METHOD FOR REDUCING GROUND SWING ON TELLUROMETER MEASUREMENTS

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In continuation of the Ordnance Survey trials of the tellurometer carried out in 1957, third order control points over an area of 230 square miles in the Southern Uplands of Scotland have been coordinated both by trilateration with tellurometer and by normal triangulation. The existing secondary triangulation was used as control for both methods. The area had previously been reconnoitred for triangulation and all points had been marked by the standard Ordnance Survey triangulation pillar. Hence the selected sites were designed to give a good clearance for the triangulation rays and to avoid grazes. They were by no means ideal for the tellurometer, for which a grazing ray is preferable.

The area was typical moorland with open rolling hills. There was little vegetation and it was therefore expected that several lines would be found in the area where the tellurometer measurement would be handicapped by excessive ground swing, which was at that time thought to be one of the most serious limitations to the instrument. Ground swing is caused by stray reflections of the microwaves from the ground between the two terminals and results in variations in the tellurometer readings.

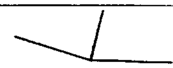
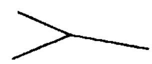
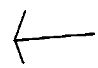
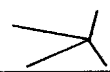
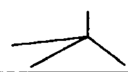
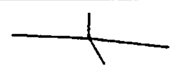
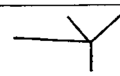
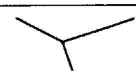
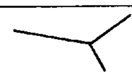
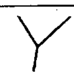
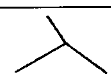
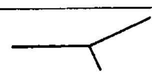
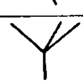
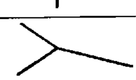
The tellurometer measurements were made during October and November 1957 and the triangulation observations in the spring of 1958. Table I shows the comparison between the trilateration and triangulation coordinates.

It is not proposed at this stage to comment in detail on these results, since the statistical analysis is not yet completed. The indications are that the two methods are of comparable accuracy, since the maximum accidental error of position of third order triangulation points is estimated to be between 0.05 and 0.10 metres. It will be noted that the greatest vector differences occurred at stations where only three rays had been used in the trilateration fix and of these three rays, two cut at a very oblique angle.

In fact very little trouble was experienced from ground swing in the tellurometer measurements done in October and November 1957. Out of 64 lines measured, 57 lines had a swing of less than 5 millimicroseconds

TABLE I

Comparison between triangulation and trilateration fixations

Station	Triangulation-Trilateration		Vector (metres)	Diagram of cuts
	ΔE (metres)	ΔN (metres)		
Din Fell	— .17	+ .13	.21	
Dolphinston	+ .02	— .21	.21	
Tudhope Hill	+ .18	— .10	.20	
Skelfhill Pen	+ .09	+ .17	.19	
Shaw Craig	— .13	+ .07	.15	
Pike Fell	— .14	+ .02	.14	
Glendhu Hill	+ .11	+ .02	.11	
Gray Hill	— .10	— .02	.10	
Penchrise Pen	— .10	— .01	.10	
Hawthornside Hill	— .09	+ .01	.09	
Saughtree Fell	+ .03	— .07	.08	
Blinkbonny Heights	+ .04	+ .07	.08	
Southdean Law	— .06	— .03	.07	
Wolfelee Hill	+ .06	+ .03	0.7	
Kiln Knowe	+ .05	— .04	0.6	
Priest Hill	+ .02	+ .05	.06	
Arnton Fell	— .02	+ .03	.04	

(mμs). Only on four lines was the ground swing excessive, ranging between 19 and 32 mμs. It was immediately obvious from the readings in the field that the results of these four lines would be unsatisfactory and this was subsequently confirmed when the tellurometer measurements were compared with the distances derived from triangulation (see table II, serials 1, 6, 11 and 16).

