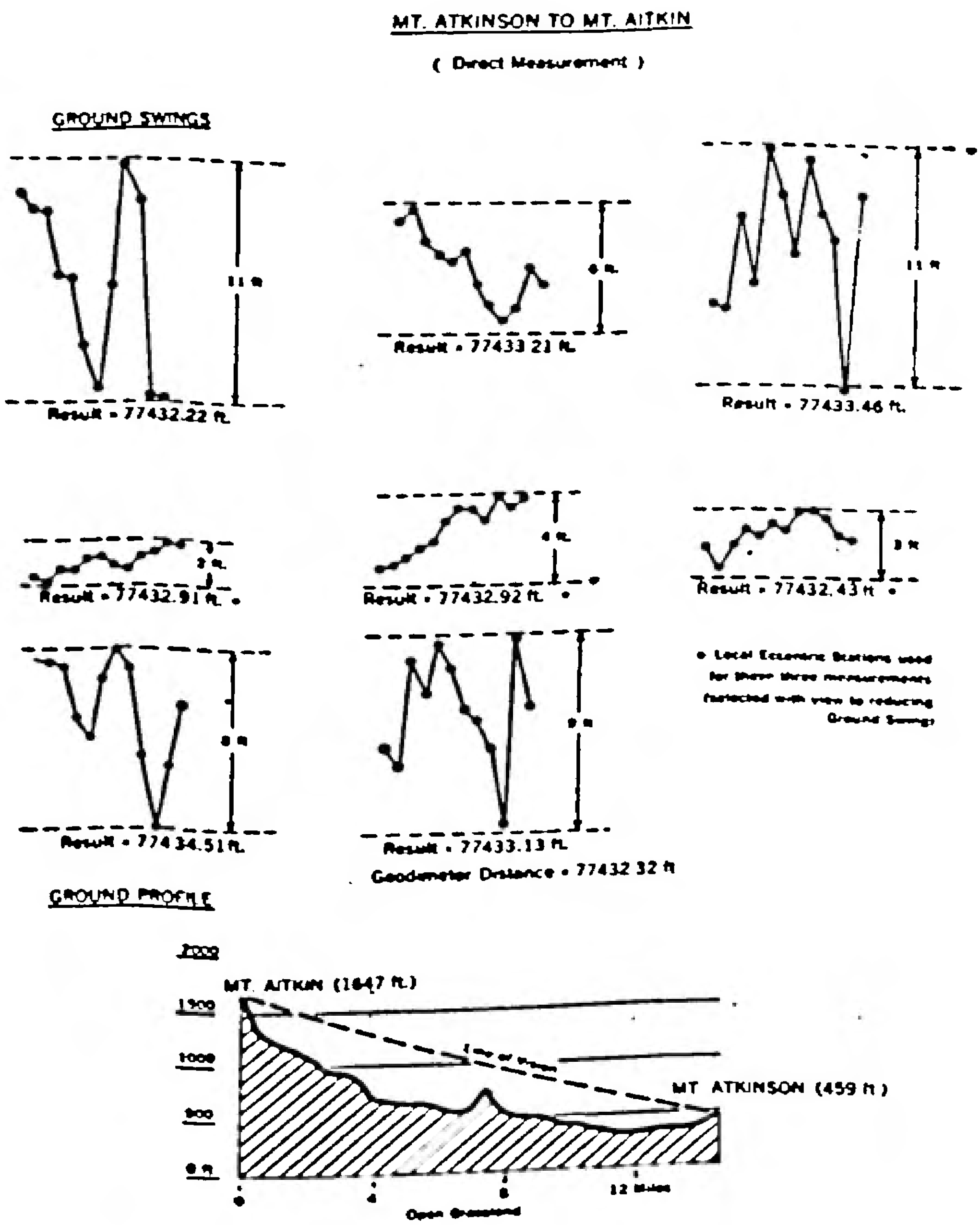

Fig. 7

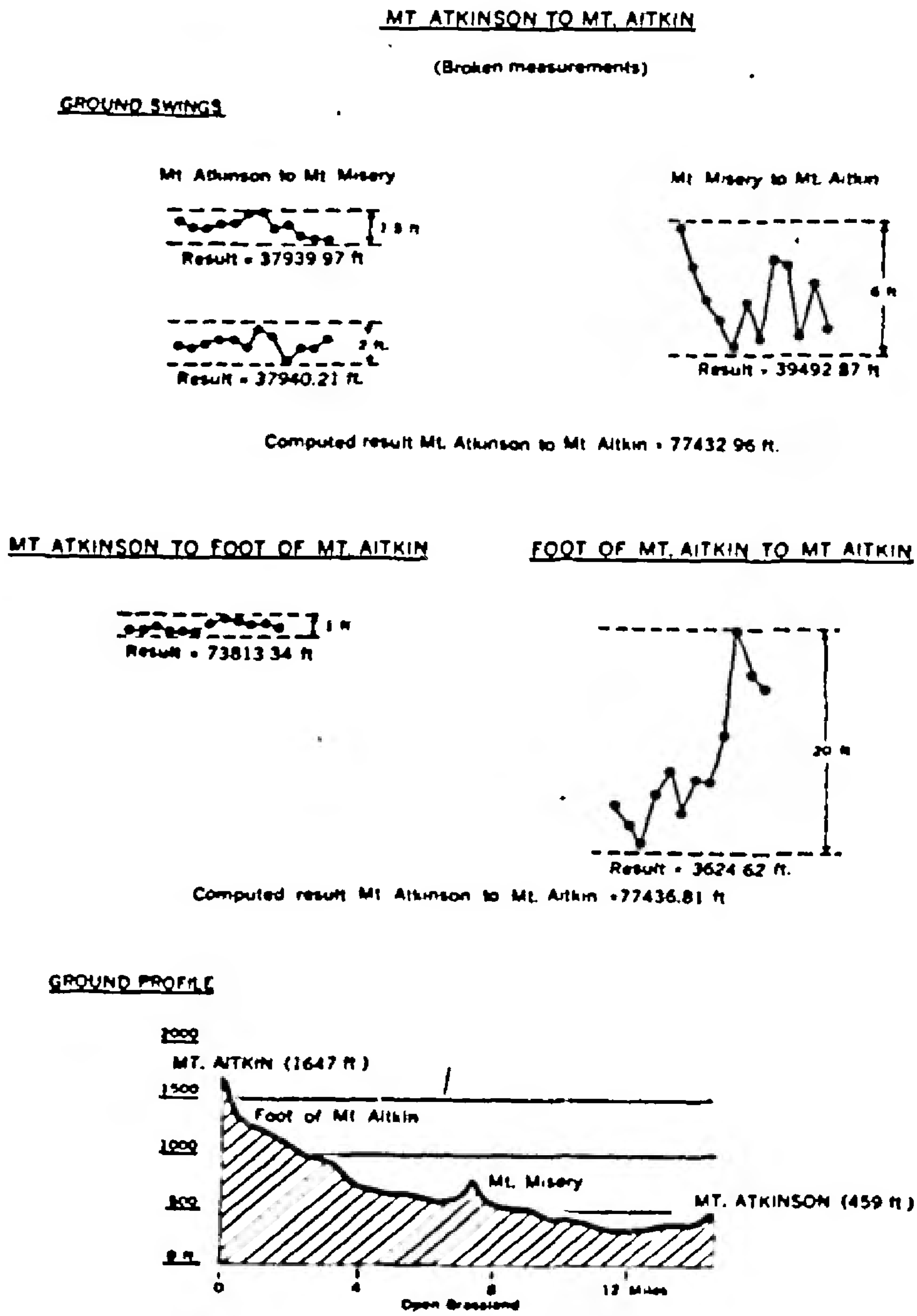

Fig. 8

Observation	Range of Set	Geodimeter-Tellurometer	Difference in parts/10^6
1	11 ft.	+0.10 ft.	1.3
2	6 ft.	—0.89 ft.	11.9
3	11 ft.	—1.14 ft.	14.8
	Mean	—0.64 ft.	8.3

These results showed such large swings and deterioration of accuracy that the advice of the manual was followed, i.e., an attempt was made to reduce the swings by relocation of the Master.

Therefore, on 3rd June, the line was remeasured with the Master (Aitkin) station situated behind the original mark in such a position that Mt. Atkinson was just visible from the centre of the centre of the reflector.

It was noticed that the display lost its clean-cut appearance and was showing the effect of reflections from the ground in front of the instrument. Results were:

Observation	Range of Set	Geodimeter-Tellurometer	Difference in parts/10^6
1	4 ft.	—0.60 ft.	7.8
2	3.0 ft.	—0.11 ft.	1.4
3	2.0 ft.	—0.59 ft.	7.6
		Mean — .43	5.6

This showed that the relocation of the station, whilst not wholly eliminating the effect of the ground swing, could largely ameliorate the effects. Reliability of the result, however, deteriorated below what would be expected under normal conditions. Obviously under conditions of heavy ground swings it is necessary to relocate the station and take several sets if a good result is required.