Reduction of ground swing over tertiary distances

In June and July 1958 experiments were carried out along the four lines mentioned above to see if the ground swing could be reduced. In each case the whole of the valley between the terminals of the line could be seen from pillar height (4 feet above ground level). The ground in the valley consisted of smooth and slightly undulating grass slopes. The tellurometer beam is relatively wide (about 10°) and on these lines the swing was probably caused by the rays from the lower part of the beam being reflected by the bare ground in the valley. It was thought that by lowering the tellurometer so that its ray grazed the ground close to the instrument, the rays from the lower part of the beam might thereby be absorbed or diffracted by the ground nearby and prevented from causing reflections in the valley. This lowering of the instruments is recommended in the tellurometer handbook for lines across water but not for land lines.

The lines were first remeasured with the tellurometers on the triangulation pillars to confirm that excessive ground swing would again be encountered at pillar height. The results of these measurements are given at serials 2, 7, 12 and 17 of table II. In three out of the four lines there was a considerable reduction in the ground swing and a corresponding improvement in the accuracy of the measurements, which is difficult to understand. A likely explanation was that in November 1957 the average temperature was 46° F. At the time, muffs had not yet been obtained for the tellurometers and difficulty was experienced in maintaining a steady crystal temperature during measurements. A more powerful heater (1 amp bulb instead of a 0.5 amp) was used in the master and similar heaters were installed in the remotes. These heaters had to be kept on throughout the measurements to maintain the crystal temperatures within the normal operating temperature ranges. When the remeasurements were done in 1958 the average temperature was 66° F and the crystals were operating at ambient temperature without heaters. It was subsequently found, during laboratory calibration of the master crystal, that the variations of up to 3 parts per million (p.p.m.) in crystal frequency were obtained when the heaters were left switched on during measurement. This tended to confirm that to some extent the improvement obtained in the remeasurements in the summer of 1958 was due to greater crystal stability under the more favourable temperature conditions. However, this can only account for a small part of the improvement in accuracy which was of the order of 50-100 p.p.m.

The instruments were then moved from the triangulation pillars and were placed at right angles to the line at a height such that the line from the aerial dipoles cleared the ground immediately in front by about 1 foot.

TABLE II

Reduction of ground swing obtained by movement of the tellurometer terminals

M = Master
R = Remote
P = Instrument on pillar
GL = Instrument at ground level
LT = instrument on low tripod

Date	Serial	Master station	Remote station	Tellurometer position		Range of ground swing mμs	Approx. length of line (metres)	Comparison with triangulation	
				M	R			Diff. (trig. minus tellr.) (metres)	p.p.m.
Nov. 1957	1	Priest Hill	Arnton Fell	P	P	30	6 600	— 0.69	105
June 1958	2	» »	» »	P	P	16		— 0.18	27
June 1958	3	» »	» »	GL	LT	5		+ 0.05	8
June 1958	4	Arnton Fell	Priest Hill	P	P	17		— 0.37	56
June 1958	5	» »	» »	GL	GL	3		— 0.02	3
Nov. 1957	6	Gray Hill	Hummel Knows	P	P	24	8 100	— 2.85	350
July 1958	7	» »	» »	P	P	33		— 1.05	130
July 1958	8	» »	» »	GL	P	6		— 0.47	58
July 1958	9	Hummel Knows	Gray Hill	P	P	22		— 0.78	96
July 1958	10	» »	» »	GL	GL	2		— 0.04	4
Nov. 1957	11	Wolfelee Hill	Faw Hill	P	P	19	6 400	— 0.539	85
June 1958	12	» »	» »	P	P	11		— 0.142	22
June 1958	13	» »	» »	GL	P	3		— 0.03	5
July 1958	14	Faw Hill	Wolfelee Hill	P	P	12		— 0.21	33
July 1958	15	» »	» »	GL	GL	1		— 0.12	18
Nov. 1957	16	Priest Hill	Saughtree Fell	P	P	32	12 000	— 1.770	147
June 1958	17	» »	» »	P	P	10		+ 0.15	12
June 1958	18	» »	» »	GL	P	5		+ 0.08	6
June 1958	19	» »	» »	LT	P	4		+ 0.13	11
July 1958	20	Saughtree Fell	Priest Hill	P	P	12		— 0.13	11
July 1958	21	» »	» »	GL	GL	2		— 0.15	13

The sets were placed either on the tripod with the legs retracted (called low tripod) or were placed actually on the ground. In the latter position the operator had to lie full length on the ground and operation of the set was by no means easy. The results of measurements taken in such positions on the four lines are given in table II. In each case the ground swing was ultimately reduced to 5 mμs or less and a satisfactory measurement obtained for the line. The resulting lengths agreed with the triangulation lengths to 13 p.p.m. or less, compared with up to 350 p.p.m. previously obtained from pillar height in November 1957.

The effect of various alterations in height of both master and remote can be seen in table II. In serials 3 and 5 the movement of the remote from a low tripod to ground level made no appreciable difference to the result, which was completely satisfactory in both cases. Unfortunately these two measurements were made in opposite directions which makes comparison between them less conclusive. In contrast to this, the movements in serials 8 and 10 of the remote from pillar to ground level achieved an improvement of accuracy from 58 p.p.m. to 4 p.p.m. Again these measurements were in opposite directions but nevertheless in this case the improvement is large enough to appear conclusive.

Serials 13 and 15 reveal a different tendency, since a slightly better result was apparently obtained with only one set at ground level (serial 13) than with both at ground level (serial 15). However, it must be borne in mind that the triangulation lengths are subject to errors of 20 p.p.m. or more and that any agreement within 20 p.p.m. must be considered as satisfactory. On this basis the technique of lowering the ray was completely successful on these four particular lines.

It therefore appears likely that over distances of 4-8 miles the ground swing problem may be overcome by obtaining a grazing ray by this method. From the experience gained so far, it would appear that one requires to arrange the tellurometer so that the ray travels parallel to the ground and about 1 foot above it, for about 30 feet immediately in front of one set, preferably the master. In some cases slight losses in signal strength are caused by this but on the other hand cases have occurred when the signal is improved. The loss of signal strength over these relatively short distances is of little consequence but this would not apply over longer distances.

Trials of the method over a primary distance

An opportunity to test the method over a primary distance occurred during recent work in southwest Scotland, when a side of the primary triangulation across Luce Bay between the Mull of Galloway and Burrow Head was measured. This line — Carleton Fell to Inshanks — was 18 miles long mainly over the sea, with a clearance of 460 feet in the centre. A cross section of the line is given in fig. 1. At both terminals the ground sloped steadily away at about 10° from the pillar and it was impossible to find a flat level piece of ground 30 feet in length along the line near the pillar. From Carleton Fell the whole of the intervening ground and sea was visible from the pillar; at Inshanks the coastline was just obscured by a smaller peak ½ mile from the point.

TABLE III

Reduction of ground swing obtained on the side of the primary triangulation

Date	Serial	Master station	Remote station	Tellurometer position		Signal strength			Ground swing mμs	Comparison with triangulation (p.p.m.)
						AVC		Pulse		
				M	R	M	R			
27 April	1	Carleton Fell	Inshanks	P	P	33	36	10	26	60
	2	» »	»	LT	GL	39	41	7	11	10
5 July	3	Inshanks	Carleton Fell	Various		No measurements obtained.				
6 Aug.	4	»	» »	GL	GL	34	35	9	11	1
	5	»	» »	GL	LT	33	24	9	11	7
	6	»	» »	GL	P	29	21	9	7	7

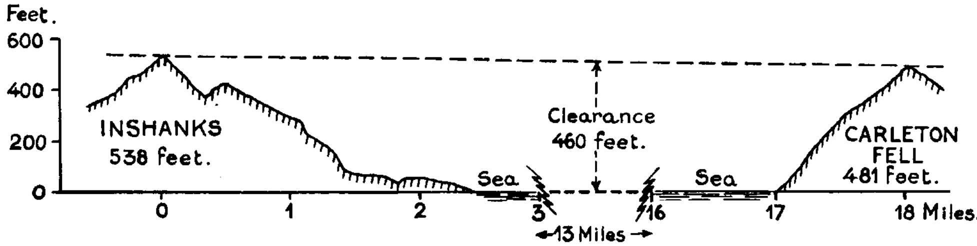


FIG. 1. — Cross section of the primary line — Inshanks to Carleton Fell.