As a verification of previous work, another set was taken from trig. point to trig. point before departure from Mt. Aitkin. Results were:

Range of Set	Geodimeter-Tellurometer	Difference in parts/10^6
9 ft.	—0.81 ft.	10.5

On 24th June, 1957, the locations of the Master and Remote were interchanged, and a measurement was made from trig. point to trig. point. Results were worse than previously experienced:

Range of Set	Geodimeter-Tellurometer	Difference in parts/10^6
8 ft.	—2.19 ft.	28.3

An attempt to relocate the Master Station behind the brow of the hill at Mt. Atkinson failed; possibly the strong wind caused the grass to make reflections which prevented a readable display.

It was then decided to attempt the measurement in two parts. The Master was located on the flank of Mt. Misery, on line near the mid-point.

The distance was then measured to Mt. Atkinson, after which the Remote Station was moved to Mt. Aitkin and the balance of the line was measured. The results were:

Line	Range of Set	Distance
Mt. Misery to Mt. Atkinson	2.0 ft.	37940.21 ft.
Mt. Misery to Mt. Atkinson	1.5 ft.	37939.97 ft.
	Mean	37940.09 ft.
Mt. Misery to Mt. Aitkin	6 ft.	39492.87 ft.

Total Reduced Distance = 77432.96 ft.

Geodimeter minus Tellurometer = —0.64 = 8.3/10^6.

The following day the Master Station was located at the foot of Mt. Aitkin (not on line) and another attempt was made to measure the line in two parts. Results were:

Line	Range of Set	Distance
Foot of Mt. Aitkin to Mt. Atkinson ..	1.0 ft. ..	73813.34 ft.
Foot of Mt. Atkinson to Mt. Aitkin ..	20 ft. ..	3624.62 ft.

Total Reduced Distance = 77436.81 ft.

Geodimeter minus Tellurometer = —4.49 ft. = 58/10".

It is quite clear that with a ground swing of 20 feet one cannot hope to achieve any degree of accuracy. As a check, however, the Remote Station was re-sited approximately at the mid-point from top to foot of Mt. Aitkin and still a very large ground swing was present.

No satisfactory explanation can be offered for the abnormal swings encountered on this line and it cannot be claimed that the small amount of work done to date has given enough experience to enable the correct interpretation of such large ground swings.

In the results quoted for the direct measurements between trig. stations the arithmetic mean of each set was adopted, but it is interesting to consider the results that would be obtained if the mid-point of extremes of swing were adopted instead of the arithmetic mean.

	Arithmetic Mean (ft.)	Geodimeter-Tellurometer (ft.)	Using Mid-point of Swing (ft.)	Geodimeter-Tellurometer (ft.)
	77432.22	+0.10	77432.35	—0.03
	77433.21	—0.89	77433.91	—1.59
	77433.46	—1.14	77431.93	+0.39
	77433.13	—0.81	77431.72	+0.60
	77434.51	—2.19	77433.11	—0.79
Mean	77433.31	—0.99	77432.60	—0.28

CONCLUSIONS:

The following are considered opinions regarding the performance of the Tellurometer based on the experimental work completed to date:

(1) The equipment is extremely portable and can operate efficiently under conditions of poor (or non-existent) visibility.

(2) The operation of the instrument is simple and existing field survey personnel can be easily trained to use it.

(3) A single set of distance measurements can be completed in twenty minutes.

(4) Abnormal conditions can occasionally be encountered. They are, however, immediately recognisable from the range of the ground swing and may be largely ameliorated or avoided by appropriate re-siting of the instruments.

(5) Under normal conditions and in the absence of abnormal surface reflections, short distances from 500 to 5,000 feet can usually be measured with an error not greater than 0.20 feet in any one set.

(6) Under favourable conditions, distances from 10 to 40 miles can usually be measured with an error not greater than 5 parts in 10^6 in any one set.

(7) The accuracies quoted above can be improved by taking more than one set.

(8) The manufacturers' claim "that the estimated probable error of a single set is plus or minus 2 inches plus 3 parts in 10^6 of the length" has certainly been substantiated.

APPENDIX 1

STATISTICS

Complete station equipment (for either Master or Remote Station) consists of:

Item	Dimensions	Weight
Station instrument	21″ x 17″ x 10″	24 lbs.
Carrying case (with back straps)	22″ x 18″ x 11″	14 lbs.
Power Pack	10″ x 5″ x 5″	10 lbs.
Tripod (telescopic)	36″ x 6″ x 6″	9 lbs.

Battery (standard 6-volt 40 amp. hour).
Aneroid Barometer.
Whirling Hygrometer.
Operators' kit of spare parts.

Additional equipment required:
Handbook on operation.
Field observation forms.
Computation forms.
Small hand operated calculating machine.