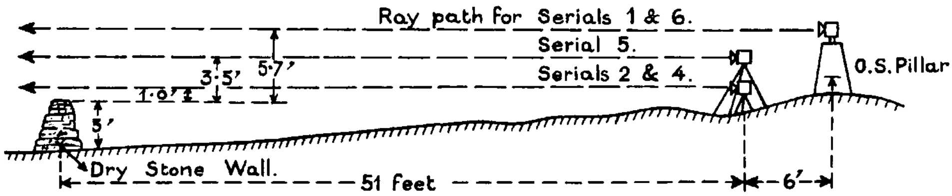


FIG. 2. — Showing the tellurometer positions at Carleton Fell.

The first measurement was made on 27 April with the master at Carleton Fell, the remote at Inshanks and with both sets on the pillars. The signal was weak and an unsatisfactory result was obtained (see table III, serial 1). The ground swing graph showed a steady increase throughout the frequency band and had no cyclic tendency (see fig. 4). However, at Carleton Fell there was a substantial dry stone wall 5 feet in height which crossed the ray obliquely about 50 feet from the pillar. For the next measurement (serial 2) the master was placed on a low tripod on the line in front of the pillar so that the tellurometer ray cleared the wall by 1 foot

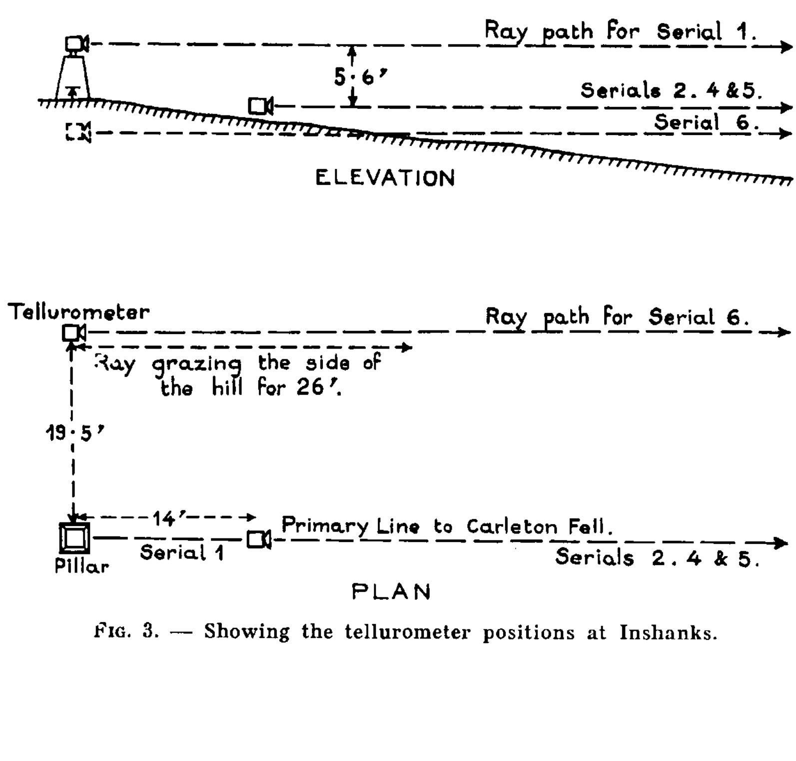


FIG. 3. — Showing the tellurometer positions at Inshanks.

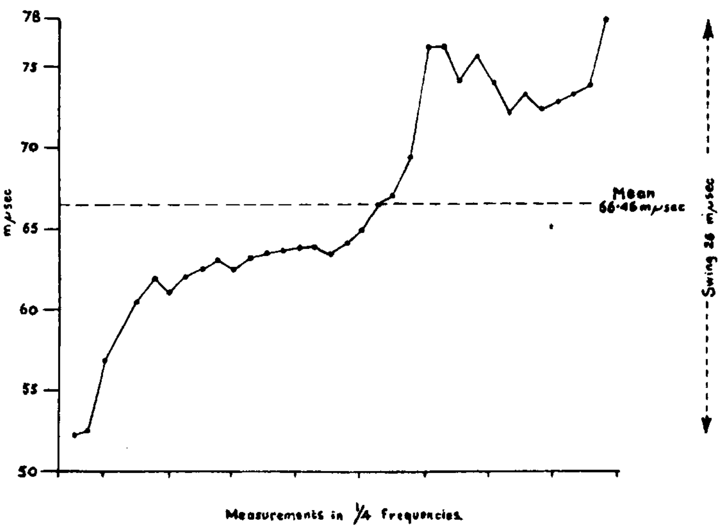


FIG. 4. — Ground swing diagram (table III, serial No. 1).
Tellurometer at pillar height, at Carleton Fell.

(see fig. 2). The signal strength was considerably improved with an automatic volume control (AVC) reading of 39 at pulse amplitude 7 compared with 33 automatic volume control at pulse 10 on the previous readings from the pillar. The resulting ground swing graph was a great improvement on the previous one (see fig. 5) and the derived result agreed to 10 p.p.m. with the triangulation length.

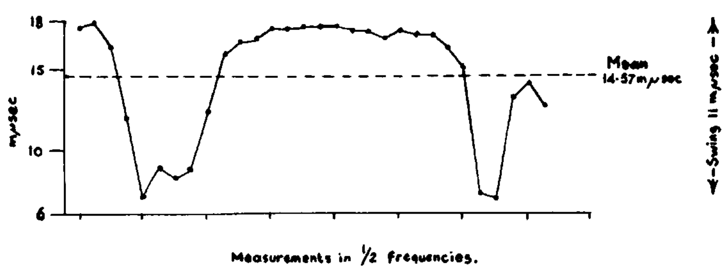


FIG. 5. — Ground swing diagram (table III, serial No. 2).
Tellurometer lowered so that the ray just cleared the wall, at Carleton fell.

However, when the measurement of this line was attempted from the other direction on 5 July (serial 3) no measuring break could be obtained no matter how the sets were moved. At Inshanks every possible position for the master along the line was tried without success. Also a landrover was driven beside the pillar so that its bonnet was just below the aerial dish to act as a screen, but this too was unsuccessful. At Carleton Fell the remote was also moved to various positions but it was not placed in the position above the wall that the master had occupied during serial 2.

On 6 August further measurements (serials 4, 5 and 6) were taken along the line. For serial 4 at Carleton Fell, the remote was placed in the position occupied by the master in serial 2 (thereby using the wall as a shield). At Inshanks the master was at ground level (fig. 3). From these positions a satisfactory measurement was made. For the next measurement (serial 5) the remote was raised onto a tripod so that the ray cleared the wall by about 3 ½ feet. This had little effect on the signal strength at either instrument in the lower part of the frequency band, but at higher frequencies the signal strength at the remote was seriously weakened and at one frequency the display could not be read. Nevertheless a satisfactory result was obtained.

It was clear that by using the dry stone wall at Carleton Fell as a shield to cut out the lower part of the beam, satisfactory measures could be obtained. However this did not test the method of using the ground itself for this purpose and therefore for the next measurement (serial 6) the remote was replaced on the pillar at Carleton Fell to obtain the maximum clearance over the wall. The master at Inshanks was placed on the ground down the slope at right angles to the line and some 20 feet from the pillar. From this position the ray passed parallel to the sloping surface of the ground for 26 feet. The signal strength at both instruments was reduced slightly from the previous two measurements. At three frequencies no measurement was possible due to the weak signal, but a satisfactory result was obtained from the remaining frequencies. It is clear that the lowering of the ray causes loss of signal strength and this may prevent the use of this method over longer distances.

Conclusions

The above results demonstrate that excessive ground swing along lines of tertiary length can be reduced by lowering the instruments. Furthermore the method may be successfully used over primary distances but the resulting loss of signal strength may prevent its use on very long lines. Considering that excessive ground swing is relatively rare in this country one can say with some confidence that the ground swing problem no longer presents as serious a limitation on the use of the tellurometer as was originally thought.